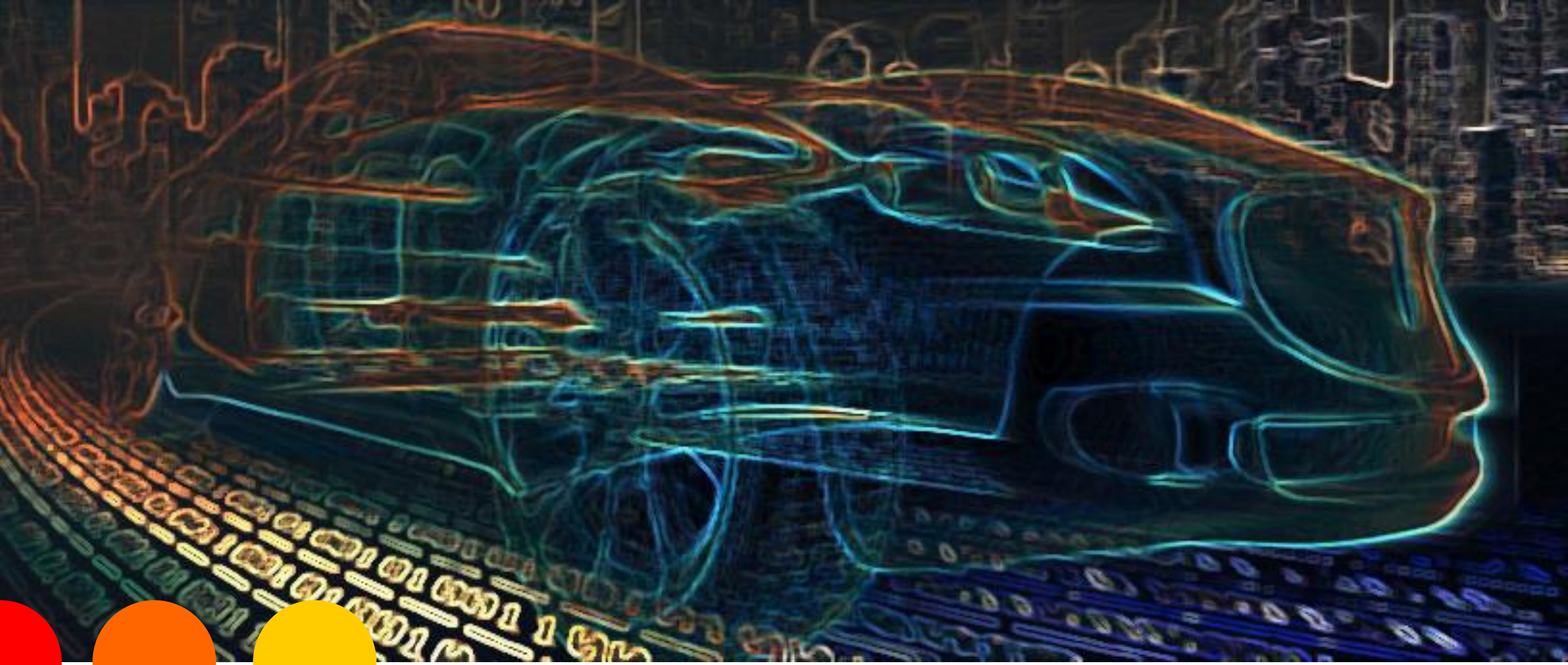

GRSG-BMFE – Madrid 27/11/2018

Simulations and experiments of bus fires, a literature review

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A selection of relevant studies

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- Statistics: 7 studies
  - Sweden: 1996 – 2004 ; 1996 – 2009 ; 2003 – 2013
  - USA: 2004 – 2006 ; 2006 – 2010
  - Finland: 2010 – 2011
  - UK: 1963 – 2013
  - Berlin: 2004 – 2014
- Evacuation: 2 studies
- Simulations: 2 studies
- Experiments: > 5 studies

Statistics: Berlin (2004-2014)

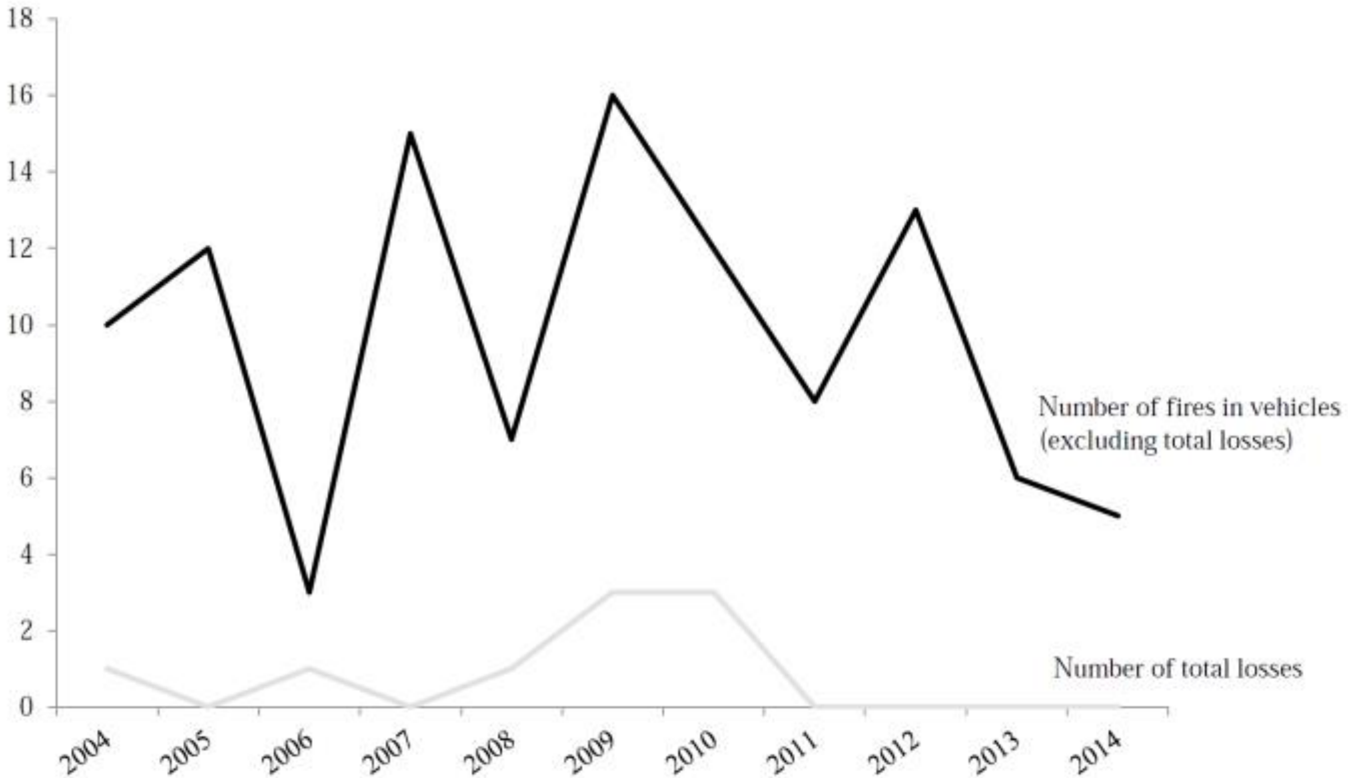

Figure 6: Number of fire incidents and total losses in BVG buses between 2004 and 2013

"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"

Statistics: United Kingdom (1963 – 2013)

- 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.

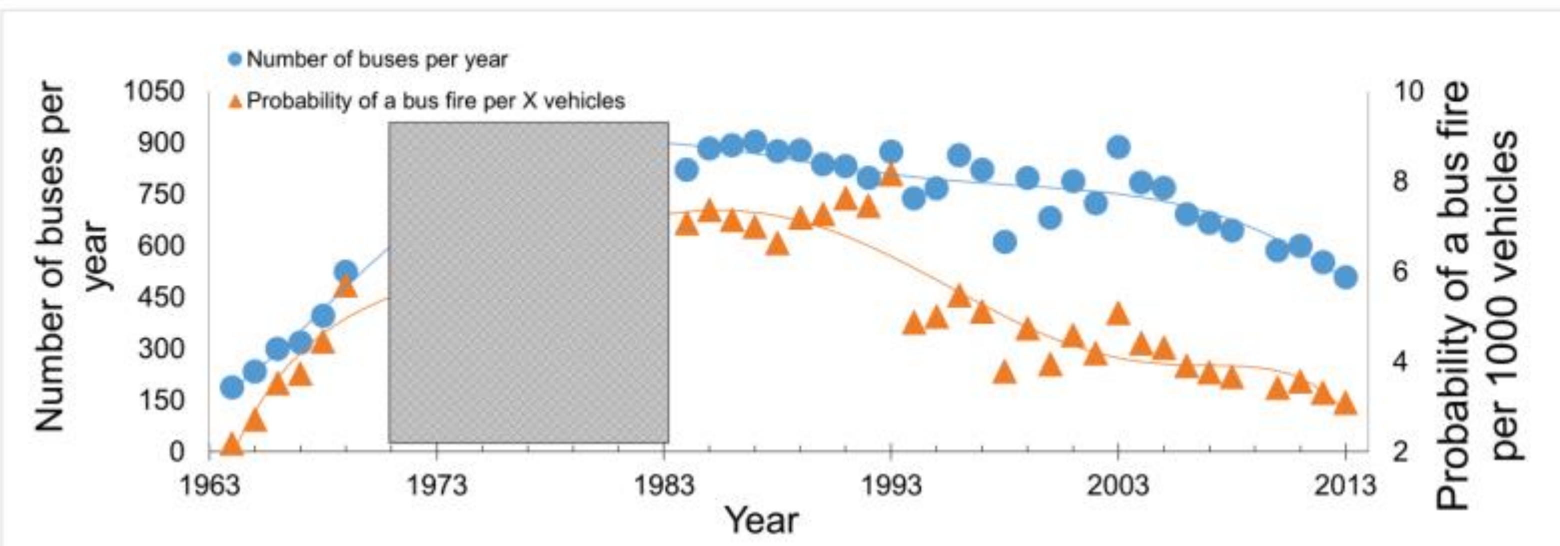

Figure 2 Number of bus fires and probability of bus fires from 1964 to 2013

Statistics: USA (2004 – 2006)

Model Year and Vehicle Age

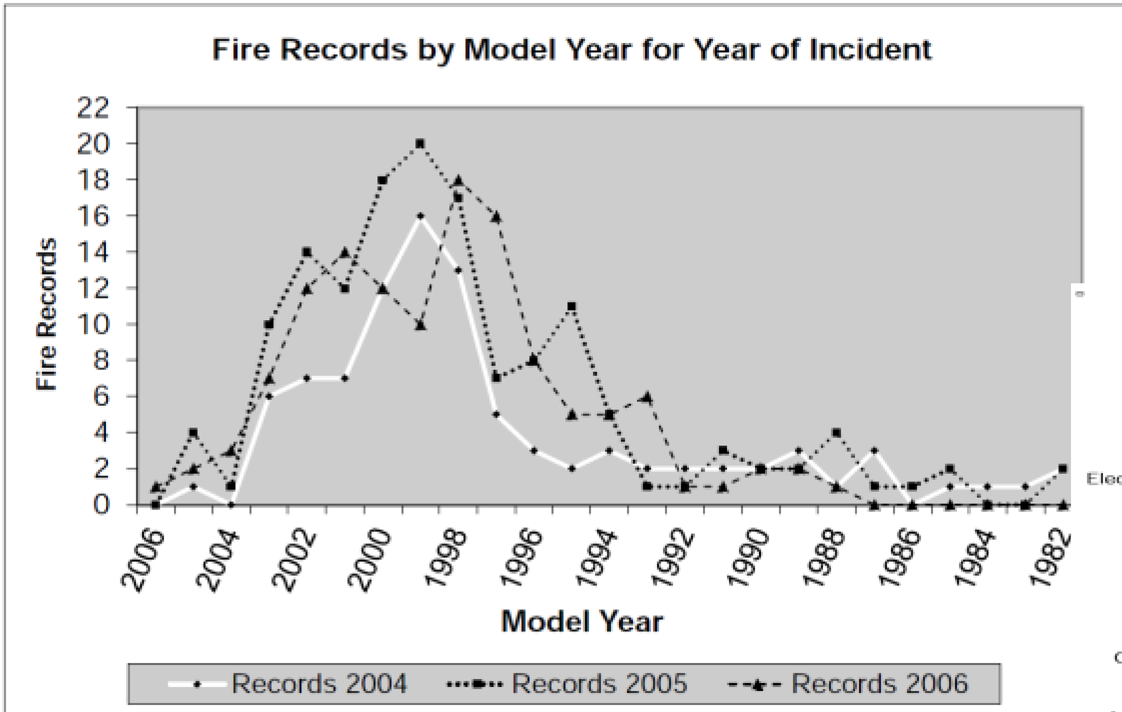

Figure 3 Fire records by model year, 2004–2006.

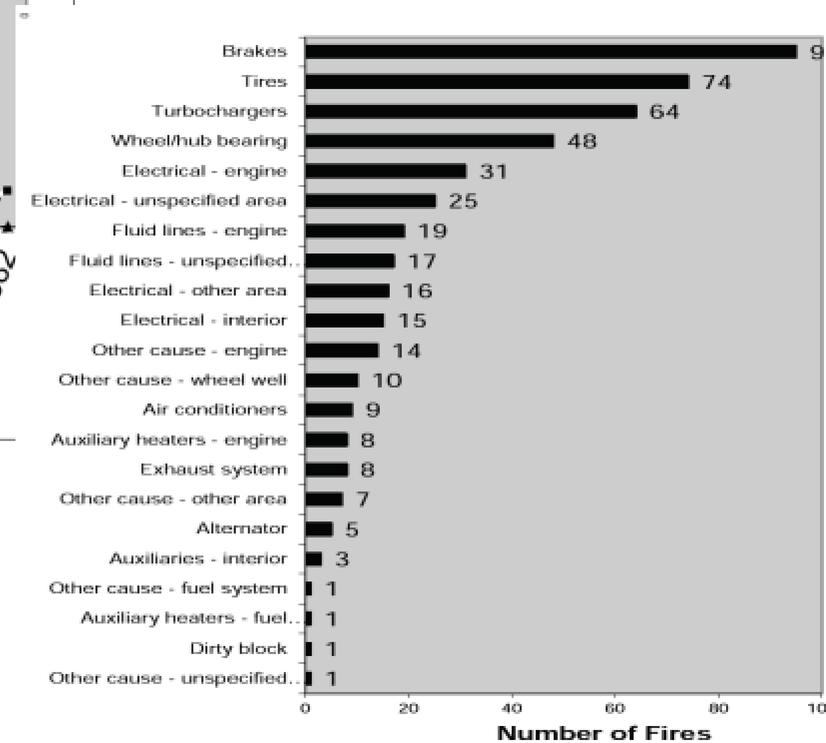

Figure 2 Reported ignition points, 1995–2008.

Statistics: USA (2006 – 2010)

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Vehicle type	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions US)	
Passenger road vehicles	202,800	(91%)	277	(84%)	1,077	(88%)	$776	(76%)
Automobile, passenger car, ambulance, race car or taxi-cab	152,300	(68%)	209	(63%)	764	(63%)	$536	(52%)
Unclassified passenger road vehicle	41,200	(18%)	56	(17%)	173	(14%)	$144	(14%)
Motor home, camper mounted on pickup	2,700	(1%)	5	(2%)	60	(5%)	$45	(4%)
Bus, school bus or trackless trolley	2,100	(1%)	0	(0%)	22	(2%)	$29	(3%)
Motorcycle or trail bike	1,600	(1%)	3	(1%)	19	(2%)	$5	(0%)
Off-road recreational vehicle	1,300	(1%)	1	(0%)	10	(1%)	$4	(0%)
Towable travel trailer	1,300	(1%)	3	(1%)	23	(2%)	$11	(1%)
Collapsible camper trailer	200	(0%)	0	(0%)	4	(0%)	$1	(0%)
Portable building or manufactured home	200	(0%)	0	(0%)	2	(0%)	$2	(0%)
Freight road vehicles	20,500							
Semi-trailer, with or without tractor	5,900	(3%)	23	(7%)	38	(3%)	$92	(9%)
General use truck	4,600	(2%)	7	(2%)	32	(3%)	$39	(4%)
Unclassified freight road vehicle	4,600	(2%)	10	(3%)	30	(2%)	$68	(7%)
Pickup truck or hauling rig	3,000	(1%)	6	(2%)	23	(2%)	$14	(1%)
Garbage, waste or refuse truck	1,700	(1%)	0	(0%)	9	(1%)	$18	(2%)
Tank truck for flammable or combustible liquid	400	(0%)	4	(1%)	10	(1%)	$13	(1%)
Tank truck for nonflammable cargo	300	(0%)	2	(1%)	1	(0%)	$4	(0%)
Tank truck for compressed or LP-gas	100	(0%)	0	(0%)	1	(0%)	$1	(0%)
Total	223,300	(100%)	329	(100%)	1,221	(100%)	$1,025	(100%)

Bibliography for statistics

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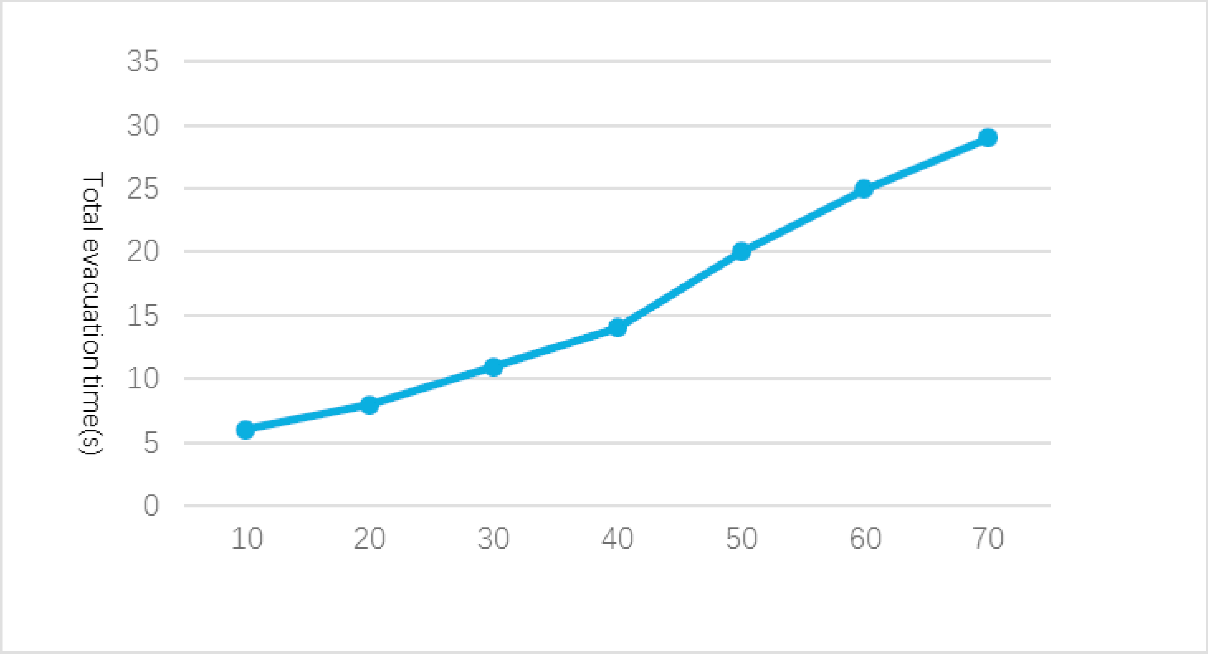
- **Experience with fire safety measures in public transport buses -** Horst Schauerte, in proceedings of international conference on fires in vehicles, 2014
- **Analysis of Fire Protection of UK Buses from 1964 to 2013 –** V. Alonso & G. Rein, in proceedings of international conference on fires in vehicles, 2016
- **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
- **Testing active fire protection systems for engine compartments in buses and coaches - a pilot study -** Jonas Brandt and Michael Försth. Fire Technology SP Report 2011:22
- **Bus fires in Sweden 2005 - 2013** Alen Rakovic, Michael Försth, Jonas Brandt. SP Report 2015:43
- **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
- **Automobile fires in the US: 2006- 2010 estimates** - Marty Ahrens, 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.



Experimental studies: Bus Fire Safety
R. Hammarström et al. 2008

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- 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:
  - Fire development from the engine compartment into the passenger compartment.
  - Smoke spread and visibility in the passenger compartment.
  - Concentrations of toxic gases in the passenger compartment.
  - 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.

Experimental studies: Fire safety performance of buses – A. Hoffmann 2012

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

Results of the Cone Calorimeter tests					
Material	**Input data**		**Measured values**	**Thresholds**	
	Requirement No.	**Irradiance [kW/m²]**	**MARHE [kW/m²]**	**HL 1 [kW/m²]**	**HL 2 [kW/m²]**
Body insulation (1st)	R1	50	334,5	-	90
Body insulation (2nd)	R1	50	309,0	-	90
Floor covering	R9	25	32,5	-	50
Side panel (1st)	R1	50	64,8	-	90
Side panel (2nd)	R1	50	54,2	-	90
Flooring	R9	25	1,6	-	50
GRP part (1st)	R1	50	258,5	-	90
GRP part (2nd)	R1	50	280,9	-	90
Ceiling over seats (1st)	R1	50	247,2	-	90
Ceiling over seats (2nd)	R1	50	215,7	-	90
Ceiling over gangways (1st)	R1	50	307,7	-	90
Ceiling over gangways (2nd)	R1	50	255,5	-	90
Foam of seats (1st)	R20	25	309,2	75	50
Foam of seats (2nd)	R20	25	166,7	75	50

Table 2 – Results of Cone Calorimeter tests

Experimental studies: Fire safety performance of buses – A. Hoffmann 2012

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Results of the Smoke Density Chamber, part 1												
		Components of CIT-value								CIT-value		
Material (material requirement)		CO_2 [ppm]	CO [ppm]	SO_2 [ppm]	NO_x [ppm]	HBr [ppm]	HCl [ppm]	HF [ppm]	HCN [ppm]	Calculated CIT-value	HL1 (CEN/ TS 45545-2)	HL2 (CEN/ TS 45545-2)
IMO MSC 61(67) Annex 1, Part 2		-	*1450*	*120*	*350*	*600*	*600*	*600*	*140*	-	-	-
ABD 00031 (Airbus)		-	*1000*	*100*	*100*	-	*150*	*100*	*150*			
BSS 7239 (Boeing)		-	*3500*	*100*	*100*	-	*500*	*200*	*150*	-	-	-
SMP 800-C (Bombardier)		*90000*	*3500*	*100*	*100*	*100*	*500*	*100*	*100*	-	-	-
First symptoms of intoxication		*20000*	*200*	*4*	*10*	*22*	*5*	*10*	*18*			
Lethal concentrations		*80000*	*1000*	*100*	*100*	*120*	*50*	*44*	*100*			
Body insulation (R1)	4 min	5900	99	5	73	0	1	0	36	0,3	1,2	0,9
	8 min	6900	168	25	54	0	3	4	52	0,3	1,2	0,9
Floor covering (R9)	4 min	7500	793	0	31	0	4050	2	3	6,6	1,2	0,9
	8 min	10100	931	0	8	0	3572	4	5	5,8	1,2	0,9
Side panel (R1)	4 min	3600	1076	80	0	1	0	0	167	0,4	1,2	0,9
	8 min	4400	2004	41	1	0	0	0	245	0,6	1,2	0,9
GRP part (R1)	4 min	19800	682	0	0	4	0	0	10	0,1	1,2	0,9
	8 min	35700	1122	0	0	7	2	0	16	0,2	1,2	0,9
Ceiling above seats (R1)	4 min	11900	668	0	87	0	1013	1	39	1,9	1,2	0,9
	8 min	14700	967	0	97	1	923	0	40	1,8	1,2	0,9
Ceiling above gangways (R1)	4 min	16500	762	52	111	0	1528	3	33	2,9	1,2	0,9
	8 min	20000	984	40	149	0	1385	0	40	2,7	1,2	0,9
Foam of seats (R20)	4 min	14200	23	1	82	0	0	0	5	0,3	1,2	0,9
	8 min	15800	53	0	74	0	1	0	7	0,2	1,2	0,9

Table 9 – Measured concentrations of toxic smoke gas components

Experimental studies: Fire safety performance of buses – A. Hoffmann 2012

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Results of the Cone Calorimeter tests, part 2							
Material	**Requirements No.**	**$D_s(4)/D_{s,max}$**			**VOF4**		
		Measured	**HL 1**	**HL 2**	**Measured**	**HL 1**	**HL 2**
Body insulation (1st)	R1	127,5	600	300	260,8	1200	600
Body insulation (2nd)	R1	70,0	600	300	233,5	1200	600
Floor covering (1st)	R9	620,1	600	300	Not required		
Floor covering (2nd)	R9	695,4	600	300	Not required		
Side panel (1st)	R1	453,8	600	300	918,7	1200	600
Side panel (2nd)	R1	560,2	600	300	1102,7	1200	600
GRP part (1st)	R1	797,5	600	300	1194,1	1200	600
GRP part (2nd)	R1	1320,0	600	300	1843,9	1200	600
Ceiling over seats (1st)	R1	839,5	600	300	2389,9	1200	600
Ceiling over seats (2nd)	R1	803,9	600	300	2013,6	1200	600
Ceiling over gangways (1st)	R1	601,8	600	300	2133,6	1200	600
Ceiling over gangways (2nd)	R1	622,5	600	300	2224,8	1200	600
Foam of seats	R20	100,5	300	300	Not required		

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

Experimental studies: Fire safety performance of buses – A. Hoffmann 2012

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Test results according to CEN/TS 45545-2							
Material	Requirement No.	MARHE [kW/m²]	CIT [1]	$D_s(4)/D_{s,max}$ [1]	VOF4 [min]	Valid for HL1	Valid for HL2
Body insulation	R1	334,5	0,3	127,5	260,8	No	No
Floor covering	R9	32,5	6,6	695,4	Not required	No	No
Side panel	R1	64,8	0,6	560,2	1102,7	Yes	No
Flooring	R9	1,6	Not tested				
GRP part	R1	280,9	0,2	1320,0	1843,9	No	No
Ceiling over seats	R1	247,2	1,9	839,5	2389,9	No	No
Ceiling over gangways	R1	307,7	2,9	622,5	2224,8	No	No
Foam of seats	R20	309,2	0,3	100,5	Not required	No	No

Table 11 – Summary of measurements according to CEN/TS 45545-2

Bibliography for experimental studies

- **Fire Safety in Buses - WP2 report: Fire safety review of interior materials in buses** P. Johansson, J. Axelsson. Fire Technology SP Report 2006:59
- **A comparative study of test methods for assessment of fire safety performance of bus interior materials** - Michael Försth et al. Fire and Materials, 2011.
- **Bus Fire Safety** - R Hammarström et al. SP Report 2008:41
- **Fire safety performance of buses** – A. Hoffmann & S. Dulssen, in proceedings international conference on fires in vehicles, 2012
- **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
- **Testing active fire protection systems for engine compartments in buses and coaches - a pilot study -** Jonas Brandt and Michael Försth. Fire Technology SP Report 2011:22
- **Can everyone safely escape from a burning CNG bus?** Hjohlman, M. and J. Brandt, Brandposten **48**, Borås, Sweden, 2013.

Numerical simulations

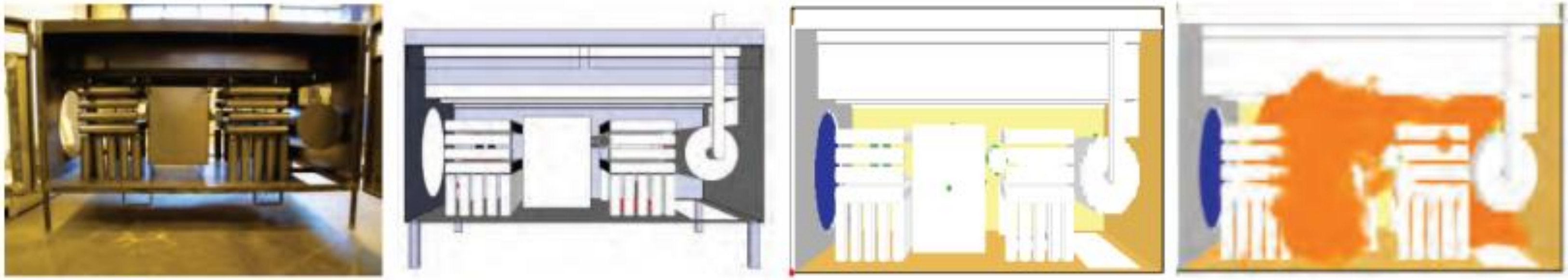

Figure 10 – the original, a CAD draft and numerical simulations of the engine compartment test rig at SP (Sweden)

- 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.

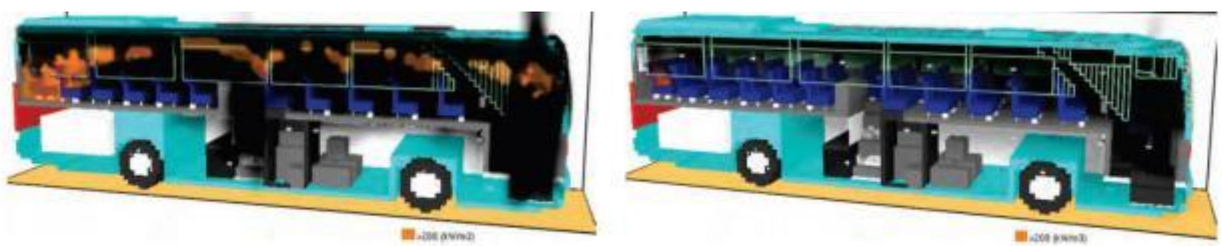

Figure 8 – Numerical fire simulations of a bus equipped with interior materials for busses (left) and trains (right)

Bibliography for simulations

- **Bus Fire Safety** - R Hammarström et al. SP Report 2008:41
- **Fire safety performance of buses** – A. Hoffmann & S. Dulssen, in proceedings of international conference on fires in vehicles, 2012
- **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.