Simulations and experiments of bus fires, a literature review
A selection of relevant studies

- Statistics: 7 studies
  - Finland: 2010 – 2011
  - UK: 1963 – 2013
- Evacuation: 2 studies
- Simulations: 2 studies
- Experiments: > 5 studies
“no total loss of a bus had to be recorded after the installation of the fire extinguishing systems and the thorough examination of all Mercedes Citaro 12 metre buses in 2010”
• Recent data in the UK show that the probability of bus fires is 2.3 times higher than cars, 8 times higher than trains, and 2.7 times higher than ships.

• This paper presents a systemic approach to quantify the impact of the prevention layer to UK buses using statistics from 1964 to 2013.

• The statistics in the UK collected for this paper show that the number of bus fires has increased exponentially from 1964. This increase is related to a larger number of licensed buses per year.

Model Year and Vehicle Age

Figure 3  Fire records by model year, 2004–2006.

Figure 2  Reported ignition points, 1995–2008.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Fires</th>
<th>Civilian Deaths</th>
<th>Civilian Injuries</th>
<th>Direct Property Damage (in Millions US)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passenger road vehicles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automobile, passenger car, ambulance, race car or taxi-cab</td>
<td>202,800 (91%)</td>
<td>277 (84%)</td>
<td>1,077 (88%)</td>
<td>$776 (76%)</td>
</tr>
<tr>
<td>Unclassified passenger road vehicle</td>
<td>152,300 (68%)</td>
<td>209 (63%)</td>
<td>764 (63%)</td>
<td>$536 (52%)</td>
</tr>
<tr>
<td>Motor home, camper mounted on pickup</td>
<td>41,200 (18%)</td>
<td>56 (17%)</td>
<td>173 (14%)</td>
<td>$144 (14%)</td>
</tr>
<tr>
<td>Bus, school bus or trackless trolley</td>
<td>2,700 (1%)</td>
<td>5 (2%)</td>
<td>60 (5%)</td>
<td>$45 (4%)</td>
</tr>
<tr>
<td>Motorcycle or trail bike</td>
<td>1,600 (1%)</td>
<td>3 (1%)</td>
<td>19 (2%)</td>
<td>$5 (0%)</td>
</tr>
<tr>
<td>Off-road recreational vehicle</td>
<td>1,300 (1%)</td>
<td>1 (0%)</td>
<td>10 (1%)</td>
<td>$4 (0%)</td>
</tr>
<tr>
<td>Towable travel trailer</td>
<td>1,300 (1%)</td>
<td>3 (1%)</td>
<td>23 (2%)</td>
<td>$11 (1%)</td>
</tr>
<tr>
<td>Collapsible camper trailer</td>
<td>200 (0%)</td>
<td>0 (0%)</td>
<td>4 (0%)</td>
<td>$1 (0%)</td>
</tr>
<tr>
<td>Portable building or manufactured home</td>
<td>200 (0%)</td>
<td>0 (0%)</td>
<td>2 (0%)</td>
<td>$2 (0%)</td>
</tr>
<tr>
<td><strong>Freight road vehicles</strong></td>
<td>20,500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semi-trailer, with or without tractor</td>
<td>5,900 (3%)</td>
<td>23 (7%)</td>
<td>38 (3%)</td>
<td>$92 (9%)</td>
</tr>
<tr>
<td>General use truck</td>
<td>4,600 (2%)</td>
<td>7 (2%)</td>
<td>32 (3%)</td>
<td>$39 (4%)</td>
</tr>
<tr>
<td>Unclassified freight road vehicle</td>
<td>4,600 (2%)</td>
<td>10 (3%)</td>
<td>30 (2%)</td>
<td>$68 (7%)</td>
</tr>
<tr>
<td>Pickup truck or hauling rig</td>
<td>3,000 (1%)</td>
<td>6 (2%)</td>
<td>23 (2%)</td>
<td>$14 (1%)</td>
</tr>
<tr>
<td>Garbage, waste or refuse truck</td>
<td>1,700 (1%)</td>
<td>0 (0%)</td>
<td>9 (1%)</td>
<td>$18 (2%)</td>
</tr>
<tr>
<td>Tank truck for flammable or combustible liquid</td>
<td>400 (0%)</td>
<td>4 (1%)</td>
<td>10 (1%)</td>
<td>$13 (1%)</td>
</tr>
<tr>
<td>Tank truck for nonflammable cargo</td>
<td>300 (0%)</td>
<td>2 (1%)</td>
<td>1 (0%)</td>
<td>$4 (0%)</td>
</tr>
<tr>
<td>Tank truck for compressed or LP-gas</td>
<td>100 (0%)</td>
<td>0 (0%)</td>
<td>1 (0%)</td>
<td>$1 (0%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>223,300 (100%)</td>
<td>329 (100%)</td>
<td>1,221 (100%)</td>
<td>$1,025 (100%)</td>
</tr>
</tbody>
</table>
Experience with fire safety measures in public transport buses - Horst Schauerte, in proceedings of international conference on fires in vehicles, 2014


Fire safety in buses - WP1 report: Bus and coach fires in Sweden and Norway - Rold Hammarstrom et al. SP Fire Technology SP Report 2006:26


Motor coach fire safety analysis: the causes, frequency and severity of motorcoach fire in the USA - Niel R. Meltzer in proceedings of international conference on fires in vehicles, 2012

Bibliography for evacuation

• **Experimental Analysis of Human Evacuation From Bus Fire** - Hung-Chieh Chung et al. in proceeding of international conference on fires in vehicles, 2016

• **The experiment and simulation analysis of bus emergency evacuation** - Jing Liang; Yong-feng Zhang; Hao Huang; Procedia Engineering, Volume 211, 2018.
A number of materials used in the interior of buses were tested:
- 3 seats, 11 wall and ceiling materials and 2 floor systems
- The tests aimed to evaluate flame spread behaviour, heat and smoke release rates, ignition resistance and generation of toxic gases.
- The test results were compared to existing criteria for other applications. The main conclusion was that the present fire test does not provide a sufficiently high level of fire safety in the passenger compartment of buses.
- In the last part of the project a conventional coach for 49 passengers was used for three different real scale tests:
  - Fire in the engine compartment
  - Fire in a tyre
  - Full scale fire of the entire coach
Experimental studies: Bus Fire Safety
R. Hammarström et al. 2008

• The purpose with the last test was to study:
  o Fire development from the engine compartment into the passenger compartment.
  o Smoke spread and visibility in the passenger compartment.
  o Concentrations of toxic gases in the passenger compartment.
  o Heat release rate from a developed fire in the coach.

• The test showed that the time for evacuation of the passengers was 4 – 5 minutes at a maximum. After this time the concentration of toxic gases reached dangerous levels.
• The visibility in the passenger compartment decreased rapidly. After 5 – 6 minutes the visibility was just a few meters.

- Comparison between requirements for buses and trains
- To show the difference between bus and rail interior material fire performance, material from buses were evaluated according to rail standard CEN TS 4554-2

<table>
<thead>
<tr>
<th>Material</th>
<th>Requirement No.</th>
<th>Irradiance [kW/m²]</th>
<th>MARHE [kW/m²]</th>
<th>HL 1 [kW/m²]</th>
<th>HL 2 [kW/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body insulation (1st)</td>
<td>R1</td>
<td>50</td>
<td>334.5</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Body insulation (2nd)</td>
<td>R1</td>
<td>50</td>
<td>309.0</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Floor covering</td>
<td>R9</td>
<td>25</td>
<td>32.5</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Side panel (1st)</td>
<td>R1</td>
<td>50</td>
<td>64.8</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Side panel (2nd)</td>
<td>R1</td>
<td>50</td>
<td>54.2</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Flooring</td>
<td>R9</td>
<td>25</td>
<td>1.6</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>GRP part (1st)</td>
<td>R1</td>
<td>50</td>
<td>258.5</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>GRP part (2nd)</td>
<td>R1</td>
<td>50</td>
<td>280.9</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Ceiling over seats (1st)</td>
<td>R1</td>
<td>50</td>
<td>247.2</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Ceiling over seats (2nd)</td>
<td>R1</td>
<td>50</td>
<td>215.7</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Ceiling over gangways (1st)</td>
<td>R1</td>
<td>50</td>
<td>307.7</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Ceiling over gangways (2nd)</td>
<td>R1</td>
<td>50</td>
<td>255.5</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Foam of seats (1st)</td>
<td>R20</td>
<td>25</td>
<td>309.2</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>Foam of seats (2nd)</td>
<td>R20</td>
<td>25</td>
<td>166.7</td>
<td>75</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 2 – Results of Cone Calorimeter tests
**Experimental studies: Fire safety performance of buses – A. Hoffmann 2012**

![Image](image.png)

<table>
<thead>
<tr>
<th>Material (material requirement)</th>
<th>Components of CIT-value</th>
<th>CIT-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMO MSC 61(67) Annex 1, Part 2</td>
<td>- 1450</td>
<td>120</td>
</tr>
<tr>
<td>ABD 00031 (Airbus)</td>
<td>- 1000</td>
<td>100</td>
</tr>
<tr>
<td>BSS 7239 (Boeing)</td>
<td>- 3500</td>
<td>100</td>
</tr>
<tr>
<td>SMP 800-C (Bombardier)</td>
<td>90000</td>
<td>3500</td>
</tr>
<tr>
<td>First symptoms of intoxication</td>
<td>20000</td>
<td>200</td>
</tr>
<tr>
<td>Lethal concentrations</td>
<td>80000</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Body insulation (R1)**
- 4 min: 5900 [CO₂] ppm, 99 [CO] ppm, 5 [SO₂] ppm, 73 [NOₓ] ppm, 0 [HF] ppm, 0 [HCN] ppm, 36 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]

**Floor covering (R9)**
- 4 min: 7500 [CO₂] ppm, 793 [CO] ppm, 0 [SO₂] ppm, 31 [NOₓ] ppm, 0 [HF] ppm, 4050 [HCN] ppm, 2 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]
- 8 min: 10100 [CO₂] ppm, 931 [CO] ppm, 0 [SO₂] ppm, 8 [NOₓ] ppm, 0 [HF] ppm, 3572 [HCN] ppm, 4 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]

**Side panel (R1)**
- 4 min: 3600 [CO₂] ppm, 1076 [CO] ppm, 80 [SO₂] ppm, 0 [NOₓ] ppm, 1 [HF] ppm, 0 [HCN] ppm, 167 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]
- 8 min: 4400 [CO₂] ppm, 2004 [CO] ppm, 41 [SO₂] ppm, 1 [NOₓ] ppm, 0 [HF] ppm, 0 [HCN] ppm, 245 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]

**GRP part (R1)**
- 4 min: 19800 [CO₂] ppm, 682 [CO] ppm, 0 [SO₂] ppm, 4 [NOₓ] ppm, 0 [HF] ppm, 0 [HCN] ppm, 10 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]
- 8 min: 35700 [CO₂] ppm, 1122 [CO] ppm, 0 [SO₂] ppm, 7 [NOₓ] ppm, 2 [HF] ppm, 0 [HCN] ppm, 16 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]

**Ceiling above seats (R1)**
- 4 min: 11900 [CO₂] ppm, 688 [CO] ppm, 0 [SO₂] ppm, 87 [NOₓ] ppm, 0 [HF] ppm, 1013 [HCN] ppm, 1 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]
- 8 min: 14700 [CO₂] ppm, 967 [CO] ppm, 0 [SO₂] ppm, 97 [NOₓ] ppm, 1 [HF] ppm, 923 [HCN] ppm, 0 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]

**Ceiling above gangways (R1)**
- 4 min: 16500 [CO₂] ppm, 762 [CO] ppm, 52 [SO₂] ppm, 111 [NOₓ] ppm, 0 [HF] ppm, 1528 [HCN] ppm, 3 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]
- 8 min: 20000 [CO₂] ppm, 984 [CO] ppm, 40 [SO₂] ppm, 149 [NOₓ] ppm, 0 [HF] ppm, 1385 [HCN] ppm, 0 [CIT-value], 2.7 [HL1 (CEN/TS 4545-2)], 1.2 [HL2 (CEN/TS 4545-2)]

**Foam of seats (R20)**
- 4 min: 14200 [CO₂] ppm, 23 [CO] ppm, 1 [SO₂] ppm, 82 [NOₓ] ppm, 0 [HF] ppm, 0 [HCN] ppm, 5 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]
- 8 min: 15800 [CO₂] ppm, 53 [CO] ppm, 0 [SO₂] ppm, 74 [NOₓ] ppm, 0 [HF] ppm, 1 [HCN] ppm, 7 [CIT-value], 1.2 [HL1 (CEN/TS 4545-2)], 0.9 [HL2 (CEN/TS 4545-2)]

**Table 9 – Measured concentrations of toxic smoke gas components**
### Results of the Cone Calorimeter tests, part 2

<table>
<thead>
<tr>
<th>Material</th>
<th>Requirements No.</th>
<th>( D_{s}(4)/D_{s,max} ) Measured</th>
<th>( D_{s}(4)/D_{s,max} ) HL 1</th>
<th>( D_{s}(4)/D_{s,max} ) HL 2</th>
<th>VOF4 Measured</th>
<th>VOF4 HL 1</th>
<th>VOF4 HL 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body insulation (1&lt;sup&gt;st&lt;/sup&gt;)</td>
<td>R1</td>
<td>127.5</td>
<td>600</td>
<td>300</td>
<td>260.8</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Body insulation (2&lt;sup&gt;nd&lt;/sup&gt;)</td>
<td>R1</td>
<td>70.0</td>
<td>600</td>
<td>300</td>
<td>233.5</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Floor covering (1&lt;sup&gt;st&lt;/sup&gt;)</td>
<td>R9</td>
<td>620.1</td>
<td>600</td>
<td>300</td>
<td>Not required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor covering (2&lt;sup&gt;nd&lt;/sup&gt;)</td>
<td>R9</td>
<td>695.4</td>
<td>600</td>
<td>300</td>
<td>Not required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side panel (1&lt;sup&gt;st&lt;/sup&gt;)</td>
<td>R1</td>
<td>453.8</td>
<td>600</td>
<td>300</td>
<td>918.7</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Side panel (2&lt;sup&gt;nd&lt;/sup&gt;)</td>
<td>R1</td>
<td>560.2</td>
<td>600</td>
<td>300</td>
<td>1102.7</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>GRP part (1&lt;sup&gt;st&lt;/sup&gt;)</td>
<td>R1</td>
<td>797.5</td>
<td>600</td>
<td>300</td>
<td>1194.1</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>GRP part (2&lt;sup&gt;nd&lt;/sup&gt;)</td>
<td>R1</td>
<td>1320.0</td>
<td>600</td>
<td>300</td>
<td>1843.9</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Ceiling over seats (1&lt;sup&gt;st&lt;/sup&gt;)</td>
<td>R1</td>
<td>839.5</td>
<td>600</td>
<td>300</td>
<td>2389.9</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Ceiling over seats (2&lt;sup&gt;nd&lt;/sup&gt;)</td>
<td>R1</td>
<td>803.9</td>
<td>600</td>
<td>300</td>
<td>2013.6</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Ceiling over gangways (1&lt;sup&gt;st&lt;/sup&gt;)</td>
<td>R1</td>
<td>601.8</td>
<td>600</td>
<td>300</td>
<td>2133.6</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Ceiling over gangways (2&lt;sup&gt;nd&lt;/sup&gt;)</td>
<td>R1</td>
<td>622.5</td>
<td>600</td>
<td>300</td>
<td>2224.8</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Foam of seats</td>
<td>R20</td>
<td>100.5</td>
<td>300</td>
<td>300</td>
<td>Not required</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 10 – Measurements regarding the light transmission according to CEN/TS 45545-2*
### Test results according to CEN/TS 45545-2

<table>
<thead>
<tr>
<th>Material</th>
<th>Requirement No.</th>
<th>MARHE [kW/m²]</th>
<th>CIT [h]</th>
<th>$D_2(4)/D_{5,max}$ [h]</th>
<th>VOF4 [min]</th>
<th>Valid for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HL1</td>
</tr>
<tr>
<td>Body insulation</td>
<td>R1</td>
<td>334.5</td>
<td>0.3</td>
<td>127.5</td>
<td>260.8</td>
<td>No</td>
</tr>
<tr>
<td>Floor covering</td>
<td>R9</td>
<td>32.5</td>
<td>6.6</td>
<td>695.4</td>
<td>Not required</td>
<td>No</td>
</tr>
<tr>
<td>Side panel</td>
<td>R1</td>
<td>64.8</td>
<td>0.6</td>
<td>560.2</td>
<td>1102.7</td>
<td>Yes</td>
</tr>
<tr>
<td>Flooring</td>
<td>R9</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td>Not tested</td>
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<td>R1</td>
<td>280.9</td>
<td>0.2</td>
<td>1320.0</td>
<td>1843.9</td>
<td>No</td>
</tr>
<tr>
<td>Ceiling over seats</td>
<td>R1</td>
<td>247.2</td>
<td>1.9</td>
<td>839.5</td>
<td>2389.9</td>
<td>No</td>
</tr>
<tr>
<td>Ceiling over gangways</td>
<td>R1</td>
<td>307.7</td>
<td>2.9</td>
<td>622.5</td>
<td>2224.8</td>
<td>No</td>
</tr>
<tr>
<td>Foam of seats</td>
<td>R20</td>
<td>309.2</td>
<td>0.3</td>
<td>100.5</td>
<td>Not required</td>
<td>No</td>
</tr>
</tbody>
</table>

*Table 11 – Summary of measurements according to CEN/TS 45545-2*
Bibliography for experimental studies


- **Bus Fire Safety**  - R Hammarström et al. SP Report 2008:41


- **Motor coach tire fires – passenger compartment penetration, tenability, mitigation, and material performance**  – Erik Johnson & Jiann Yang in proceedings of international conference on fires in vehicles, 2012


Numerical simulations

- A study has shown that automatic opening of the roof hatches effectively reduces smoke levels in the event of a fire, thereby facilitating a safe escape.
- Another study has shown that CFD can be used in the design phase of detector installations on buses.
- CFD modelling can be particularly useful when the movement of smoke and heat inside the bus.
• **Bus Fire Safety** - R Hammarström et al. SP Report 2008:41
• **Fire detection & fire alarm systems in heavy duty vehicles, WP5** – Fire detection in bus and coach toilet. Willstrand, O., J. Brandt, and R. Svensson,
Conclusions

Statistics:
- Most statistics are only available for Sweden, Finland, UK, USA and Berlin. But all prior to 2013.
- Central database for bus fires would be helpful. Such a database should cover at least the European road net.
- Proposal: Request for harmonized method to collect statistics of fire buses. e.g. number of fires, origin of fire, number of casualties, construction year, type of bus, breaching regulation /or not…

Simulations:
- Some studies used CFD simulations to evaluate the fire behaviour in a bus. This method can cost effectively estimate smoke and fire propagation in a bus and in different configuration.

Experiments:
- Various small scale and large scale tests have already been done on bus material and/or bus mockups.
- Suggestion to the group: To consider these studies before performing large scale tests, to determine appropriate goal, instrumentation and testing scenarios.