MOTOR COACH FIRES – ANALYSIS AND SUGGESTIONS FOR SAFETY ENHANCEMENT

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ABSTRACT

Motor coach fires are rare events – the resulting endangerment for the occupants exceeds that of passenger cars by far. A large number of persons is threatened by fire and smoke in an unfamiliar surrounding, panic reactions can occur. The clearance of the escape routes is limited and often blocked by luggage and personal belongings.

To find out more about the real life fire occurrence the German Federal Ministry of Transport, represented by the Federal Highway Research Institute entrusted DEKRA Accident Research to analyse bus fires and to work out a package of measures for safety improvement.

Current regulations for fire testing do not mirror all the requirements resulting from the findings won in the analyses of bus fires. A catalogue of alternative test procedures was compiled, geared to the procedures used in the railway industry to harmonise the requirements and to minimize the costs.

Additional proposals for effortless and cheap realisable measurements like smoke and fire monitoring of the passenger and engine compartment, another assortment of fire extinguishers, and passenger safety information cards have been added.

The complete research report [1] has been verified for practicability and effectiveness due to a series of full scale fire testing and an expert meeting.

Most analysed fires started in the engine compartment and spread there very fast. The extinguishing attempts of the bus drivers and persons passing by have been unsuccessful in the majority of the incidents. Nearly all fires started while the bus was driving, the fires were noticed in an advanced stadium by engine problems, malfunctions, or other drivers.

The presentation will give an overview of the suggested measures, the results of the analysis of the real world fire occurrence, and the full scale fire testing.

INTRODUCTION

Merely 190 motor coach fires have been reported to the German insurance companies in 1999 [2] – limited to this figure, improvements regarding the fire protection in motor coaches do not seem to be necessary. But on closer examination of the risk potential the endangerment of the persons affected by a motor coach fire is by far higher than that of those affected by a car fire. Without warning a large number of persons is exposed to a hazard in an unfamiliar surrounding. Design and utilisation lead to difficulties during the evacuation, particularly in combination with line-of-sight obstruction caused by smoke and panic reactions.

The endangerment resulting from a fire does not only stem from the flames but rather from the fires side effects like the smoke density and toxicology, and the heat release rate.

Within the DEKRA study the following motor coaches were analysed: Vehicles designed and built for long distance travel, equipped with special comfort features for seated passengers. Standing passengers are not transported by these vehicles. The coaches have more than 9 seats including the driver's seat [3]. These coaches are called "Reisebus" in Germany.

European rules and regulations handling motor coach fire protection are limited to small scale fire testing of single components. There are no tests concerning the emitted smoke or the fire growth rate. Constructional guidelines are limited to special components, e.g. regulating the fuel system integrity or safe distances of the exhaust system.

For a further improvement of the motor coach fire safety the DEKRA units "Accident Research" and "Fire and Arson Investigation" elaborated a catalogue of measures as part of the research report [1]. Besides new fire tests, mostly adapted from railroad regulations, a series of cheap and easy to implement organisationally measures have been listed.

MOTOR COACH FIRE OCCURRENCE

The selection of effective and realizable measurements for motor coach fire safety improvements requires an extensive knowledge of the real world fire occurrence. The official German on Road Traffic Accidents Statistic can only offer little information on that topic, fire is not listed at all [4].

The DEKRA evaluation is based on legal expert opinions, elaborated by own fire and accident reconstruction assessors. All together 55 written opinions from the period 1999 to 2004 could be collected and used for the evaluation.

Outside influences

Most of the analysed fires started while the engine was running. In 46 (84%) out of 55 cases the coach was driving, in three other cases (5.5%) the coach was stationary with the engine running. This is of great importance for the risk estimation – these are the states of operation occupants may be on board. The operation status while ignition is shown in Figure 1.

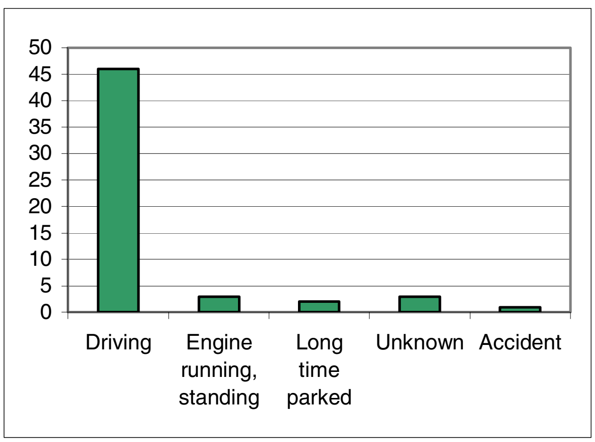

Figure 1 Operation status in the moment of ignition.

Taking a closer view to the locations the fires started, the urban roads and the rural roads are most frequently represented, followed by the Autobahns, Figure 2. Thus, it appears that the driven speed plays a subsidiary role. The engine temperature is of more importance. There was no ignition in the engine compartment while the engine was cold.

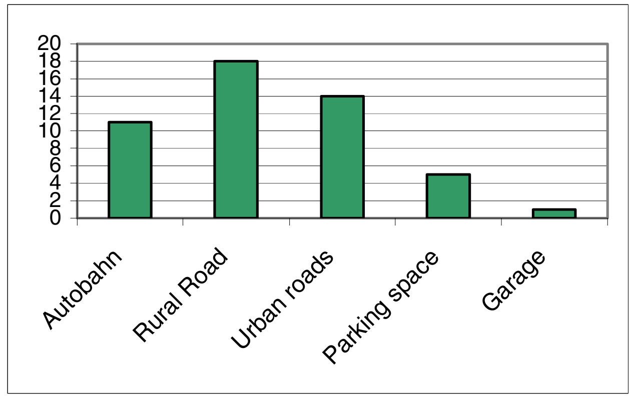

Figure 2 Location of ignition.

The date of first registration of the involved motor coaches was known in 42 (76%) cases. The distribution is shown in Table 1.

Table 1.
Distribution of the age of the analysed motor coaches.

Age distribution	Number
0 years	1
1 years	16
2 years	8
3 – 5 years	7
6 – 10 years	4
11 - 14 years	6

Cause of fire

For an effective countering of an ignition it is of importance to know the causes of fire and the components leading to the fire.

Leakages in the fuel- and oil-systems have been of relevance in 21 (38%) cases. With 11 (20%) cases each, mechanical damages and electric defects caused the ignition, Figure 3. It must be pointed out that the aforesaid causes are only one of the factors necessary for a combustion. Oil and fuel offer a combustible, mechanical and electric defects an ignition source Figure 4.

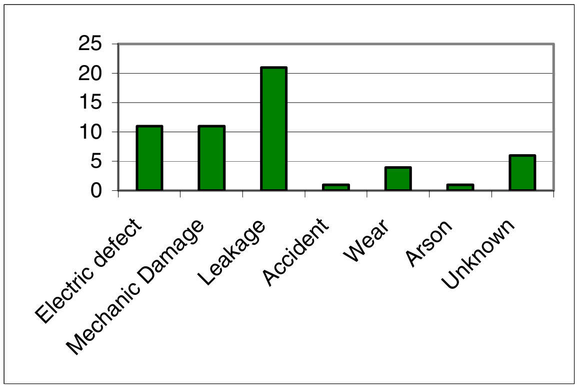

Figure 3 Causes of fire.

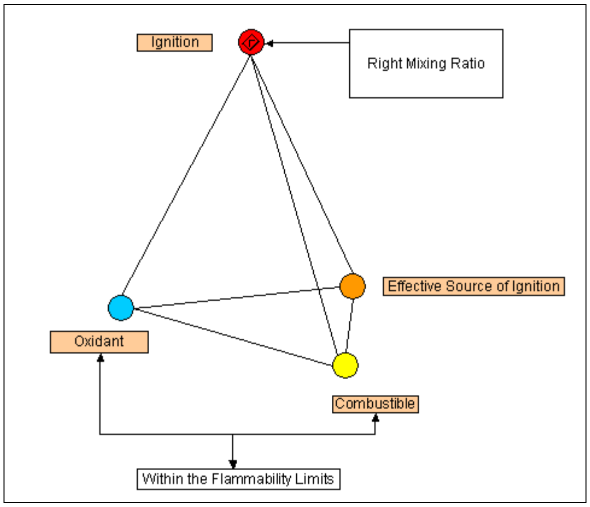

Figure 4 Ignition Tetrahedron based on Emmons

Documented sample cases

Exemplarily two cases are displayed here in the paper. In the first an electric defect of a hand-dryer led to a fire in a toilet of a parked coach. The plastic body of the dryer burnt, emitting large amounts of smoke. Moreover the plastic dropped on the floor burning. The close locking of the toilet's door cut off the oxygen supply, the fire died down itself, Figure 5, and Figure 6.

Figure 5 Melted hand-dryer and smoke damage.

Figure 6 Toilet door with smoke-marks.

The second case is a well documented motor coach fire, starting from the engine compartment, leading to a total loss of the vehicle.

The fire was detected when the front door opened while driving on the Autobahn. After evacuating the coach, the driver tried to extinguish the fire, using the coaches fire extinguisher and two additional ones, made available by passing by truck drivers. Because of a lack of training in fire extinguisher handling the driver did not manage to put the fire out Figure 7.

Figure 7 Driver's attempts to extinguish the fire [5].

After turning away the attached luggage box, the engine fire spread very fast, the occupant compartment is already filled with smoke. Nevertheless some passengers re-entered the coach to get out personal belongings, Figure 8, Figure 9.

Figure 8 Engine fire after turning away the luggage box [5].

Figure 9 Passengers re-entering the coach [5].

After about 10 minutes the rear part of the occupant's compartment is on fire, the whole compartment is filled with thick smoke, Figure 10. Less than one minute later a flashover sets the complete coach on fire, Figure 11. The thermal radiation heats up the luggage stored next to the bus, leading to a pyrolysis, Figure 12, and a self ignition, Figure 13.

Figure 10 Fast fire spread, the complete coach is filled with thick smoke after about 10 minutes [5].

Figure 11 Flashover [5].

Figure 12 Pyrolysis of the luggage stored besides the bus [5].

Figure 13 Self ignition of the luggage [5].

When the fire brigade arrived about 16 minutes after the detection of the fire, neither the coach nor the luggage could be rescued, Figure 14. The Autobahn has not been closed before the fire brigade arrived. The occupants have additionally been endangered by the running traffic.

Figure 14 Arriving of the fire brigade after about 16 minutes [5].

ESTABLISHED LAW AND LEGISLATION

Currently the German national regulations regarding the motor coach fire safety are limited to the requirement of a single 6 kg dry powder fire extinguisher for long distance motor coaches and a second extinguisher for double deck busses [6]. Additional demands are made on European basis.

Regulation 95/28/EC prescribes three different small scale fire tests for motor coach internal fittings. This directive applies to the burning behaviour (ignitability, burning rate, and melting behaviour) of interior materials used in vehicles carrying more than 22 passengers, not being designed for standing passengers and urban use (city busses).

The interior materials of the passenger compartment, used in the vehicle to be type-approved, shall undergo one or more of the following tests (if necessary the composite materials, as used in the vehicle, are to be tested):

1. Test to determine the horizontal burning rate of materials, similar to FMVSS 302 [8].
2. Test to determine the melting behaviour of materials: the sample is placed in a horizontal position and is exposed to an electric radiator. A receptacle is positioned under the specimen to collect the resultant drops. Some cotton wool is put in this receptacle in order to verify if any drop is flaming.
3. Test to determine the vertical burning rate of materials: the sample is held in a vertical position, exposed to a flame. Measured is the speed of propagation of the flame over the material.

The tests 2 and 3 are only used for motor coach fire safety testing. This makes the procedures expensive and reduces the number of testing facilities to be considered. Moreover the tests do not really mirror the entire real life fire occurrence. Interactions of different components during the combustion and the smoke emission are not tested at all.

Constructional guidelines are given in regulation 2001/85/EC [9] applying to every single deck, double deck, rigid or articulated vehicle of category M2 or M3 (as defined in Annex II, Part A, of Council Directive 70/156/EEC [10]). Herein a partition of heat-resistant material between the engine compartment or any other source of heat is approved. Electrical cables shall be located in a manner that no part can make contact with any fuel line or any part of the exhaust system, or be subjected to excessive heat, unless suitable special insulation and protection is provided. Additional requirements concering the battery accessability and placement are formulated. Spaces for a fire extinguisher and a first aid kid are to be provided.

Many similar requirements are given by ECE R 36 [11]. Extra are rules for the mounting of fuel system components and an electric emergency switch to cut off the energy supply.

DEKRA DEMANDS

Based on the findings won during the research DEKRA worked out a catalogue of demands to improve the fire safety of long distance motor coaches and to further limit the risk of the driver and the passengers. Beside new fire test procedures, primarily adopted from the railroad standards, easy realisable and cheap improvements have been taken up in the catalogue.

Fire detection

With the most fires starting in the engine compartment an automatic fire detection and alarm device should be mandatory. In fact, this is very important within the scope that most fires have been detected in a very late state. An early detection is important to extend the time for an evacuation and to increase the chance for an effective fire fighting by laities. Suggested is a system working with thermo detectors.

Automatic fire suppression systems are very effective and already offered as an extra for many coach types Figure 1. But they are still expensive and weighty. DEKRA favours the installation of such systems, but they should not be mandatory.

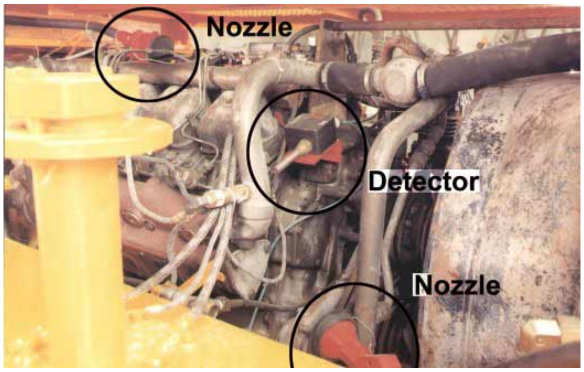

Figure 15 Automatic fire suppression system [12].

An early detection is also of importance in the passenger compartment. DEKRA suggests the use of optic smoke detectors. By placing them at the ceiling and in the toilet's cab a smoke development can be noticed in an early stadium. This is relevant during rides at night with the passengers sleeping and while driving without passengers on board. The cross-linking of the fire alarm system with that of the burglar alarm does also protect the parked bus.

Fire extinguishers

Actually there is no uniform regulation for fire extinguisher needs in motor coaches in Europe. If there are any requirements they are based on national law. E.g. the German Road Traffic Regulations [6] demand a 6 kg dry powder fire extinguisher. This is based on a redeemed German DIN standard [13], already replaced by the European Standard EN 3 [14]. A 6 kg type does no longer exist in that standard.

DEKRA suggests a dry powder extinguisher with a minimum of at least 6 extinguishing agent units nearby the driver's seat and a foam fire extinguisher with at least 4 extinguishing agent units (Calculated on basis of [14] and [15]). All together 12 extinguishing agent units are necessary.

Dry powder is the best extinguishing agent for engine fires. Foam is the better choice for the passenger compartment. Foam is, what most people expect to be a fire extinguisher's filling. The use of foam does not lead to a powder cloud (line of sight obstruction and difficulties of breathing), and the consequences of a misuse are not that serious.

An additional foam fire extinguisher with at least 4 extinguishing agent units is suggested for each stairway of double deck coaches.

Battery and electric components information

Interviews of fire fighters showed that they need a clearly visible pictogram on the battery-box and a map showing the locations of potentially existing extra batteries, of the emergency switch and the laying of the main wires. This can help to prevent an electric ignition after e.g. an accident.

Passenger information

The passengers should be informed about the safety features of the bus before starting the tour. Beside the location of the emergency exits and their handling, information about the places of the fire extinguishers and first aid kit, the safe storage of the luggage and the regulations concerning seat belt wearing should be covered. Additional proper instructions about the right behaviour in emergency situations are essential.

Passenger information cards, as used in the aviation sector, are very useful for that. For the design, pictograms should be used – that way language problems can be circumvented.

Driver education

The analysis of the real world fire occurrence and the questioning of persons who have been involved in bus fires have shown that many drivers are not sufficiently trained in handling a fire extinguisher.

Most passengers injured during the analysed fires have already been brought out of the bus, before they re-entered it to get out personal belongings. Hereby they sustained smoke intoxications. It is the bus driver's job to evacuate the vehicle completely and lead the passengers to a safe place. He additionally has to avert that anybody is re-entering the bus, expect for live saving measurements. The right behaviour in case of a fire needs to be an important point in the drivers education.

Design features

With most fires starting in the engine compartment this is the area with the largest potential for fire prevention and limitation of the fire spread.

The use of porous materials for insulation should be limited. Also coated materials should be banned – the coating can be damaged and loosing its function. Even if the porous material is non flammable it works like a candlewick by carrying the combustible mixture of oil, soot and other dirt.

The separation of the passenger compartment and the engine compartment, the firewall, should withstand a developed engine fire for a couple of minutes and offer enough resistance against heat transfer ().

Critical accumulations of spilling fluids need to be easily detected during the regular checks by the driver and the garage.

The battery box needs to be an own unit separated to all other areas, only accessible from outside the bus. It needs to be resistant against battery acid.

Fire testing

The existing regulations for fire testing of materials used in motor coaches do not mirror the real life fire occurrence. The emitted smoke is not tested at all, the tests are limited to single materials, the cross-influences of materials used in larger components like the seats are not analysed.

The number of standardised fire tests does not require the "invention" of a new one for motor coaches. Very useful tests can be adopted from the railway sector. It is also advantageous that many companies supply parts and components for both, railway and coach industries.

The listing of the recommended tests would go beyond the scope of that paper. Exemplified with the UIC paper cushion test [16] the suggestion for seat testing are described. Within that test, a standardized paper cushion made of newsprint is placed on the seat cushion at the edge with the backrest. After ignition at all four corners the burning behaviour is observed. Among other criteria, the fire must have self extinguished after at least ten minutes to pass the test.

DEKRA FIRE TESTING

To validate the suggested tests, to check the fire performance of actual offered components, and to get further information about the temperatures and variation in time during the fire spread DEKRA carried out some fire tests.

For the tests an old coach was equipped with different actual seats and an actual floor and wall lining. In the first step an on-seat-paper-cushion test was carried out. The seat passed that test explicitly. The first smoke detector, attached to the ceiling nearby the rear exit, set off after about two minutes, immediately after the seat started to emit smoke. The CO-concentration arose to 44 ppm in the fifth minute before declining again (AEGL-2 limit: 420 ppm, AEGL = Acute Exposure Guidline Levels, [17]). The HCN concentration reached the ETW-limit of 5 ppm but did not exceed it (ETW = Einsatz Toleranz Wert [18]). Both measuring points were located nearby the seat, an endangerment for occupants has not existed at any time, Figure 16 and Figure 17.

Figure 16 Configuration of test 1 with paper cushion.

Figure 17 Burnt down paper cushion.

In the second test a paper cushion was placed under a seat. Also that test was passed by the seat explicitly. The thermal load of the floor-lining led to an enormous smoke emission. The CO-concentration climbed to uncritical 84 ppm, HCN could not be detected. The smoke emitted by the floor lining would have led to line-of-sight obstructions and irritations of the respiratory tract, Figure 18 and Figure 19.

Figure 18 Configuration of test 2 with paper cushion.

Figure 19 Burning paper cushion.

In a third test the seat was set on fire by using half a litre of fuel. The smoke alarm set off after just 16 seconds. The luggage rack started to burn with burning drops falling on the floor, igniting that. It took 44 seconds until the smoke filled the complete bus down to the upper edge of the backrests. The complete passenger compartment was filled with smoke after 160 seconds. A self-rescue was impossible after 84 seconds.

The coach was completely closed during the first 530 seconds after ignition to get further information about the influence of air ventilation. The flash-over started 70 seconds after opening the doors.

The maximal temperature was measured in the moment of the flash-over. The temperature at the ceiling reached nearly 1,000°C, Figure 20 to Figure 23.

Figure 20 Seat set on fire with 0,5l of fuel (t = 10s).

Figure 21 Smoke-filled coach after opening the doors in second 530.

Figure 22 Flash-over and start of fire fighting (t = 600s).

Figure 23 Breaking of the side windows during the flash-over (t = 600s).

The very high level of fire performance of the tested seats was obvious after that test. The seats located in front of the ignited one had only received little fire damage. That status could be documented by starting the fire extinguishing immediately after the flash-over, Figure 24.

Figure 24 Seat row in front of the ignited seat. Covering removed by the fire brigade.

CONCLUSIONS AND DEMANDS

Motor coach travelling is with just 0.14 killed per milliard person kilometres one of the safest ways to move from A to B. But that does not mean that no more improvements for coach safety are required. Within a research-project of the German Federal Ministry of Transport, represented by the Federal Highway Research Institute, DEKRA Accident Research was entrusted to work out a catalogue of demands to improve the fire safety of motor coaches. Based on the real world fire occurrence a list of measures, easy and cheap to implement, was developed. Additionally a catalogue of fire tests was drawn up.

Good progress can be made by simple organisational measures. A better training of the drivers, an optimised fire extinguisher concept (dry powder for the engine, foam for the passenger compartment), rescue service information about the battery location, emergency switch and wiring, and passenger information cards are most promising.

With most fires starting in the engine compartment, mostly noticed only in a late stadium of fire propagation by the driver, an automatic detection is of importance. DEKRA suggests a thermal fire detection system for the engine compartment and an optic system for the passenger compartment.

Design features need to prevent the fire spread from one compartment to the other. Especially the sealing of the engine compartment to the passenger compartment needs to be mentioned here. The battery should be located in a separate box, only accessible from outside the bus and resistant against battery acid.

In the long term a replacement of the currently mandatory fire tests is advantageous. Yet neither the smoke nor cross influences of different materials are observed. By adapting the test procedures of the railway industries also extra costs can be saved by not having a special coach procedure.

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