Accident Investigation, Reconstruction, Interpretation & the Law
20-23 October, 1997
AIRIL '97

THE IDENTIFICATION AND QUANTIFICATION OF INCIDENTS INVOLVING GENERAL MOTORS (GM) TRUCKS WITH SIDE MOUNTED FUEL TANKS

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SUMMARY

An important issue in the determination of crashworthiness for engineering analysis and litigation is the identification and quantification of other incidents. This paper presents an approach to the identification and quantification of other incidents predominantly from an engineering perspective relative to incidents involving General Motors (GM) light trucks with fuel tanks mounted outside the frame rails. Important variables were classified as: event variables, vehicle variables, occupant variables, data source variables, and fuel leakage variables. A database was created based on these variables. As an example, included in the vehicle damage variables is a first damage causing event, the most damage causing event to the fuel system, and three variables based on a modified Collision Deformation Classification (CDC). The database consists of a physical set of files and software that includes accident reports, photos, medical reports, occasionally legal documents, and miscellaneous documents pertaining to each incident. All of the incidents identified by GM and The United States, Department of Transportation, Office of Defect Investigation (ODI) are included in the database.

INTRODUCTION

In September of 1972, General Motors (GM) introduced for sale in the United States the first of its C/K series pickup truck for the 1973 model year. A notable difference in the 1973 model year truck was the location of the fuel tank at the mid-ship, outside the frame location (often referred to as side mounted or saddle tank design). This General Motors truck was sold for the next 18 years together with a variety of chassis sizes, truck beds, and utility producing unit sales of 9.2 million trucks. In 1987, while still manufacturing its existing truck design, General Motors introduced for sale an all new pickup truck which located its fuel tank in the mid-ship position inboard of the drivers side frame rail.

In August of 1992, the United States Department of Transportation (USDOT), National Highway Traffic Safety Administration (NHTSA), Office of Defects Investigation (ODI), initiated an engineering analysis and ultimately a defect investigation of the General Motors C/K light trucks with side-mounted fuel tanks. The governmental review was initiated after the Washington, D.C. based Center for Auto Safety (CAS) and the Public Citizen petitioned the National Highway Traffic Safety Administration's ODI. (Ditlow, 92).

On October 19, 1994, the U.S. Department of Transportation Secretary, Federico Pena, issued an engineering analysis report and initial decision that the subject vehicle (GM C/K Trucks) contained a safety-related defect (Pena, 94). On Friday, December 2, 1994, before the Tuesday start of a required public hearing, GM and NHTSA announced an agreement that settled the dispute, ending the possibility of a recall and vacating Pena's October 17, 1994 report. The terms of the agreement required GM to pay or pledge in excess of $51.355 million to current or future projects. "This settlement will save hundreds of lives - far more than could ever have been saved by proceeding with a recall or closing the case," said Pena. "The alternative was to close the case with no public benefit or to proceed with a forced recall that would have involved years of litigation, an uncertain outcome, and prevented few, if any, deaths." (USDOT, 1994)

The governmental investigation and concurrent class action litigation in the United States, resulted in voluminous reports of engineering analysis, crash tests, statistical analysis, and failure mode analysis. In addition, voluminous data was collected of the facts concerning individual crashes by General Motors, ODI, and independent organizations. Despite the volume of data available on individual crashes, a comprehensive computer database for ready access and comparison of these incidents had not been developed.

ENGINEERING

The retrospective analysis of the General Motors truck fuel tank design is formulated predominantly through statistical analysis and experimentally based engineering analysis. A critical review of both General Motors and the NHTSA's statistical analysis, describes the statistical work and the conflicting conclusions. (Hubele, 94; Hubele, Arndt, 95) A comprehensive engineering analysis encompassing an examination of over 50 staged car-to-truck crash tests evaluating fuel tank design, and 30 in-depth investigations of real world crashes of GM light truck post crash fires has also been conducted (Stevens, Hurley, 95) Many of the underlying assumptions associated with the statistical and experimentally based engineering analysis leaves unanswered interesting engineering questions about the performance of the General Motors C/K truck fuel containment system.

The study of fuel containment system performance has always been a challenging proposition using statistical analysis. Overall, the rates of post-crash, fuel-fed fire are relatively low and observation of fuel containment system crash performance may go unnoticed without the occurrence of fire. For these reasons, databases of in-depth crash investigations may lack sufficient resolution to adequately analyze a motor vehicle relative to collision associated fuel leakage and fire, and population based databases, notably those from crash reports and the USDOT Fatal Accident Reporting System (FARS) lack sufficient detail to evaluate detailed engineering questions.

Conversely, experimentally based engineering analysis, while providing significant engineering knowledge, lacks the ability to represent the entire distribution of possible crashes. Depending upon the test intent and/or method, significant insight into the fuel system design's performance may be missing and/or lost. Misconceived, inadequate or poorly documented tests of a product may force the domination of the engineering effort to issues that are of minor consequence in the real world.

The collection of individual crash data provides the opportunity, through retrospective engineering analysis, to bridge the gap between information available through statistical analysis and detailed theoretical and experimental engineering analysis. For the manufacturer of a product, the collection of detailed engineering information on individual crashes provides the opportunity for a running, real world view of its products' performance. For the database, which is the subject of this paper, inquiries of the physical documents that make up the database can be made which address specific shortcomings, questions or issues that arose in the statistical and detailed engineering analysis.

LEGAL

Since the introduction of the General Motors C/K truck for sale in September of 1972, hundreds of lawsuits have been filed on the behalf of plaintiffs involving the truck where fuel leakage or fire was alleged to have been involved. The first known incident causing a lawsuit on the behalf of a plaintiff occurred in December of 1973, approximately 15 months after the first truck was sold. The first known trial in the United States, involved an incident which occurred in December of 1976, resulting in a jury verdict for the plaintiff and ultimate post-trial compromise and resolution by the adverse parties.

Subsequent litigation occurred with the notable verdict in 1993 in which a jury awarded in excess of $105 million U S. dollars in compensatory and punitive damages in an incident involving a fatal collision caused fire in a 1985 General Motors C/K truck (General Motors Corporation v. Moseley, 94). The presiding State Court of Appeals ultimately overturned the jury verdict, partially on the grounds of improper introduction of evidence regarding other similar incidents (OSI) (Court Ruling, 94). At issue was whether "substantial similarity" existed between the other incidents presented as evidence to the jury and the incident that was the subject of the litigation at hand. Incidents that are "substantially similar" to the circumstances surrounding the case at trial are considered relevant among numerous issues "to demonstrate notice, or the existence of a defect." "The threshold question and the admissibility of any evidence at trial (in the United States) is whether it is relevant to the jury's determination of the issues in dispute (Laura G. Bishop v. General Motors Corporation, 95)."

In part, because of the difficulties and issues in the proceeding discussion, the collection, tabulation, and analysis of the voluminous information of other incidents involving General Motors trucks, was of interest from a legal perspective. The notion of "substantial similarity" is a legal phrase. Engineering opinion on this issue may be of great assistance on the issue of identifying incidents in which a manufacturer may gain knowledge of a potential defect. Similarly, engineers may identify incidents where a defect has manifested itself or proved itself in the real world.

DATABASE OVERVIEW

Upon the resolution of the USDOT and General Motors dispute concerning the design of the General Motors C/K light truck fuel system, the ODI had identified 550 incidents where a C/K truck was involved in a collision with fuel leakage or fire (Pena, 94). To date (July 1997), 644 incidents have been assigned incident numbers and listed by General Motors, apparently due to some relationship to the allegation of design defect.

The database, which is the subject of this paper, is populated by incidents which have either been assigned an incident number by General Motors or meet the criteria of being a General Motors truck with a fuel tank located outside the frame rail, involved in a collision with fuel leakage or fire or an allegation of fuel leakage or fire. The physical documents that make up the database were originally identified in the ODI Public File. Two study trips to Washington, D.C. to review and analyze the original ODI investigative file of other incidents were conducted and two separate trips to the General Motors Reading Room to read, acquire and analyze other incidents were conducted. Finally, a thorough search of other sources, including investigative files of individuals, lawyers, and other investigators, produced additional incidents and documents for inclusion in the database. To date (July 1997), 665 other incidents involving General Motors trucks, either identified by General Motors or involved in collisions in which there was fuel leakage or fire, have been reviewed. However, the data in this paper represents Version 1.0 of the database. which contains 641 incidents.

The database consists of a physical set of files and software. The physical files include a log file, data sheets, accident reports, primary photos, medical reports, legal documents, other documents, and other photos. The log file indicates where information for each incident is located in the ODI public file (ODI, 92). The data sheets contain an extraction of information from the primary documents in the physical files. The primary documents from which data was extracted are typical documents upon which individual crash data is collected and relied upon by engineers. The primary documents include police reports, fire reports witness statements, consumer reports, consumer complaints, photographs, investigative reports, insurance reports, medical records, and investigators' drawing or diagrams. Accident reports include all investigative reports such as police reports, fire reports, and other engineering analysis reports or consumer reports/complaints. Primary photos are the set of photos necessary to complete the data coding (for Version 1.0.) When available, all views of the vehicle where collected (right, left, front, back, and underside) including a view of the fuel tank. Medical reports include any document describing injury (e.g., hospital reports and death certificates). When available, legal documents were noted and retrieved. Other documents are those that did not fit into the preceding categories, such as news reports. The software product contains an encapsulation of the coded data sheets along with scanned images of the physical files, which has been stored on compact discs,so that the documents can he accessed and viewed.

Version 1.0 (July 1996 release) of the database, which the next sections describe, contains 641 distinct incidents spanning the period of 1973 to 1996. A subset of the FARS coding structure and the Society of Automotive Engineers (SAE) Collision Deformation Classification (CDC) (SAE, 95) structure is used for this database. For analysis purposes we have modified these database structures and added other information. This paper emphasizes the distinctions between our structure and these other structures. Version 1.0 of the database is divided into four categories of information. These categories are: Events Information, Vehicle Information, Occupant Information, and Other Information. Other information includes a table of available data and the scanned documents that are available on CD ROM. The present version of the database has the added category of fuel leakage coding. In the next sections these categories are discussed.

Events Information

The Events Information consists of data fields for the incident number, date, time, and state of incident, roadway information, the number of vehicles involved, and information pertaining to the known legal status of the incident. Figure 1 presents the number of incidents per year between 1973 and 1996 as extracted from the database. There is a lag of one to two years in the appearance of many of the incidents into the public data[1]. Therefore, years 1994 to 1996 are probably incomplete.

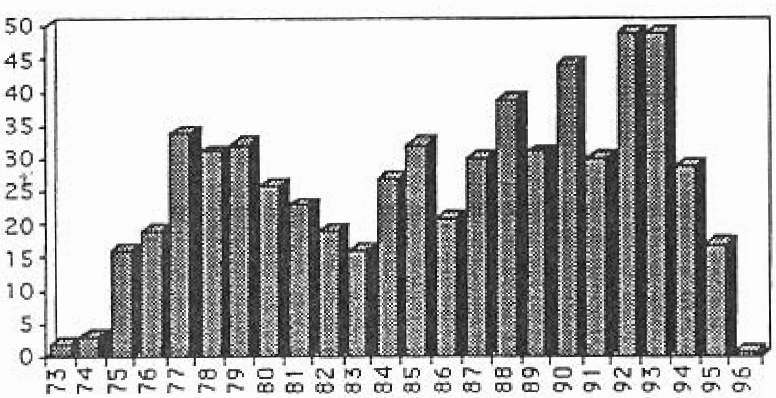

Figure 1. GM C/K Incidents by Year

[1] Inferred from GM reading room data

Vehicle Information
Vehicle information consists of basic vehicle information including the vehicle identification number (VIN), non-OEM equipment information, fuel tank information, and vehicle damage information. The distribution of this data is interesting, in that there is a significant drop in incidents after 1979. This likely was a result of the change of standard gas tank location from the left side of the truck to the right side of the truck in 1980 and reductions in sales volume.

Non-OEM equipment including running boards, modified beds, racks, hitches, wrecker packages, campers, and trailers were identified. Trucks, by their design and utility, will have significant additional equipment installed. Fuel tank information includes the number of fuel tanks, the tank mounting location, evidence of a non-OEM fuel tank and evidence of non-OEM fuel tank involvement. General Motors 1973-1979 model year trucks have a standard right side tank. GM 1980-1987 GM trucks have a standard left side tank.

The term "evidence of" is used throughout the database and denotes the existence of any description of ("evidence of") the occurrence. An affirmative answer to "evidence of" in database coding does not mean that an occurrence has occurred as a matter of fact, but, merely that somewhere in the supporting documents such an occurrence has been noted. For example an investigator unfamiliar with the GM truck fuel system may indicate in his written report that a non-GM fuel tank was involved in a fire, when in fact the fuel tank was a GM product. Such a note would be coded as evidence of non-OEM fuel tank involvement in the fire based upon the investigative note. This coding provides a flag for conducting further investigation into the circumstances of the incident.

The vehicle damage information characterizes the physical damage of the entire vehicle with primary emphasis on the fuel system. The design of the vehicle damage coding represents some major innovations of the database. The first data field records the fuel and fire involvement. A criterion for acceptance to the database was that there was fuel or fire involvement. Of the 641 incidents in Version 1.0, 559 had both fire and fuel involvement, 28 had only fuel involvement and there were 54 incidents for which there was insufficient information to determine fuel and/or fire involvement. These cases were included in the database because they had been identified by General Motors, presumably relevant to the USDOT investigation.

Another field in the vehicle damage information is the burn damage location. The SAE Collision Deformation Classification (CDC) for Specific Longitudinal Location of Deformation was modified to accommodate this coding. Figure 2 shows the modified classification with frequency data extracted from the database. The difference between the Figure and the CDC system is the addition of zones G, H, I, and J, which more closely correspond to the fuel tank location. When any burn damage was detected in a particular region, that region was included in the coding.

A field for evidence of fire due to other causes than fuel leakage from the fuel tank is also included. Evidence of this sort typically came from investigative reports (such as a police report) that indicated a particular source of the fire, and does not represent definitive engineering conclusion or fact as to other fire cause. Information for number of other vehicles (in the incident) with fire involvement and for evidence of under-ride has been included. Under-ride occurs when the striking vehicle moves underneath the incident vehicle and is a crash characteristic noted in testing which affected fuel system performance.

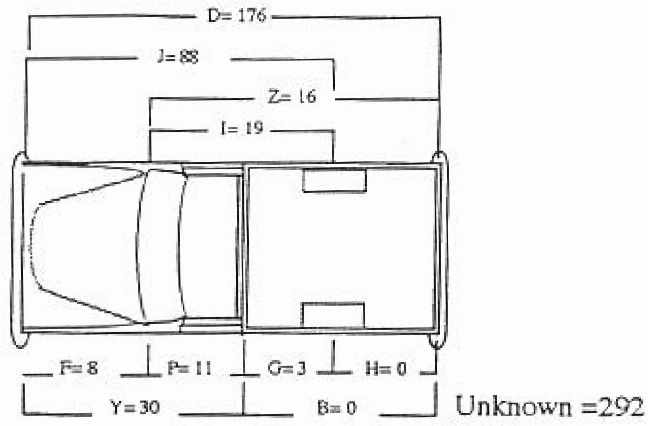

Figure 2. GM C/K Burn Damage Location Frequency

The FARS database structure includes a field for the first and most injury or property damage causing event. We have modified these variables to specifically indicate the first damage causing event to the vehicle and the most damage causing event to the fuel system. The damage causing events are collision events. Interest in the most damage causing event to the fuel system vs. vehicle relates to the goal of the database to study fuel system crash performance. Fuel system crash performance is considered a post crash event that is distinct from most vehicle crashworthiness systems which are concerned with occupant protection during the crash. Crash events which are most harmful to occupants may not necessarily be the same as most harmful crash events to the fuel system. A general principle of crashworthy fuel system design is to provide fuel system integrity in crashes in which occupants are expected to survive. For each of the damage causing events a 7-digit CDC was coded based on the SAE Collision Deformation Classification (CDC) structure. The CDC lateral damage location coding was modified consistent with the changes made in the burn damage location above. The third digit of the CDC is the area of deformation. The area of deformation is divided into front (F), right (R), left (L), back (B), top (T), and underneath (U). The area of deformation for the Most Damage Causing Event to the Fuel System is shown in Figure 3.

A third CDC was used to code rollover deformation when rollovers greater than or equal to two quarter rolls were noted. The rollover CDC is intended to capture damage to the top of the vehicle. The final vehicle information is in the damage matrix. The damage matrix is a gridwork laid over the truck. Each cell of the grid represents crush damage on the vehicle at that location. Crush producing a void in a matrix cell would be coded as damage to that cell. The damage matrix was developed as a possible substitute or enhancement to the CDC coding. The CDC coding requires the categorizing of collision deformation into areas (digit 3) then coding of damage extent (digit 7) based upon the area. Since the performance of fuel systems in crashes is dependent on the damage to the fuel tank itself the damage matrix allows for the documentation of vehicle damage without confinements of the CDC coding method. The fuel system of the GM pickup truck is generally susceptible to compromise due to collision-induced side damage irrespective of the principal direction of force (CDC digit one and two) or CDC damage area (CDC digit 3). There were 272 incidents for which there was insufficient information to code the matrix. Results of the Damage Matrix are shown in Figure 4.

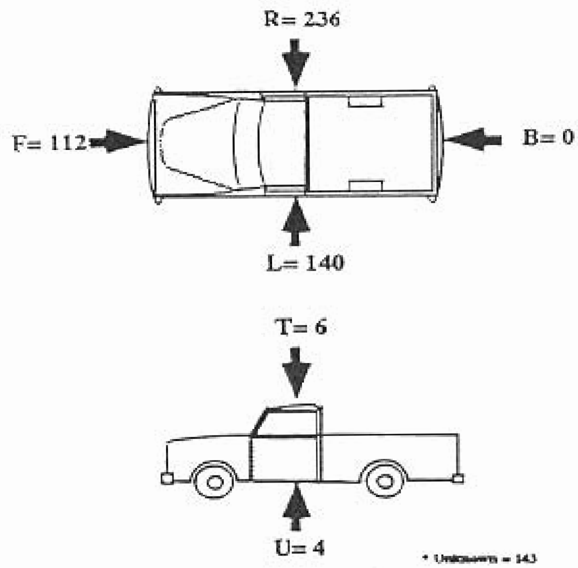

Figure 3. Area of Deformation for Most Damage Causing Event

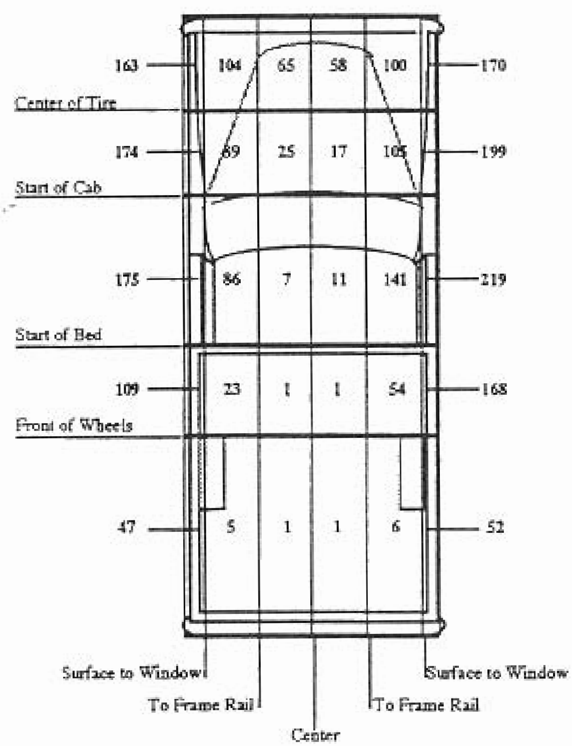

Figure 4. Damage Matrix shows the number of incidents for which there was crush damage to the specific region of the truck

Occupant Information

The occupant information was collected for the occupants in all of the involved vehicles and for pedestrians. Information was collected for the number of people burned, which is referred to as fire involvement. Fire involvement is defined as bums or smoke inhalation. Information on fatalities with fire involvement was also collected. Fire involvement was assessed for all people surrounding the post crash environment, including occupants of other vehicles, pedestrians and civilian rescuers because spilled fuel at a crash scene presents a hazard not just to the incident vehicle but to all people and property in the post crash environment. Data for these fields was taken primarily from police reports and medical reports. Since medical reports were not available for many of the incidents this data should be considered as a minimum number of fire injuries. In all, documentation has been located to identify a total 676 people with fire involvement. Table 1 presents this occupant data.

Table 1. GM/CK Light Truck Fire Involvement for all Vehicles and Pedestrians

Number of People with Fire Involvement	Number of Incidents for which the associated number of people in the Incident Vehicle had Fire Involvement	Number of Incidents for which the associated number of people in the Other Vehicles had Fire Involvement	Number of Incidents for which the associated number of Pedestrians had Fire Involvement
0	172	439	602
1	303	40	5
2	88	12	1
3	17	6	0
4	6	3	0
5	1	2	0
6	1	0	0
Unknown	53	139	33
Total Incidents	641	641	641
Total People with Fire Involvement	565	104	7

To understand Table 1, follow one row across to find the number of people with fire involvement. For example, row three, column one has a "2" for the number of people with fire involvement. In the next column there is an entry of 88. This means that there were 88 incidents where two people had fire involvement in the incident vehicle.

Survivability information was also collected. Table 2 presents this survivability data. The table shows that there were 1541 total occupants (933 + 608) accounted for in incidents with sufficient information. There were also 656 known fatalities. There is evidence of trauma as principal cause of death in 269 of these fatalities. Evidence of trauma is treated similar to the prior discussion of "evidence of," meaning that trauma has been noted in a reviewed document to be the principal cause of death and is not necessarily based upon a medical determination as to cause of death.

The numbers in columns 2 through 7 in Table 2, except for the final row, represent incidents, not people. In row three the number of occupants from column one is "2." The entry in column two is 165 which means that there were 165 incidents in which there were two people in the incident vehicle. Continuing across the table, column three shows that there were 65 incidents in which there were two fatalities in the incident vehicle, which are not necessarily related to column two since there might have been two fatalities in vehicles with more than two occupants. The final row is the total number of people, not incidents. We were able to obtain evidence of 933 occupants of incident vehicles. There are 531 fatalities observed in the database, and there were 203 fatalities in which evidence of trauma as a principal cause of death is observed. This does not imply that there were 203 deaths due to trauma, nor does it imply that 328 fatalities (531 - 203 = 328) occurred where fire was the principal cause of death. A medical diagnosis of cause of death was available in some instances but, to date no attempt has been made to independently determine the survivability of occupants for a particular crash or assess the basis of any cause of death comments within the physical files of the database.

Table 2. GM C/K Light Truck Survivability Data

Number Of Occu-pants	Number of Incidents with the associated number of Occupants in the Incident Vehicle	Number of Incidents with the associated number of Fatalities in the Incident Vehicle	Number of Incidents with the associated number of Trauma Induced Fatalities in the Incident Vehicle	Number of Incidents with the Associated number of Occupants in the Other Vehicles	Number of Incidents with the Associated number of Fatalities in Other Vehicles	Number of Incidents with the associated number of Trauma Induced Fatalities in Other Vehicles
0	-	145	308	241	452	460
1	328	328	147	152	61	32
2	165	65	19	82	14	5
3	43	15	3	26	2	5
4	19	1	0	18	5	1
5	3	3	0	11	2	1
6	0	0	0	5	0	0
7	2	0	0	2	0	0
8	4	0	0	1	0	0
9	1	1	1	1	0	0
13	0	0	0	2	0	0
Unknown Incidents	76	83	163	100	105	137
Total Incidents	641	641	641	641	641	641
Total People	**933 occupants**	**531 fatalities**	**203 trauma fatalities**	**608 occupants**	**125 fatalities**	**66 trauma fatalities**

Fuel Leakage Information

The first question in coding the database for fuel leakage information is: In the incident, did fuel leakage occur in the fuel containment system due to the most damage causing event to the fuel containment system? The basis for confirmation of fuel leakage is provided and if possible the individual failure mode of the fuel containment system is coded. Coding of failure mode is performed consistent with known crash-induced failure modes of motor vehicle fuel systems and reports of failure modes of GM pickup trucks. (Arndt, 93). To date 26 incidents have been confirmed to have no fuel leakage from the fuel containment system due to collision and 310 are confirmed to have fuel leakage. Analysis of the database for fuel leakage has only occurred on incidents which have been judged to contain information sufficient to initiate some engineering analysis (approximately 500 incidents).

DISCUSSION

The design of the other incident database, the subject of this paper, tailored the engineering inquiry to the issue of motor vehicle fuel containment system crashworthiness and post-crash, fuel-fed fire issues. This design was incorporated throughout the database. The database was populated with incidents containing the actual or alleged occurrence of fuel leakage or fire involving a collision of a GM truck. While in general it would be of interest to study a larger distribution of crashes, including those which produce fuel system damage without fuel leakage, it is the notoriety a motor vehicle post crash fire which generates the potential for awareness of a fuel system failure. Of particular interest in the detailed study of a population of particular crashes is the opportunity for the manifestation of the vehicles design to be fully expressed in the real world. Data describing the collision exposure of a vehicle and in this case the fuel system exposure may be developed. Finally, the opportunity to provide objective, yet comprehensive insight into issues underlying crashworthy fuel system design performance is available.

In the legal setting, the database, including both the physical files and the software, are a tremendous tool for characterizing, cataloging, filtering and querying the population of known incidents. Because the database was designed from the perspective of engineering inquiry, underlying the database design from a legal perspective was the question: how would a product manufacturer set out to identify and collect data on a product for which it might have interest or responsibility in monitoring field performance? Coding of data was performed using documents and other data which an engineer would normally rely upon to gain knowledge of a product's field performance.

The database has been used as a tool to identify incidents which courts have allowed as similar incidents for the purpose of the legal concepts of Notice, Proof of Defect, and Punative Damages. For example for the legal concept of Notice, other incidents in the database which provide the possibility for engineering knowledge of a potential defect have been ruled as substantially similar provided they meet the criteria of (1) a GM truck with fuel tanks outside the frame rails, (2) involved in a collision, (3) in which there was fuel leakage or fire, (4) such incidents with sufficient information to initiate engineering analysis (the CDC is not null) and (5) eliminating incidents with evidence of non-OEM fuel tank fire involvement have been ruled as substantially similar. There are approximately 500 incidents in the database which meet this criteria for Notice of a possible defect. On the issue of Proof of Defect the manifestation of a Defect in the real world is evidence of Defect. Fuel Leakage information contained within the database addresses this issue. For example, the known side impact crashes which manifest the crashworthiness design defect present in GM truck fuel systems and meet the five criteria discussed for These incidents evidencing a design defect meet the five criteria discussed for Notice and the additional criteria of (6) confirmed fuel leakage from the fuel containment system as a result of a collision, and (7) an identified failure mode due to design has occurred.

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