ISSN 2347 - 3983
Volume 8. No. 9, September 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter259892020.pdf
https://doi.org/10.30534/ijeter/2020/259892020

# Improvement of Fire Safety upon Vehicle Operation: Opportunities and Trends

**Le Quang Hai**
University of Fire Prevention and Fighting , Ha Noi, Vietnam

**ABSTRACT**
Every year thousands of lives and millions of assets are lost as a consequence of fires occurred using some vehicles. Fire safety awareness is being improved all over the world. Governmental offices, industrial associations, manufacturers of proprietary equipment, and even specialized protection groups established committees and platforms of knowledge in order to discuss these issues. This article reviews publications devoted to the issues of fire safety upon vehicle operation. The main approaches are highlighted regarding interpretation of investment climate by various scientists. On the basis of expert survey, the fire scenarios for buses are determined, as well as constituents of fire protection measures in buses and standards of fire safety of buses in foreign countries.

**Key words :** fire safety, vehicles, buses, fire scenarios; fire safety measures; regulation No. 107.

## 1. INTRODUCTION

Human errors, flammable liquids, damaged wiring, or excessive heating are common causes of fires at vehicles. Only US fire services response to about 287,000 fires at vehicles every year. Fires, related with transport, result in loss of about 500 lives every year and damages of about USD 1.3 billion. [1]

Airplanes, trains, and passenger vessels are regulated by established standards, rules, and certifications so that to guarantee high level of safety upon implementation of new materials and structures. However, bus sector relies mainly on manufactures of proprietary equipment, operators and suppliers of fire protection system in order to provide safety using several stringent rules.

Despite the fact that buses proved to be one of the most safe kind of public transport, manufactures and operators of buses put a lot of efforts to establish and to support this high level of safety, and millions of passengers travel safely to work, school, and on personal affairs. Nevertheless, fire after collisions or failure of bus component endangers people's lives and can influence significantly the operation costs and customer confidence [2].

That is why the subject matter of this work is the opportunities and trends of improvement of fire safety upon operation of buses.

Fire safety of buses includes numerous aspects of designing, operation, maintenance, evacuation, and even rapid-response services. All they play decisive role in establishing efficient standards and advanced practices; however, this is responsibility of various interested parties during development. Buses create numerous unique problems regarding fire safety. Various operation modes (city, highway, long distances), unique types of vehicles (school bus, public transport, intercity bus) provide conditions for fire safety; however, each fire hazard, either motor compartment, battery compartment, wheel arch, or even luggage compartment, results in unique problems in terms of geometry, air flow, spreading of flame and evacuation [3].

Fires in buses are common, buses participate every day in fire incidents. For instance, about six fires in school buses are registered in USA daily [4]. In Germany from 0.5 to 1% of all buses suffer from fires every year, which equals to at least 350-400 fires [5]. From time to time bus fires result in numerous victims. Fortunately, most fires do not result in death, however, property loss and expenses due to business termination, rescue activities and road jams can be extensive. This article is aimed at determination of opportunities and trends of improvement fire safety upon operation of bus vehicles.

Hypothesis of the studies is as follows: due to new requirements to automatic systems of fire extinguishing, it is possible to expect that fire safety of buses will be improved.

On the basis of the obtained results, it is possible to conclude that the formulated aim has been achieved.

## 2. METHODS

The following methods were used during the studies:

- analysis of scientific publications devoted to improvement of fire safety upon operation of bus vehicle;
- expert survey to determine the following: fire scenario for buses; components of fire protection measures; development of standards of fire safety of buses in foreign countries.

Forty experts participated in online survey (EMERCOM officers, employees of carriers, officers of municipal transport agencies), whose areas of interest included the issues of fire safety upon operation of buses.

## 3. RESULTS

On the basis of expert survey, let us arrange fire scenarios for buses. The experts highlight three important fire scenarios for buses based on conditions describing fire origin site: fire in passenger compartment, fire in motor compartment, and fire in wheel compartment (Table 1).

**Table 1:** Fire scenarios for buses

| No. | Scenario | Description | %* |
|---|---|---|---|
| 1 | Fire in passenger compartment | Modern buses are equipped with such flammable materials as cotton, wool or cellulose in order to provide the appropriate comfort (for instance, convenient seats, air conditioner, curtains, and blinds) for passengers. The main sources of combustion in passenger compartment are faults of wiring, deliberate actions (arson), and accidental ignition by any passenger (cigarette, lighter) | 80% |
| 2 | Fire in motor compartment | This compartment is isolated room where engine is installed. There are numerous flammable materials, such as fuel, oil, plastics, and rubber. Easily flammable fluids are as follows: motor oil (diesel or gasoline), transmission oil, antifreeze. The main sources of ignition are fuel leaks in combination with faulty wiring. | 90% |
| 3 | Fire inside wheel arch | Wheels, transmission, and brakes are installed in this compartment. It contains several flammable materials in the form of solids, such as tire rubber and plastic, as well as fluids (brake fluid and oil/lubricant for bearings). Overheated brakes, frozen wheel bearings, soft tires, or lack of lubricant resulting in friction can be sources of combustion of bus in this zone. | 75% |

Note: on the basis of expert survey; * – percent of expert references

According to the experts' opinion, fire safety of bus fleet is comprised of a set of measures (preventive measures, passive systems, detection, evacuation and extinguishing), their application depends on fire scenario.

It is believed that peculiar attention should be paid to preventive measures (Table 2), their main aim is to avoid bus fire or to decrease its scope. Any preventive measures are based on destruction of fire triangle: oxygen, heat, and fuel. Therefore, the preventive measures are concentrated on combustibles and ignition (heating) and are subdivided by the experts into three levels of fire prevention: improvement of fire resistance, control of combustibles, and eliminating of source of combustion.

**Table 2:** Preventive measures of fire safety for bus fleet

| No. | Level of preventive measures | Description | %* |
|---|---|---|---|
| 1 | Improvement of fire resistance | In the case of passenger compartment, this is based on obligatory flammability tests of compartment materials. The motor compartment is especially sensitive to inflammation due to fuel, oils, and high interior temperatures, thus, flammability tests of materials in the motor compartment should be performed. | 75% |
| 2 | Control of combustibles | In the case of passenger compartment, the control of combustibles is based on elimination or decrease in their amount in the compartment. Combustibles in the motor compartment and wheel arch are as follows: diesel fuel of gasoline, motor oil, transmission oil, brake fluid, oil/lubricant for bearings). In the considered scenarios, fires can be prevented by elimination of their leaks. In this regard, the control of combustibles is based on the appropriate maintenance by strict adherence to its schedule. | 90% |
| 3 | Elimination of source of combustion | There are two main sources of combustion in passenger compartments: wiring faults or accidental actions. Wiring faults can be eliminated by appropriate maintenance based on strict adherence to its schedules. As for the passenger compartment, driver and passengers should be responsible for monitoring any suspicious activity by other passengers, who intentionally or unintentionally can cause fire. In the motor compartment, elimination of source of combustion is concentrated on prevention of wiring faults and hot surfaces. The wheel arch is oriented at prevention or elimination of wiring faults and friction. The most suitable measure for passenger compartments and wheel arches is comprised of appropriate maintenance by strict adherence to its schedule. | 85% |

Note: on the basis of expert survey; * – percent of expert references

In addition to preventive measures, the experts analyze such measures of fire safety of bus fleet as passive systems, detection, evacuation and extinguishing (Table 3).

**Table 3:** Other measures of fire safety of bus fleet

| No. | Other measures | Description | %* |
|---|---|---|---|
| 1 | Passive systems | The aim of passive systems is to avoid fire propagation between compartments. The level of passive systems is oriented on localization. In buses the motor compartment is separated from passenger compartment and wheel arch by fire resistant materials and flame retardants. It was demonstrated in [6] how fire in wheel arch propagated to passenger compartment. However, no separation into compartments is required in wheel arch. | 85% |
| 2 | Detection | The main aim is to detect as rapid as possible and to inform about fire or smoke. Rapid detection of fire reduces time of response to bus fire, which is the key factor in favor of role of other levels of fire safety. In passenger compartments, the level of detection is focused on two aspects: visual and automatic detection. Alarm systems detecting smoke or excessive temperature should be installed in toilet, driver compartment, and other separate compartments, such as luggage compartment. These systems should provide audible and visual signal to driver cab. Motor compartment should be equipped with alarm systems with audible and visual signal to driver cab. Up till now there are no rules regarding detection in wheel arch. | 80% |
| 3 | Evacuation | Its main aim is to provide rapid escape of passengers from bus before the conditions become unbearable. Evacuation covers only the portion of passenger compartment, which requires for appropriate number of exits with at least two exit doors. Usually this is determined on the basis of maximum number of passengers in the bus. An important factor is relevant evacuation procedure and personnel training. Drivers (and accompanying persons) should be trained to respond adequately and quickly in the case of fire. The level of evacuation can include information about safety during travels so that passenger are aware of evacuation in the case of fire. | 75% |
| 4 | Extinguishing | It is required to provide extinguishing at the early stages of fire so that to prevent its progress and propagation. In this regard, Swedish insurance companies starting from 2004 require the buses to be equipped with extinguishing system in motor compartment. In passenger compartment, fire extinguishing is based on manual and automatic fire suppression. It is stated by regulations that buses should be equipped with fire extinguishers, at least one of them should be placed near driver. The driver and accompanying persons should be trained to work with extinguishers. Passenger compartment should be equipped with extinguishing systems, especially in the rooms of nonvisual access, such as toilet and luggage compartment. | 75% |

Note: on the basis of expert survey; * – percent of expert references

## 4. DSCUSSION

As demonstrated in [7, 8], about 2/3 of all bus fires originate in motor compartments. This obviously resulted in efforts to decrease fire hazard of bus motor compartments. One of the methods to improve fire protection, which is becoming more and more common, is installation of automatic extinguishing system in motor compartment. Such systems are comprised of one or several containers with firefighting agent and fire detection system, which releases the agent in the case of combustion. In order to distribute the agent from container into various regions of motor compartment, pipeline system is used. Some systems, for instance, with aerosol generators, are equipped with generators installed in machine compartment and releasing the agent directly from the generator. In addition to fire suppression, these systems usually inform the bus driver by fire alarms. Various types of agents are applied, including dry reagents, water mist, foam, aerosol, gas agents, as well as combinations thereof.

Installation of automatic system of fire detection and suppression on buses was recommended by fire researchers, trading associations, accident investigators, and transport authorities [9, 10, 11]. In general case, this is not considered as a final solution to bus fires, but as a tool required to restrict the scales and consequences of bus fires. For instance, in [12] it is stressed that installation of automatic extinguishing systems in bus motor compartment should by prioritized among other measures to improve fire safety of buses.

In 2015 GRSG decided that automatic extinguishing systems were required for buses with more than 22 passengers. UNECE Global Forum aiming at coordination of regulations for vehicles (WP.29), subsequently declared the decision adopted by GRSG in the form of requirements regarding fire safety of vehicles. One of them, Regulation No. 107 [13], covers wide range of subjects for buses, many of them are related with fire safety. The main requirements related with fires are as follows: application of flammable or fluid absorbing insulators in motor compartment is prohibited; heat resistant membrane between motor compartment (or any heat source) and other portion of bus; safe design and mounting of cables; insulated switch for circuit voltage higher than 100 V; safe and accessible mounting of battery; special place for fire extinguishers and first aid kits; no flammable materials in the radius of 10 cm from any potential heat source, for instance, exhaust systems or high voltage equipment; alarm systems detecting excessive temperature in motor compartment and heater of passenger compartment (if motor compartment is located near driver). Alarm systems detecting smoking or excessive temperature should be also installed in toilets, driver sleeping compartment, and other separate compartments.

Regulation 107 was signed by 45 states–participants. They include not only the EU members but also such states as Russia, Turkey, Kazakhstan, Egypt, Tunisia, and Malaysia.

Regulation 107 stipulates two alternative methods of tests and approval of extinguishing systems [6]: in order to approve the system in any bus, it should be tested using standard testing simulator. As an alternative variant, it could be tested in motor compartment and heater of certain bus model, where it should be installed.

The procedure is comprised of four tests:

- testing high fire load. The test includes minor fuel spraying, fire in fuel accumulations, and fire in fibrous material. The test is performed without air flow;
- testing high fire load with forced air flow rate of 1.5 m3/s. The test includes high fuel spraying, fire in fuel accumulations, and fire in fibrous material (other locations than in Test 1);
- testing low fire load with forced air flow rate of 1.5 m3/s. The test includes minor fires in fuel accumulations in various locations;
- testing repeated combustion with oil dropping on hot surface heated to 600°C.

In order to obtain permission, all combustion should be suppressed. Repeated combustion test is performed, when repeated combustion is prevented for at least 45 s. The system should have the same setting (nozzle position, etc.) during the tests. For larger or smaller motor compartments, the setting procedure is based on certain scaling rules.

In addition to fire tests for each type of vehicles, where extinguishing system should be installed, complete documented analysis should be performed to identify fire hazard aiming at adaptation of the system to bus model. Such analysis should be carried out before installation in order to determine location and direction of release of firefighting agent (for instance, nozzles). Potential fire hazard in motor compartment and heater of passenger compartment should be identified and the release points should be located so that fire suppressing agent is distributed to cover fire hazard upon activation of the system. Spraying pattern and direction of releasing points as well as release distance should cover the detected hazardous factors of fire. In addition, appropriate operation of the system should be provided irrespective of vehicle height.

Some manufacturers of extinguishing systems develop their own tests for optimization of extinguishing systems and demonstration of their efficiency, for instance, the researchers from Harbin Institute of Technology published the article about development of tests of extinguishing systems for buses [14]. In recent years some large-scale researching incentives have been carried out [15] aimed at development of standardized tests of fires in motor compartments, development of testing devices and testing procedures for estimation of potential systems of detection and suppression of fires in bus motor compartments.

## 5. CONCLUSION

The obtained results have confirmed the hypothesis that due to new requirements to automatic extinguishing systems, it is possible to expect significant improvement of fire safety of buses. This improvement is related not only to existence of extinguishing systems, since such systems are already commonly used, but also to the fact that, as expected, the quality of design and assembling will be improved, because the system design including identification of fire hazard will be included into bus production process, the installation will be performed at factory and not during modernization after bus delivery. When bus manufacturer undertakes higher general responsibility for fire safety, including extinguishing systems, this will for sure result in more integrated and smart decisions.

It is important to monitor continuously the operation of extinguishing systems during fires so that to obtain data about the system performance and to improve continuously both the systems and the standards of fire safety. This is especially important when considering the appearance of new and alternative fuels regarding which less data on fires are available.

An important step to continue this work is improvement of requirements to possible detection of fire in motor department. If the detection function of automatic extinguishing systems operates improperly, then the firefighting agent could be released improperly, and total efficiency of the system would be impaired.

**REFERENCES**


1. S.E. Hodges, Vehicle Fire Research − a Review, Proceedings from 3rd International Conference on Fires in Vehicles – FIVE 2014. Berlin, Germany, pp. 17-24, 2014.
2. M. Försth, Bus Fire Safety – State of the Art and New Challenges, Proceedings from 3rd International Conference on Fires in Vehicles – FIVE 2014. Berlin, Germany, pp. 39-50, 2014.
3. V. Alonso, G. Rein, Analysis of Fire Protection of UK Buses from 1964 to 2013, Proceedings from 4th International Conference on Fires in Vehicles – FIVE 2016. Baltimore, USA, pp. 39-48, 2016.
4. R.A. Crescenzo, Bus Fires in the United States: Statistics, Causes and Prevention, Proceedings from 2nd International Conference on Fires in Vehicles – FIVE 2012. Chicago, USA, pp. 9-16, 2012.
5. A. Hofmann, S. Dülsen, Study on smoke production, development and toxicity in bus fire. Berlin: BAM. 2014.
6. P. Karlsson, M. Rosengren, J. Brandt, New certification system for enhanced fire safety of vehicles, Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018. Vienna, Austria. Retrieved from: https://www.diva-portal.org/smash/get/diva2:1267640/FULLTEXT01.pdf
7. J. Peoples, Fire Suppression Systems in Buses and Coaches – How, Where and Why, Proceedings from 4th International Conference on Fires in Vehicles – FIVE 2016. Baltimore, USA, pp. 37-46, 2016.
8. D. Wolpert, M. Egelhaaf, Examples of Bus Fire Investigations, Proceedings from 4th International Conference on Fires in Vehicles – FIVE 2016. Baltimore, USA, pp. 71-81, 2016.
9. H. Schauerte, Experience with Fire Safety Measures in Public Transport Buses, Proceedings from 3rd International Conference on Fires in Vehicles – FIVE 2014. Berlin, Germany, pp. 25-38, 2014.
10. M. Hagen, Means of Escape in the Event of Bus/Coach Fires, Proceedings from 3rd International Conference on Fires in Vehicles – FIVE 2014. Berlin, Germany, pp. 79-86, 2014.
11. M. Engelhaap, F.A. Berg, Motorcoach Fires – Analysis and Suggestions for Safety Enhancements, Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles. Washington, D.C., pp. 26-35, 2005.
12. J. Panagiotou, Motorcoach Fire Investigation and Wheel Well Fire Testing, Proceedings from 2nd International Conference on Fires in Vehicles – FIVE 2012. Chicago, USA, pp. 47-58, 2012.
13. Regulation No. 107 of the Economic Commission for Europe of the United Nations (UNECE) — Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction. 2015. Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/d8730fbc-157e-11e5-8817-01aa75ed71a1
14. S. Feng, Z. Li, X. Sun, Analysis of Bus Fires Using Interpretative Structural Modeling, Journal of Public Transportation, vol. 19, no. 3, pp. 1-17, 2016.
15. J. Brandt, M. Försth, New International Test Method for Fire Suppression Systems in Bus and Coach Engine Compartments, Proceedings from