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# Vehicle Fires: Research and Effective Mitigation

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## ABSTRACT

When combustible fluids and flammable materials are stored in close proximity to potential ignition sources, as they inevitably are in self-propelled highway and military vehicles, fires are a real and present danger. Fortunately there are often means to mitigate the risks and damage caused by fire on a vehicle, but the fire risk, and therefore the mitigation approach, varies with application. While most vehicle fires are due to mechanical or electrical problems not associated with a collision, most fatalities attributed to automobile fires are reported to occur after a collision. In contrast, in most cases, fire-related fatalities on passenger buses are not due to engine compartment fires or collisions. Vehicle fire research involving statistics, cause and origin, materials, and fire protection systems is almost as old a pursuit as the automobile itself, and such work continues. This paper presents an overview of vehicle fire incidents and research and concludes by contrasting effective fire protection mitigation approaches for automobiles, passenger buses and military ground vehicles.

**KEYWORDS:** vehicle fires, fire research, fire protection

## INTRODUCTION

Fire safety is an important issue on any vehicle. As long as vehicles carry flammable materials such as fuel, lubricants, plastics, and ammunition in the case of military vehicles, fires are possible. Generally vehicle occupants, flammable materials and ignition sources are in close proximity and it is not always easy or practical for the occupants to safely evacuate in the event of a fire. Fortunately, vehicle design features can reduce the risks of fire, and, in some cases, fire suppression systems can slow or limit the damage caused by fires. Many of the most effective design features are the product of experience and extensive research and development.

Some of the first automobiles had fiery endings. As early as 1891, a prototype three-wheeled, single-cylinder automobile was reported to be lost to fire [1]. The first patents describing means of (air and ground) vehicle fire protection date to the early 20$^{th}$ century, and at least one described precursors to modern methods, including automatic actuation where an orientation-insensitive extinguisher (based on a flexible dip tube) was released by heat, radiation and mechanical shock sensors; see Figure 1 [2]. Despite such efforts, vehicle fire risks, real and perceived, persist; notable examples include the Ford Pinto recall in 1975 [3] and General Motor's (GM) third generation C/K pickup truck controversy which ended in a settlement with the US' National Highway Transportation Safety Administration (NHTSA) in 1994 [4]. Recalls of popular automobiles due to fire risks are a continuing issue [5].

Similarly, fires on heavy-duty vehicles, from passenger buses to tanks, have driven application-specific research and development [6, 7]. While there are many similarities between fire protection methods, the differences between vehicle platforms, e.g., automobile, truck, bus or military, result in significant variations in approaches [8].

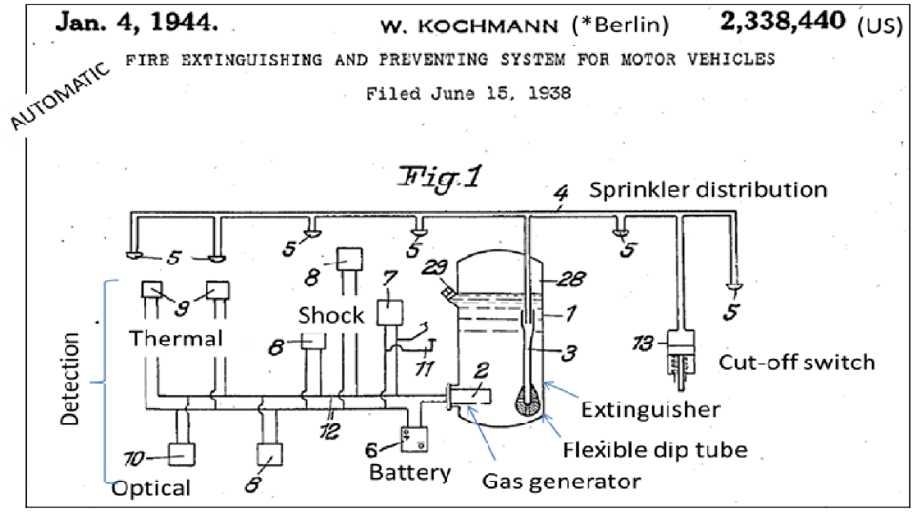


*Figure 1 A 1944 patent described an automatic vehicle fire protection system where an orientation-insensitive extinguisher was actuated by shock, thermal and optical sensors.*

## VEHICLE FIRE RESEARCH

Significant vehicle fire research has been conducted over the last few decades. The goal of this research has been to further fire science as it relates to our understanding of vehicle fires, with the aim of reducing injuries and fatalities associated with motor vehicle fires. Notably, this growing body of important work, motivated in part by GM's 1994 settlement with NHTSA, led to the organization of the SAE International (formerly Society of Automotive Engineers) Fire Safety Committee in 2005.

Since the inception of the Fire Safety Committee, 129 peer-reviewed papers have been presented at the SAE World Congress and subsequently published [9]. The fire safety sessions have also included interactive panel discussions that featured experts in vehicle fire protection [10]. In 2013 an overview of vehicle fire statistics in the US was presented as a keynote [11] and in 2012 and 2014, keynotes were presented that described the unique challenges in the fire protection of electric vehicles [12, 13]. Session topics have ranged from laboratory science, including flammability properties of materials and analytical tools, such as computational fluid dynamic modeling, to the methodologies of field investigation, such as the correlation of burn patterns and fire origin. Other studies have addressed the prospective means of fire risk reduction in future technologies – for example, the flammability of next generation refrigerants – to retrospective studies of risk characteristics in designs currently on the road.

Advancements in vehicle development, especially those associated with the power train and fuel, may involve relatively new fire hazards that often require somewhat unique mitigation means. Recent collaborative efforts to understand emerging electric vehicle fire hazards (e.g., those associated with certain battery technologies) and develop applicable safety standards are notable examples [14, 15]. Clearly the need for vehicle fire research, in all applications, continues.

### Highway Vehicles

Among the most dramatic fires are those that occur along with an automobile crash – at least in the movies. In reality post-collision fires are rare, usually relatively small and slow growing, and may start minutes after the crash. However, if an occupant is trapped inside a crashed vehicle, even a small, slowly growing fire can be dangerous. And in fact, while the vast majority of vehicle fires are due to mechanical or electrical problems and do not involve a collision or overturn, most of the fatalities attributed to automobile fires occur after a collision or overturn. Overall, in the US, vehicle fire-related deaths account for approximately ten percent of all deaths attributed to fire [11].

Many significant aspects of vehicle fire protection have been described in SAE Fire Safety papers and presentations. While mainly focused on automobiles, the papers have also addressed fire research aimed at the significant problems faced in many heavy-duty vehicular applications such as buses and trucks. Topics covered include (selected references given):

- Statistical overviews of the highway vehicle problem. The National Fire Protection Association (NFPA) and others have reported detailed statistics on vehicle fire causes, origins, and damage, as well as given guidance on the fire investigation methods that underlie the data, most of it based on the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association's (NFPA's) fire department surveys [11, 16-19].
- In 2003 the first post-collision fire created in laboratory conditions was reported to the National Highway Transportation Safety Administration (NHTSA) [20]. The results, including the difficulty of pre-engineered fire protection systems to cope with post-collision automobile distortions, were summarized and discussed in a 2005 SAE Fire Safety paper [21].
- In 2005, the first production automotive active fire protection system, developed by Ford and their suppliers for the Crown Victoria Police Interceptor, was described [22].
- The work of the SAE Technical Working Group (and others) studying hydrogen and fuel-cell vehicle safety standards and test protocols was reported annually from 2005 through 2011 [23-26].
- Other groups have expanded ideas developed in SAE Committees and Working Groups into prototype test protocols [27, 28].
- Several papers reported studies of hot surface ignition of underhood fluids. These were summarized in a 2010 paper [29].
- The flammability of plastics and the combustion byproducts of materials have been evaluated [30-32].
- The flammability of new and existing refrigerants has been studied [33, 34].
- Everything in a vehicle has a trade-off, and safety systems are no exception. The design trade-offs and cost-benefit analysis of fire protection methodologies have been the object of several studies [35-38].
- Evaluations of vehicle maintenance, design changes and/or features with respect to their effect on fire safety have been described [39-42].
- Full scale vehicle burn tests indicate that oxidation patterns and melted aluminum do not necessarily correlate with fire origin as is often assumed [43].
- Active fire protection systems have been discussed and evaluated [8, 10, 20-22, 44-46].

Fires on passenger buses and freight trucks are relatively rare but do occur, mainly due to mechanical or electrical problems in machinery spaces, e.g., the engine compartment [11, 47-50]. Related to this is the trend toward better vehicle design, maintenance and operator training, and, in the case of passenger buses, the increased application of active fire protection systems for the engine compartment [49]. While a fire protection system in the bus engine compartment arguably may increase the level of passenger safety, the main benefit is asset protection. This is indicated by the fact that injuries and fatalities attributed to bus fires almost always started outside the engine compartment (e.g., in a wheel well, or at a fuel tank), so active fire protection systems as currently designed and deployed in the engine compartment would have had no mitigation effect [51-55]. Strategic use of fire resistant materials, better means of egress and more thorough maintenance have been suggested as improvements that would be most effective, in addition to evaluating possible fire protection technologies for the wheel wells and other currently unprotected areas [53, 54].

A notable and lamentable limousine fire in 2013 resulted in the deaths of five of the ten vehicle occupants. The fire, similar to most fatal passenger bus fires, did not involve a collision and the fire origin had nothing to do with the engine compartment: “Friction heat produced by the rear drive shaft coming in contact with the drive shaft tunnel ignited the car’s floor, carpet, and rear seat, trapping five of the nine passengers.” Tragically, and also similar to passenger bus fires involving fatalities, it appears that limited and ineffective means of egress was a significant contributor to the loss of life [55].

**Military Ground Vehicles**

Militaries around the world operate many thousands of tactical and combat ground vehicles in hostile environments. Fire protection for these vehicles has been, and is, a significant design and development area [7]. Fires on military ground vehicles fall into two broad categories: peacetime and combat.

Peacetime fires in military ground vehicles are similar to vehicle fire experiences in the commercial sector:

- Fuel, hydraulic fluid, or lubricating oil component failures can lead to leakage of flammable liquids that are ignited by contact with hot surfaces and/or sparks;
- Electrical component failures or corrosion can lead to overheated circuits that ignite wire insulation or oily contaminants and other combustible materials; and
- Overheated brake components and trapped road debris can cause fires in the wheel well. Wheel well fires can also occur if a vehicle operates too long on 'run-flats' designed to offer temporary support when the main tires are deflated.

Many military vehicles have fire protection systems that protect the engine, wheel well and other machinery spaces against peacetime-type fires.

Combat fires, especially ones that involve the crew area, are unique in that they may demand what is essentially explosion protection of occupied areas. They are caused by threats that defeat other survivability layers, for example, armor, generally start and grow much faster than a human can respond, and can be lethal within a fraction of a second. Additionally, egress is not generally feasible in these situations. However, vehicle design can do much to mitigate these fire risks. Features such as compartmentalization, where flammable materials such as fuel and ammunition are isolated from occupied areas, and the use of fire resistant materials wherever practical, are particularly effective. The first lines of defense against catastrophic combat fires, after vehicle design, are for the vehicle to operate so as to not be seen, hit or penetrated. If all that fails then the ultimate layer of vehicle fire protection is an automatic fire protection system.

The first modern automatic fire protection system designed to protect vehicle crews from combat fires was deployed on several main battle tanks in the early 1980s. These systems effectively protected the crew and engine compartments using extinguishers charged with Halon 1301 (bromotrifluoromethane). Automatic extinguishing systems are designed to detect and extinguish fast-growth fires in a fraction of a second – much faster than any human can react. Since the Montreal Protocol was signed in 1994, many countries, including the US, agreed to phase out production of ozone-depleting substances (such as Halon 1301) as much as practical. Subsequently, for example, the fire protection materials used to protect the engine compartment in most military ground vehicles were switched from ozone-depleting ones to dry chemical and other agents with relatively benign environmental effects. Similarly, the automatic systems protecting the crew compartments of many vehicles adopted more environmentally friendly agents. Much of the international research in this area was presented in Halon Options Technical Working Committee sessions hosted by the US' National Institute of Technology (NIST) [56]. Research efforts focused on more effective and environmentally friendly fire fighting systems continue [57].

## Different Approaches to Vehicle Fire Protection

The military applies a useful categorization method to systems installed on their vehicles that depends on how the system relates to the intended vehicle mission. Obviously crew survivability is of paramount importance when evaluating a system and assigning a relative value to it.

| LAYER | MILITARY VEHICLE | PASSENGER BUS | AUTOMOBILE |
|---|---|---|---|
| 1 | Fire power | Perform Maintenance | Collision Avoidance |
| 2 | Concealment | Avoid Road Debris | Minimize Impact Effects |
| 3 | Mobility | Emergency Egress | Restraints |
| 4 | Armor | Fire Protection | Fire Protection |
| 5 | Fire Protection | | |

*Table 1. Layers of survivability*

Clearly, vehicles have different "layers of survivability." For example, fast suppression systems that are appropriate in combat vehicles may not be the best solution for protecting bus passengers. Since a highway vehicle fire, fast as it may be, is typically much slower than a combat fire in an armored vehicle, it is likely that simpler solutions will be as effective at preventing injuries due to fire. Survivability layers for military vehicles, passenger buses, and automobiles are compared in Table 1.

'Fire protection' takes many forms. For example, Table 2 lists fire protection approaches for the vehicle types listed in Table 1. The italicized text in Table 2 represents potential fire protection layers that have been suggested in the past but are not widely implemented:

- One of the early automobile fire protection studies concluded that, while effective on large vehicles, or in static situations, pre-engineered fire suppression systems are not practical on small, relatively deformable vehicles such as the automobile [20, 21]. This leaves the possibility of an overheat detection and/or suppression system that might offer effective protection against automobile fires where significant deformations, such as those caused by a collision, are not involved.
- After the deadly 2005 fire on a passenger bus in Wilmer, Texas, one of the recommendations made by the National Transportation Safety Board (NTSB), in addition to better use of fire resistant materials, and improved means of egress, was to develop overheat detection systems for the wheel wells [53].

| LAYER | MILITARY VEHICLE | PASSENGER BUS | AUTOMOBILE |
|---|---|---|---|
| 1 | Compartmentalization | Compartmentalization | Compartmentalization |
| 2 | Fire resistant materials | Fire resistant materials | Fire resistant materials |
| 3 | High-speed, automatic fire extinguishing system | Automatic engine fire extinguishing system | *Underhood fire/overheat detection & suppression* |
| 4 | External fire protection | *Wheel well overheat detection* | |
| 5 | Fire resistant uniforms | | |

*Table 2. Layers of fire protection*

The differences in fire protection approaches ultimately stem from differences in the purpose and intended use of each type of vehicle. Fire prevention is an important goal for all vehicles, as is design so that a fire, if one does occur, is limited. The last possible fire protection measure is a fire suppression system. However, the effectiveness of a fire suppression system is limited to a small area of the vehicle (for example, the engine compartment) and, further, cannot be expected to completely extinguish a fire in all cases. Therefore, it is important that vehicles are designed for effective egress and rescue. For similar reasons, parking and maintenance facilities should not rely solely on onboard vehicle fire suppression systems [58].

## CONCLUSION

The close proximity of flammable materials and ignition sources make vehicle fires a significant risk and thus an important safety issue. Fortunately there are often means to mitigate the risks and damage caused by fire on a vehicle, but the optimum approaches vary by application, and by whether the focus is on passenger or asset protection. Many of the most effective design features that reduce the risk of fire on a vehicle, and/or mitigate the effects of a fire if it does occur, are the product of experience and extensive ongoing research and development. Advancements in vehicle development, which may inadvertently introduce new fire hazards, motivate continued vehicle fire research.

## REFERENCES

Note: This paper is an updated version of the keynote paper "Vehicle Fire Research – a Review," presented at the 2014 Fire in Vehicles (FIVE) Conference, Berlin, Germany, October 2014.


1. "History of the automobile," http://en.wikipedia.org/wiki/History_of_the_automobile (accessed 28 Apr 2014).
2. Kochmann, W., "Fire-extinguishing and preventing system for motor vehicles," US Patent 2338440A, filed 15 Jun 1938, published 4 Jan 1944.
3. US National Highway Transportation Safety Administration (NHTSA) Campaign 78V143000, http://www-odi.nhtsa.dot.gov/recalls/results.cfm?start=1&SearchType=DrillDown&type=VEHICLE&year=1975&make=FORD&model=PINTO&component_id=0&TYPENUM=1&summary=true (accessed 30 May 2014).
4. Nauss, D. W. "U.S. to Drop Recall Probe of GM Trucks," http://articles.latimes.com/1994-12-03/news/mn-4220_1_pickup-truck (accessed 30 May 2014).
5. O'Dell, J. "Recalled but Unrepaired Cars Are a Safety Risk to Consumers," http://www.edmunds.com/car-safety/recalled-but-unrepaired-cars-are-a-safety-risk-to-consumers.html (accessed 30 May 2014)
6. Johnson, E.L, and Yang, J.C, "Motorcoach Flammability Project Final Report: Tire Fires - Passenger Compartment Penetration, Tenability, Mitigation, and Material Performance," NIST Technical Note 1705, July 2011.
7. "Design of Combat Vehicles for Fire Survivability," MIL-HDBK-684, 15 February 1995.
8. Hodges, S. E., "Effective Fire Protection Systems for Vehicles," 2006 SAE World Congress Proceedings, 2006-01-0792, 2006, doi:10.4271/2006-01-0792.
9. SAE Fire Safety Papers can be found at http://papers.sae.org/safety/hazards/ (accessed 15 May 2012) and at http://www.mvfri.org/ (accessed 15 May 2012).
10. The 2005 SAE Fire Safety Panel discussion is well documented in Appendix E of, Hamins, A., "Vehicle Fire Suppression Research Needs," NISTIR 7406, March 2007.
11. Ahrens, M., "Local Fire Department Responses to Fires Involving Automobiles, Buses, and Larger Trucks: 2006-2010 Estimates," SAE Technical Paper 2013-01-0210, 2013, doi:10.4271/2013-01-0210. See also "Highway Vehicle Fires (2008-2010)," Topical Fire Report Series, Vol. 13, Issue 13, January 2013.
12. Presentations by Casey Grant and other contributions to the NFPA Fire Research Foundation may be found at www.nfpa.org/foundation (accessed 14 May 2012).
13. Willette, Ken and Emery, J., "Fire Suppression 101 for HEVs & EVs: A first responder's perspective," NFPA, Keynote presentation to the 2014 SAE World Congress, Detroit, MI, Apr 2014.
14. "3rd Annual Electric Vehicle Safety Standards Summit," http://www.sae.org/events/nevss/guide.pdf (accessed 30 May 2014).
15. Durso, F., "Elemental Questions," NFPA Journal, March/April 2012.
16. Ahrens, M., "An Overview of the U.S. Highway Vehicle Fire Problem," SAE Technical Paper 2005-01-1420, 2005, doi:10.4271/2005-01-1420.
17. Ray, R. and Ahrens, M., "Vehicle Fire Data: Different Sources, Different Goals, Different Conclusions?" SAE Technical Paper 2007-01-0877, 2007, doi:10.4271/2007-01-0877.

18. De Santis, T., Adams, C., Molnar, L., Washington, J. et al., "Motor Vehicle Fire Investigation," SAE Technical Paper 2008-01-0555, 2008, doi:10.4271/2008-01-0555.
19. Ahrens, M., "Vehicle Fire Deaths Resulting from Fires Not Caused by Collisions or Overturns: How Do They Differ from Collision Fire Deaths?" *SAE Int. J. Passeng. Cars - Mech. Syst.* 1(1):215-226, 2009, doi:10.4271/2008-01-0257.
20. Santrock, J, and Hodges, S., “Part 2A: Evaluation of a Fire Suppression System in a Full Scale Vehicle Fire Test and Static Vehicle Fire Tests - Engine Compartment Fires,” National Highway Transportation Safety Administration (NHTSA) Docket # 1998-3588-202, General Motors Corporation. November 2003.
21. Santrock, J. and Hodges, S., "Evaluation of Automatic Fire Suppression Systems in Full Scale Vehicle Fire Tests and Static Vehicle Fire Tests," SAE Technical Paper 2005-01-1788, 2005, doi:10.4271/2005-01-1788.
22. Dierker, J., Thompson, R., Wierenga, P., and Schneider, M., "Development of Ford Fire Suppression System," SAE Technical Paper 2005-01-1791, 2005, doi:10.4271/2005-01-1791.
23. Scheffler, G., Veenstra, M., Chang, T., Kinoshita, N. et al., "Developing Safety Standards for FCVs and Hydrogen Vehicles," SAE Technical Paper 2010-01-0131, 2010, doi:10.4271/2010-01-0131.
24. Scheffler, G., McClory, M., Veenstra, M., Kinoshita, N. et al., "Establishing Localized Fire Test Methods and Progressing Safety Standards for FCVs and Hydrogen Vehicles," SAE Technical Paper 2011-01-0251, 2011, doi:10.4271/2011-01-0251.
25. Perrette, L., Paillere, H., and Joncquet, G., "Presentation of the French National Project DRIVE: Experimental Data for the Evaluation of Hydrogen Risks Onboard Vehicles, the Validation of Numerical Tools and the Edition of Guidelines," SAE Technical Paper 2007-01-0434, 2007, doi:10.4271/2007-01-0434.
26. Hu, J., Chen, J., Chandrashekhara, K., and Chernicoff, W., "Finite Element Modeling of Composite Hydrogen Cylinders in Localized Flame Impingements," *SAE Int. J. Passeng. Cars - Mech. Syst.* 1(1):577-589, 2009, doi:10.4271/2008-01-0723.
27. Kinoshita, N., Chang, T., and Scheffler, G., "Development of the Methodology for FCV Post-crash Fuel Leakage Testing Incorporated into SAE J2578," *SAE Int. J. Passeng. Cars - Mech. Syst.* 3(1):282-300, 2010, doi:10.4271/2010-01-0133.
28. Tamura, Y., Takabayashi, M., Takeuchi, M., Ohtuka, N. et al., "Development and Characteristics of a Burner for Localized Fire Tests and an Evaluation of Those Fire Tests," SAE Technical Paper 2012-01-0987, 2012, doi:10.4271/2012-01-0987.
29. Colwell, J., "Ignition of Combustible Materials by Motor Vehicle Exhaust Systems - A Critical Review," *SAE Int. J. Passeng. Cars - Mech. Syst.* 3(1):263-281, 2010, doi:10.4271/2010-01-0130.
30. Griffith, A., Janssens, M., and Willson, K., "Evaluation of Smoke Toxicity of Automotive Materials According to Standard Small-Scale Test Procedures," SAE Technical Paper 2005-01-1558, 2005, doi:10.4271/2005-01-1558.
31. Lyon, R. and Walters, R., "Flammability of Automotive Plastics," SAE Technical Paper 2006-01-1010, 2006, doi:10.4271/2006-01-1010.
32. Suzuki, J., Tamura, Y., Hayano, K., Oshino, K. et al., "Safety Evaluation on Fuel Cell Stacks Fire and Toxicity Evaluation of Material Combustion Gas for FCV," SAE Technical Paper 2007-01-0435, 2007, doi:10.4271/2007-01-0435.
33. Olson, J. and Lambert, S., "Hot Surface Ignition and Fire Propagation Characteristics of R134a and R1234yf Refrigerants," *SAE Int. J. Mater. Manf.* 5(2):2012, doi:10.4271/2012-01-0984.
34. Styles, B., Santrock, J., Vincent, C., Leffert, M. et al., "A Critical Assessment of Factors Affecting the Flammability of R-1234yf in a Frontal Collision," *SAE Int. J. Trans. Safety* 2(1):2014, doi:10.4271/2014-01-0419.
35. Shields, L., Scheibe, R., and Thomas, T., "Vehicle Design for Fire Safety and Evaluation of Design Trade-Offs," SAE Technical Paper 2007-01-0879, 2007, doi:10.4271/2007-01-0879.
36. Simons, J., "How NHTSA Would Analyze the Costs and Benefits of Fire Safety," *SAE Int. J. Passeng. Cars - Mech. Syst.* 1(1):227-230, 2009, doi:10.4271/2008-01-0258.

37. Shields, L., Staskal, D., Ray, R., Birnbaum, L. et al., "Evaluation of Risk Trade-offs in Passenger Compartment Fire Retardant Usage - a Case Study," SAE Technical Paper 2009-01-0014, 2009, doi:10.4271/2009-01-0014.
38. Scheibe, R., Scott, T., Shields, L., and Zerbe, R., "Design Tradeoffs: The Social Costs of Vehicle Fire Protection," SAE Technical Paper 2012-01-0985, 2012, doi:10.4271/2012-01-0985.
39. Friedman, K., Holloway, E., and Kenney, T., "Impact Induced Fires: Pickup Design Feature Analysis," SAE Technical Paper 2006-01-0550, 2006, doi:10.4271/2006-01-0550.
40. Wolpert, D. and Egelhaaf, M., "Case Studies in Germany Examining the Effect of Recent Service Work on Vehicle Fires," SAE Technical Paper 2009-01-0009, 2009, doi:10.4271/2009-01-0009.
41. Smyth, S. and Dillon, S., "Common Causes of Bus Fires," SAE Technical Paper 2012-01-0989, 2012, doi:10.4271/2012-01-0989.
42. Arndt, M.," Fuel System Crashworthiness for Recreational Off-Highway Vehicles," SAE Technical Paper 2012-01-0988, 2012, doi:10.4271/2012-01-0988.
43. Colwell, J., "Full-Scale Burn Test of a 1998 Compact Passenger Car," SAE Technical Paper 2014-01-0426, 2014, doi:10.4271/2014-01-0426.
44. Chattaway, A., Dunster, R., Weller, P., and Peoples, J., "The Development of a Standard Test for Assessing the Effectiveness of Transit Vehicle Fire Extinguishing Systems," SAE Technical Paper 2012-01-0986, 2012, doi:10.4271/2012-01-0986.
45. Brandt, J., Modin, H., Rosen, F., Försth, M., and Ochoterena, R., "Test Method for Fire Suppression Systems in Bus and Coach Engine Compartments," SAE Technical Paper 2013-01-0208, 2013, doi:10.4271/2013-01-0208.
46. Ochoterena, R., Hjohlman, M., and Försth, M., "Detection of Fires in the Engine Compartment of Heavy Duty Vehicles, A Theoretical Study," SAE Technical Paper 2014-01-0423, 2014, doi:10.4271/2014-01-0423.
47. Pearlman, J., and Meltzer, N. R., "Risk of commercial truck fires in the United States: an exploratory data analysis," Fire in Vehicles (FIVE), Proceedings, 2012.
48. Ahrens, M., "Vehicle Fires Involving Buses and School Buses," NFPA, August 2006.
49. Hammarström, R., Axelsson, J., Försth, M., Johansson, P., and Sundström, B., "Bus Fire Safety," SP Report 2008:41, 2008.
50. Meltzer, N. R., Ayres, G., Truong, M., "Motorcoach fire safety analysis : the causes, frequency, and severity of motorcoach fires in the United States,"Fire in Vehicles (FIVE), Proceedings, 2012.
51. "Feds probe safety rules after fiery bus crash in California," http://www.nydailynews.com/news/national/feds-probe-safety-rules-fiery-bus-crash-california-article-1.1755679#ixzz2zWR8SJLT (accessed 23 December 2014).
52. The majority of bus fire fatalities do not involve fires in the engine compartment, including, for example, approximately 90% of the fire fatality incidents listed in Försth, M., "Bus fire safety – state of the art and new challenges," Fire in Vehicles (FIVE), Proceedings, 2014.
53. "Highway Accident Report, Motorcoach Fire on Interstate 45 During Hurricane Rita Evacuation Near Wilmer, Texas September 23, 2005," NTSB/HAR-07/01, PB2007-916202 National Transportation Safety Board, 21 Feb 2007.
54. "U.S. Department of Transportation Motorcoach Safety Action Plan," DOT HS 811 177, November 2009.
55. Badger, Stephen G., "Catastrophic Multiple-Death Fires in 2013," NFPA, September 2014.
56. NIST Next Generation Fire Suppression Technology Program, Halon Options Technical Working Conference (HOTWC), Application: Ground Vehicles and Application: Engine Compartment," http://www.nist.gov/el/fire_research/hotwcindex.cfm, (accessed 10 June 2014).
57. Hodges, S. E. and McCormick, S. J., "Fire Extinguishing Agents for Protection of Occupied Spaces in Military Ground Vehicles," *Fire Technology*, Springer Science, May 2012.
58. It is not advisable for the fire protection of a facility to depend on onboard vehicle fire protection systems, contrary to what is proposed in Hofman, A., Dulsen, S., Scholzen, G., "Rapid Fire Spread in a Bus Depot Fire," Fire in Vehicles (FIVE), Proceedings, 2014.