APPENDIX 4 – referring to chapter 4 "*Tunnel fires*"

4.1. DATA BASIS FOR THE CALCULATION OF FIRE RATES

In the following, data have been collected in the form they were available in 2013. In most cases the information is limited to the count of numbers of fires. In some cases these fires are qualified with information about the type of vehicle (HGV or normal car), and information about the fire in terms of fire or "*other smoke releases*".

In the following, the data are presented in terms of fire rates per vehicle-km, which makes it necessary to collect also the traffic volume in tunnels for the collection period in the geographical area covered by the collection of data. For the following countries data have been available for the statistical comparison of fire rates:

- Norway
- Netherlands
- Austria
- Germany
- Italy
- Spain
- France
- United Kingdom
- Czech Republic
- Japan
- South Korea
- Vietnam

Norway

Basis

In April 2012 a report on fire events in Norway was published "*Kartlegging av kjøretøybranner i norske vegtunneler 2008-2011 (Mapping of vehicle fires in Norwegian road tunnels 2008 – 2011), TØI rapport 1205/2012*" [9]. The data collection in the report can serve as basis for establishing up-to-date specific fire rates (for Norwegian tunnels). the report includes data from the period 2001-2011.

A follow-up report has been published in 2013 with the title: "*Brannutsatte undersjøiske Vegtunneler (fire-exposed sub-sea tunnels) TØI doc: 50357*" [10].

TABLE 5: REGISTRATION OF FIRES AND OTHER SMOKE RELEASES IN NORWAY: 5 REGIONS AND TOTAL IN THE YEARS 2008 – 2011.

Year	Event	Region East	Region South	Region West	Region Middle	Region North	Total
2008	Fires	3	1	10	1	2	17
	Other smoke releases	2	1	7	2	0	12
2009	Fires	7	1	5	8	0	21
	Other smoke releases	2	1	2	2	0	8
2010	Fires	4	0	6	6	2	18
	Other smoke releases	4	2	3	2	0	11
2011	Fires	10	5	7	5	2	29
	Other smoke releases	4	2	8	6	0	19
Total		37	13	48	31	6	135
Average per year	Fires	6	1.75	7	5	1.5	21.25
	Other smoke releases	3.25	1.5	5	2.75	0	12.5
Number of tunnels / tubes		105	154	540	135	137	1071

In the analysis data have been collected from 2001 to 2012, but data have not been available from 2001 – 2008 for all regions. The main results have for this reason been focused on the period 2008 – 2011.

Quote from the report:

"*In the analysis of road tunnel fires in Norway, we chose to limit ourselves to look at the years 2008-2011, as these are the years from which we have the most complete data.*" "*The data shows that the average number of fires in Norwegian road tunnels is 21.25 per year per 1,000 tunnels*"

Quote from the report:

"*Of the 135 (events), … 8 involved minor injury to people and … 8 involved serious personal injury or death.*
40 of the 135 fires involved damage to vehicles and 20 involved damage to tunnels.
Technical problems are the most frequent cause of (events) in heavy vehicles, while single vehicle and collisions are the most frequent cause of fires in vehicles weighing less than 3.5 t.
(Tunnels with high gradients/) Undersea tunnels are substantially overrepresented in the statistics of fires in Norwegian road tunnels.
The 41 road tunnels (with gradient >5%) which together constitute 4% of road tunnels in Norway, had 44% of the (events) in the period 2008-2011.*
Heavy vehicles were overrepresented in these fires, and technical problems were the most frequent cause"

*The comparison between the number of tunnels and the number of fires may not be completely fair, as the length of the tunnels and the traffic in the tunnels in not taken into account.

TABLE 6: FIRES AND OTHER SMOKE RELEASES IN NORWAY 2001 – 2011 IN REGIONS: EAST, WEST, SOUTH, MIDDLE AND NORTH) [9]

Region	Period		Number of fire events
East	2001	2011	89
South	2001	2011	26
West	2002	2011	124
Middle	2008	2011	62
North	2006	2011	10
All			311

The full set of data collected, includes the events in the period 2001- 2011. As mentioned in the report the data may not be complete. The collection of data is partly dependent on recollection of personnel from the fire brigades and the road control centres.

Analysis

The results of the collected statistics in the report are not presented in a form where they can be used to evaluate the risk per vehicle km o the data cannot be used for estimating the fire rates for other tunnels. Hence, some additional work has to be done in order to convert the data into a suitable format.

As it appears, the information in the report "*Mapping of vehicle fires in Norwegian road tunnels*" is useful but it is lacking the length of the tunnels and the traffic in the tunnels

In the following the data from two regions are studied in further detail. The regions selected are
- Norway region East
- Norway region West

Region East is chosen, because it includes Oslo and thereby an area with relatively dense traffic and tunnels with a relatively high level of equipment, region West is chosen because more than half of the Norwegian tunnels are located in this region.

Norway region East

General fire rates (all vehicles):

Based on the length of the tunnels and the traffic in AADT within the last 10 years, the registered fire events can be transformed into fire rates per vehicle-km for each tunnel. As it appears the fire rates for the individual tunnels are between 0.5 10^{-8} to 10 10^{-8} per veh-km for the 14 tunnels where fires have been recorded. However, the majority of tunnels (approximately 60 tunnels) have had no recorded fires (or other smoke-only releases), so here the fire rate for the individual tunnels is 0.

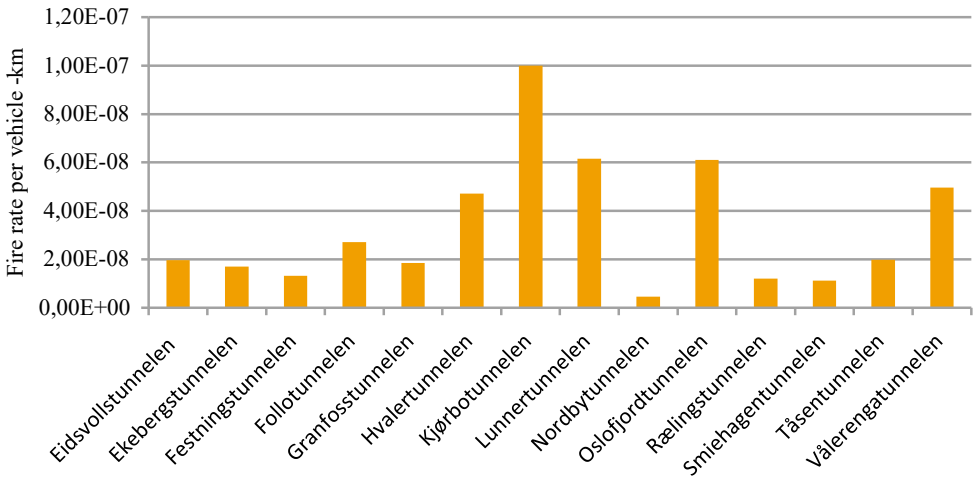

Illustration 1: Fire rates in individual tunnels in Norway Region East. Tunnels with events.

HGV fires

In the statistics it is noted whether a HGV has been involved in the fire. In addition the traffic data describe the percentage of heavy goods vehicles of the total traffic, hereby the fire rate for HGV traffic is estimated as the number of fires involving a HGV and the traffic volume of HGVs. This is counting fires with involvement of HGVs; whether the HGV is causing the fire is not discussed.

Summary

TABLE 7: SUMMARY OF STATISTICS RESULTS FOR REGION EAST, AVERAGE FOR ALL TUNNELS

Vehicle type	Fires 2001 - 2011	Tunnel traffic 2001-2011	Fire rate
All vehicles	48	3.42 10^{9} veh-km	1.41 10^{-8} per veh-km
HGVs	15	4.78 10^{8} HGV-km	3.14 10^{-8} per HGV-km

Norway region West

In a similar manner the fire rates are calculated for the tunnels in Region West. It is noted that the fire rate in Region West is significantly lower than in Region East. In Region West the fire rates for HGV is lower than for all vehicles.

Summary

TABLE 8: SUMMARY OF STATISTICS RESULTS FOR REGION WEST, AVERAGE FOR ALL TUNNELS

Vehicle type	Fires 2001 - 2011	Tunnel traffic 2001-2011	Fire rate
All vehicles	71	4.56 10^{9} veh-km	1.55 10^{-8} per veh-km
HGVs	8	5.37 10^{8} HGV-km	1.49 10^{-8} per HGV-km

Norway region West and East

The average for region East and West is calculated, taking into account the traffic in the tunnels in both regions.

Summary (weighted average for region East and West)

TABLE 9: SUMMARY OF STATISTICS RESULTS AVERAGE FOR ALL TUNNELS

Vehicle type	Fire rate
All vehicles	1.49 10^{-8} per veh-km
HGVs	2.27 10^{-8} per HGV-km

Results

As rounded numbers the following illustrations might be used:

TABLE 10: ESTIMATED FIRE RATES FOR NORWEGIAN ROAD TUNNELS

Vehicle type	Fire rate
All vehicles	1.5 10^{-8} per veh-km per veh-km
HGVs	1.5 10^{-8} per HGV-km – 3.0 10^{-8} per HGV-km

HGVs have according to these illustrations a fire rate 0 - 100% higher than the general fire rate.

Netherlands

Basis

In the Dutch model for risk analysis RWS QRA, the fire rate applied has previously been 2.0 10^{-8} fires per veh-km. The TNO report TNO 2012 R1 1094 De statistische kans op brand in tunnels (The statistical probability of fire in tunnels)of 22 January 2013 [11] reestimated the rates with focus on estimating the rates of fires in HGVs.

Collected data

After re-estimation in the TNO report TNO 2012 R1 1094 [11], the following numbers were found, based on the recording of 6 fires in 13 Dutch tunnels in the years 2006 – 2012, where the cumulated traffic has been 1.896 billion vehicle km.

Results

The TNO report is focused on the fire rates of HGVs. However, the fire rate for all vehicles is also shown in the report.

TABLE 11: SUMMARY OF THE ESTIMATED FIRE RATE IN DUTCH TUNNELS.

2006-2012	Class of fire	Fire rate
All vehicles	All	$3.2\ 10^{-9}$ per veh-km
All vehicles	> 25 MW	$1.5\ 10^{-10}$ per veh-km
HGVs	> 25 MW	$1.5\ 10^{-9}$ per HGV-km

Austria

Basis

The fire events on Autrian motorways operated by Asfinag have been registered in the period 2006 – 2012. This collection of data has been evaluated in the report *Auswertung der ASFINAG-Tunnelbrandstatistik 2006-2012 (Assessment of tunnel fire statistics 2006 – 2012 on the Austrian motorway network)* [2].

Collected data

In the period May 2006 until January 2013 68 fires were registered in tunnels on Austrian motorways (Autobahn + Schnellstrassen).

TABLE 12: REGISTRATION OF FIRES MAY 2006 – JANUARY 2012 IN TUNNELS ON THE AUTRIAN MOTORWAY NETWORK OPERATED BY ASFINAG.

Vehicle type	Number of fires	Traffic volume veh-km in tunnels (2006-2012)
All vehicles	68	$10.3\ 10^{9}$
Passenger cars	38	$9.1\ 10^{9}$
HGVs	30	$1.2\ 10^{9}$

The causes of the fires are recorded, and it is shown that a large majority of the fires (60 of 68) were caused by self-ignition. 6 fires were a result of collisions (5 with passenger vehicles, 1 with an HGV) and for 2 fires the cause was unknown. This means that 90% of all fires were caused by self-ignition and 10% were caused by collisions.

The self-ignition was measured in relation to breakdowns. Whereas passenger cars have 1.5 self-ignitions per 1000 breakdowns, HGVs have 9.9 self-ignitions per 1000 break-downs. The rate of self-ignition for HGVs is influenced by the gradients of the route leading towards the tunnel.

Results

Based on the analyses the following rates are found. It is noted that fire rate for HGVs is significantly higher than for passenger vehicles.

TABLE 13: FIRE RATES IN TUNNELS ON THE AUTRIAN MOTORWAY NETWORK OPERATED BY ASFINAG.

Vehicle type	Fire rate		
	All causes	Self ignition	Collision
All vehicles	6.5 10^{-9} per veh-km		0.46 10^{-9} per veh-km – 1.56 10^{-9} per veh-km
Passenger cars	4.2 10^{-9} per veh-km	3.6 10^{-9} per veh-km	
HGVs	25.0 10^{-9} per HGV-km	24.0 10^{-9} per HGV-km	

Germany

Basis

Three reports have been available concerning collection of fire events in Germany. The three reports comprise the official reporting from Germany to the European Commission and cover the period 1st May. 2006 – 31. Dec 2011. Ref: *Bericht über Brände und Unfälle in Tunneln gemäß Artikel 15, Absatz 1, der Richtlinie 2004/54/EG über Mindestanforderungen an die Sicherheit von Tunneln im transeuropäischen Straßennetz, (Report of fires and accidents in tunnels according to Art. 15, sec. 1 in the Directive 2004/54/EC...) Dr.-Ing. J. Krieger: 30/09/2008, 30/09/2010 and 30/09/2012* [12]. The data are covering tunnels on the TERN network.

In the report events with and without injuries are stated and also causes of the events are presented. However, these details are not given specifically for fires and other incidents.

Results

The following collection data of events appears from the three reports

TABLE 14: REGISTRATION OF FIRES IN ROAD TUNNELS ON THE GERMAN TERN NETWORK.

Registration period	Number of tunnels (TERN net Germany):	Number of tunnels with fires or other incidents	Number of fires
5.2006 – 2007	27	20	26
2008 – 2009	28	26	41
2010 – 2011	28	27	36
Average per year			18

In the appendix to the reports from 2010 and 2012 the full list of the tunnels on the German TERN network is documented with the tunnel lengths and AADT for each tunnel. Based on this list the total annual traffic volume in the 28 tunnels can be estimated to 7.25 10^{8} veh-km.

Analysis

Based on the registration of fires, the rates per veh-km can be estimated. The rate is quite constant in the registration period from May 2006 until December 2011.

TABLE 15: FIRE RATES IN ROAD TUNNELS ON THE GERMAN TERN NETWORK.

Registration period	Number of fires	Traffic volume (veh-km)	Fires per veh-km
5.2006 – 2007	26	1.11 10^{9}	2.35 10^{-8}
2008 – 2009	41	1.45 10^{9}	2.83 10^{-8}
2010 – 2011	36	1.45 10^{9}	2.48 10^{-8}
5.2006-2011	103	4.01 10^{9}	2.57 10^{-8}
Average per year	18	7.18 10^{8}	2.57 10^{-8}

Italy

Basis

The determination of fire rates in Italian Road Tunnels is based on a documentation given at the WG2 TC 3.3 meeting in Rome June 12, 2014: Feedback of experience on tunnel safety. Round table, by Carlo Ricciardi, Ministero delle Infrastrutture e dei Trasporti, Consiglio Superiore dei lavori pubblici, Commissione permanente per le gallerie, PIARC/AIPCR WG2 TC 3.3 International meeting, Rome June 12th [46].

The documentation has the format of a Powerpoint presentation including traffic data as well as numbers of collisions and fires-

Results

The report includes data from 2006 to 2012, both years included (7 years).

Traffic: The traffic is not given per tunnel, but it is specified that the daily average traffic is 6841 vehicles per day per lane. Furthermore it is specified that the statistics comprise 349 road tunnels with a total length of about 404 km, and 768 km tubes. On assumption of 2 lanes per tube, the total annual traffic can be estimated as follows:

Annual traffic volume (I): 768 km tubes * 2 lanes/tube * 6841 veh/(day*lane) * 365 days/year = 3.835 Bill Veh-km/yr

It is assumed that the traffic data are valid for 2012, on assumption of a traffic growth of 1% p.a. the total traffic for the period 2006 – 2012 is

Traffic volume (I, 2006 – 2012): 7 years * 3.835 Bill Veh-km * 0.971 = 26.1 Bill Veh-km

The following collection of fire events appears from the Italian report

TABLE 16: RECORD OF FIRES IN ROAD TUNNELS ON THE ITALIAN ROAD NETWORK.

Registration period	Number of tunnels	Number of fires
2006	349	19
2007	349	35
2008	349	24
2009	349	28
2010	349	15
2011	349	18
2012	349	8
Average per year	349	147/7=21

Analysis

Based on the records of fires, the rates per veh-km can be estimated. With a total of 147 fires and a traffic volume of 26.1 Bill. Veh-km, the average fire rate is 5.64 fires per Bill. Veh-km.

TABLE 17: FIRE RATES IN ROAD TUNNELS ON THE ITALIAN ROAD NETWORK.

Registration period	Number of fires	Tunnel traffic volume (Bill veh-km)	Fires per veh-km
2006	19	3.61	5.26
2007	35	3.65	9.59
2008	24	3.69	6.51
2009	28	3.72	7.52
2010	15	3.76	3.99
2011	18	3.80	4.74
2012	8	3.84	2.09
Average per year	21	3.72	5.64

Spain

Basis

Three reports have been available concerning collection of fire events in Spain. The three reports comprise the official reporting from Spain to the European Commission and cover the period 2005 - 2010. Ref:

- Informe Bianual (2005-2006) de Incidencias en Túneles Españoles de la Red Transeuropea, Centro de Estudios del Transporte, Madrid Oct. 2007 [13]
- Informe Bianual (2007-2008) de Incidencias en los Túneles Españoles de la Red Transeuropea, Centro de Estudios del Transporte, Madrid May. 2010 [14]
- Informe Bianual (2009-2010) de Incidencias en los Túneles Españoles de la Red Transeuropea, Centro de Estudios del Transporte, Madrid Feb. 2012 [15]

The data cover all tunnels and events in tunnels on the TERN specified separately.
In the report, events with and without injuries are stated.

Collected data

The following fire data appears from the three reports. It is explained in the reports of 2007-2008 and 2009-2010 that 52% of the tunnels are bidirectional and 48% are unidirectional. Out of the total number of tunnels, 40% of the tunnels and 27% of the total tunnel length are located on the TERN. Of the tunnels on the TERN 83% are unidirectional.

TABLE 18: RECORDS OF FIRES IN ROAD TUNNELS ON THE SPANISH ROAD NETWORK.

Recording period	Number of tunnels	Total length of tunnels (km)	Number of fires*	Hereof fires in HGV
2005-2006	#	#	6	#
2007-2008	295	151	6	0
2009-2010	313	160	6	1
Average per year			3	0.25

* The fires are defined as events where intervention has been required
# Events of 2005-2007 are reported in a different format

1 of the 12 fires in 2007-2010 led to fatalities or injuries.

In the appendix to the reports a list of selected tunnels on the Spanish network is documented with the tunnel lengths and AADT for each tunnel. If these tunnels are taken as representative for all Spanish tunnels, the AADT is estimated to approximately 15000 veh/day on average. Based on this list the total annual traffic volume in the tunnels can be estimated to 8.3 10^8 veh-km for 2007-2008 respectively 8.8 10^8 veh-km for 2009-2010. The share of HGV traffic is estimated as 15%.

Results

Based on the analyses the following rates are found.

It is noted that fire rate for HGVs is lower than for passenger vehicles. However, the result concerning HGVs relates directly to the assumption on the HGV share.

TABLE 19: FIRE RATES IN ROAD TUNNELS ON THE SPANISH ROAD NETWORK.

Vehicle type	Fire rate
All vehicles	3.5 10^{-9} per veh-km
HGVs	2.0 10^{-9} per HGV-km

France

Basis

CETU launched in 2011 a statistical survey relating to breakdowns, fires, and road collisions recorded in road tunnels from 2002 to 2011. This survey was based on a collection of data in a large sample of control centres. In practice, for certain tunnels and/or control centres, these data were available or representative only for a shorter period but in most cases not less than 4 years.

Collected data

TABLE 20: RECORDS OF FIRES IN ROAD TUNNELS ON THE FRENCH ROAD NETWORK.

Tunnel type	Recording period	Number of tunnels	TOTAL Traffic volume veh.km in tunnels (2002-11)	Number of fires
unidirectional	10 years	74	14,8 10^9	137
bi-directional	10 years	18	2 10^9	40
All types	10 years	92	16,8 10^9	177

Results

TABLE 21: FIRE RATES IN ROAD TUNNELS ON THE FRENCH ROAD NETWORK.

Tunnel type	Passengers cars Fire rate	HGVs Fire rate	All vehicles Fire rate
Unidirectional	8.74 10^{-9}	1.53 10^{-8}	9.26 10^{-9}
Bi-directional	9.50 10^{-9}	8.44 10^{-8}	2.03 10^{-8}
All tunnel types	8.82 10^{-9}	2.88 10^{-8}	1.06 10^{-8}

- In-depth statistical analyses were carried out in a French study published in 2015 [47] in order to identify and understand the influence of specific parameters on the number of breakdowns, collisions and fires. The following parameters were taken into consideration: traffic, tunnel length, type of traffic flow (unidirectional or bidirectional), urban or non-urban environment, number of HGVs, speed limits, gradient, tunnel control centre, year of occurrence.

These analyses involve isolating a parameter and studying its influence on the number of events, with all other parameters being equal. The conclusions described below refer exclusively to collisions and "*significant*" parameters. A parameter is considered as significant if it has been proved to have a significant influence on the fire rate (occurrence per veh.km).

Three main conclusions were reached based on these in-depth statistical analyses.

- First, it would appear that the number of fires is proportional to tunnel length and traffic. It is therefore pertinent to apply logic based on number of fires per veh·km.
- Second, it appears that the share of HGV-traffic has a significant influence on the fire rate. (3.3 times more fires occur for HGVs than for passenger vehicles).
- Finally, the fire rate is significantly higher in uphill tunnels. This outcome is caused by the high stresses induced on uphill sections and applied to the various technical parts of a vehicle, particularly a HGV. These stresses are likely to substantially increase the temperature of some parts (e.g. the turbo charger), and possibly lead to failure.

Furthermore, the following conclusions have been reached according to the figures calculated and in-depth statistical analyses:

- Fire rate is higher in bidirectional tunnels than in unidirectional tunnels, however, the bidirectional character has no statistically significant influence;
- Fires rate is higher in urban tunnels than in non-urban tunnels, however, the urban character has no statistically significant influence;

United Kingdom

Basis

Individual reports from seven UK tunnels have been available in the format used to report incidents according to the EU Directive 2004/54/EC. The reports available are the following:

- Report on Accident and Fire Incidents, Kent Highway Services, 3 September 2008 (Ramsgate tunnel April 2006 to March 2008) [16].
- EU Directive 2004/54/EC - Article 15 Reporting, Road Tunnel Safety Regulations 2007 - Regulation 6 Reporting, April 2006 - March 2008 EU TERN Route E22 and UK A55 Trunk Road, Welsh Assembly Government 27th August 2008, (Conwy, Penmaenbach and Pen-y-Clip-tunnels) [17].
- Dartford - Thurrock Crossing. The Road Tunnel Safety Regulations 2007, Two Yearly Tunnel Fire/Accident Report, for the Dartford Tunnels to 31st March 2008 (cover April 2006 – March 2008) [18].
- EU Directive 2004/54/EC Article 15 Reporting April 2006 - March 2008, EU TERN Route, A1 (M) Hatfield Tunnel, 24.07.2008, Highways Agency [19].
- EU Directive 2004/54/EC Article 15 Reporting April 2006 - March 2008, EU TERN Route, M25 Holmesdale Tunnel, 24.07.2008, Highways Agency [20].
- EU Directive 2004/54/EC Article 15 Reporting EU TERN Route A1(M) Hatfield Tunnel April 2010 to March 2012, July 2012, Connect Plus [21].
- EU Directive 2004/54/EC Article 15 Reporting EU TERN Route A282 Dartford Tunnel April 2010 to March 2012, July 2012, Connect Plus [22].
- EU Directive 2004/54/EC and Road Tunnel Safety Regulations 2007 Article 15 and Regulation 6 Reporting EU TERN Route E22 and UK A55 Trunk Road A55 Tunnels (Conwy,

Penmaenbach and Pen-y-Clip) Period Covered: 1st April 2010 to 31st March 2012, Welsh Government 30/08/2012 [23]
- EU Directive 2004/54/EC Article 15 Reporting EU TERN Route M25 Bell Common Tunnel April 2010 to March 2012, July 2012 Connect Plus [24]

An aggregated report on all tunnels in the UK has not been available. The tunnels reported constitute only a limited sample of all tunnels in the UK as most UK tunnels are not on the TERN.

Collected data

The following fire data appears from the nine reports: The eight tunnels covered by the reports constitute 7.5 km of the approximately 50 tunnels with a total length of 37 km of tunnel in the UK (respectively 26 tunnels over 500 m with a total length of 30 km). Data are not available for all tunnels for all years, so the sample of data may not be representative and is difficult to evaluate (particularly because no data on the AADT for the tunnels has been available).

TABLE 22: RECORDS OF FIRES IN SELECTED ROAD TUNNELS ON THE UK ROAD NETWORK.

Recording period (Apr. – Mar)	Number of tunnels	Total length of tunnels (km)	Number of fires
2004-2006	3	2.648	0
2006-2008	7	6.702	2
2008-2010	3	2.648	0
2010-2012	6	5.723	3

Results

Based on the data it is not possible to determine rates representative for fires in tunnel in UK.

In total 5 fires have occurred in the 3-7 tunnels in the period 2004-2012. This can be calculated as 0.14 fires per tunnel-km per year. If this value were to correspond to 10 per 10^9 vehicle-km, the traffic in AADT would be on average 38500 veh/day, and if it were 5 per 10^9 vehicle-km, the traffic in AADT would be on average 77000 veh/day. The former AADT is high but it might be realistic, whereas the latter is assumed to be too high.

Czech Republic

Basis

Two reports have been available concerning collection of fire events in the Czech Republic. The two reports comprise the official reporting from Czech Republic to the European Commission and cover the period 2008 - 2011. Ref:

- Report on fires in tunnels and on accidents which clearly affect the safety of road users, (2008-2009) Czech Republic Ludvík Šajtar, Satra spol.s r.o., 30. 9.2010 [25]
- 2010-2011 Fires and Accidents Report Czech Republic, Dipl. Ing. Ludvík Šajtar, 15/11/2012 [26]

The data covering all tunnels and events in tunnels on the TERN network are specified separately.

Collected data

The following collection fire data of events appears from the two reports:

In the 2012 reporting (2010-2011) 7 tunnels on the TERN network are included of which 1 has been opened in 2012 (outside the recoding period). The average AADT in the tunnels is 22000 veh/day, with a HGV percentage of 21%.

The 2010 reporting (2008-2009) comprise 3 tunnels on the TERN network and 12 tunnels outside the TERN network. The average AADT in the tunnels on the TERN network is 4100 veh/day with a HGV percentage of 26%. The AADT for the tunnels outside the TERN network is not reported.

TABLE 23: RECORDS OF FIRES IN ROAD TUNNELS ON THE CZECH ROAD NETWORK.

Recording period	Number of tunnels^	Total length of tunnels (km)	Number of fires
2008-2009#	15	10.6	5
2010-2011	6	7.9	0

Tunnels include tunnels outside the TERN network
^ Tunnels over 500 m are included in the statistics for tunnels on the TERN network
* No consequent reporting for tunnels outside TERN network,

If the AADT is estimated to approximately 10000 veh/day – 22000 veh/day in average the total annual traffic volume in the tunnels can be estimated to 3.9 10^7 veh-km- 8.6 10^7 veh-km for 2008-2009. For 2010 – 2011 the AADT is 22000 veh/day in average for the reported tunnels and the traffic volume is 6.4 10^7 veh-km. In total for the period 2008 – 2011, the traffic volume is 2.0 10^8 veh-km- 3.0 10^8 veh-km.

Results

Based on the analyses the following rates are found.

TABLE 24: FIRE RATES IN ROAD TUNNELS ON THE CZECH ROAD NETWORK.

Vehicle type	Fire rate
All vehicles	1.7 10^{-8} per veh-km / 2.5 10^{-8} per veh-km

Japan

Basis

Four accident reports concerning fire in tunnels has been received from Japan in terms of a questionnaire response with information about the tunnel and the event. The reports do not contain information about the time of occurrence of the four events, and the reports do not give any reference on the data collection period, and whether the four fires is a complete record of all fires in a period. For this reason the data cannot be used for establishing a rate valid for Japan.

Collected data

On the assumption that the four fires is the record of all fires for one year, the collective rate of these four tunnels for this year can be calculated. This will, however, be an upper value for the fire rate of tunnels in Japan, because only the tunnels with a fire event are taken into account. For the four tunnels the traffic volume is in total 1.05 10^8 veh-km.

Results

Based on the analyses, the following collective rate for the four tunnels with fire events is found (on assumption that the four fires is the record of all fires for one year).

TABLE 25: FIRE RATES IN FOUR ROAD TUNNELS ON THE JAPANESE ROAD NETWORK.

Vehicle type	Fire rate
All vehicles	$3.8\ 10^{-8}$ per veh-km

South Korea

Basis

One report has been provided with information about fires in South Korean road tunnels in the period 2004 – 2009 (six years). Ref:

- Expressway Tunnel Fire Case Analysis Effective Safety Improvement Planning, Nam Goo Kim and Jongwoo Jo, Korea Expressway Corporation.[27]

Collected data

In the period 2004 – 2009 (both years included) 30 fires were registered in South Korean Expressway tunnels. In the same time 273 collision incidents were registered.

TABLE 26: REGISTRATION OF FIRES 2004 - 2009 IN SOUTH KOREAN EXPRESSWAY TUNNELS.

Vehicle type	Number of fires	Traffic volume veh-km in tunnels (2004-2009)
All vehicles	42	$6.6\ 10^{9}$
Passenger vehicles, vans	31	
HGVs	11	

The following information is given in relation to the tunnel fires:

- Cause of fire : 22 out of 30 tunnel fires are caused by vehicle defects (6 by collision)
  - By vehicle type : 9 fires in buses and HGV and none of them caused by collision
  - Ignition point: 90% in the engine room
- Fire size(Peak fire Heat-Release Rate) : Average 6.3MW(Max. 50MW)
  - By vehicle type : 14.9MW for buses and HGV
- Fire duration: Average 27 min. (Max. 65min.)
  - The fire duration for tunnels shorter than 1km, where water hydrants are not installed (fire extinguishers only), is 4~5 min. longer than average.

From the text in the report it can be deducted that the total annual traffic volume in South Korean Expressway tunnels is $1.1\ 10^{9}$ veh-km.

Results

Based on the analyses the following rates are found.

TABLE 27: FIRE RATES IN SOUTH KOREAN EXPRESSWAY TUNNELS (2004-2009).

Vehicle type	Fire rate
All vehicles	$6.4\ 10^{-9}$ per veh-km

Vietnam

Basis

For Vietnam the statistics for one single tunnels has been available: the Hai Van Tunnel. The data are available in the following report for the period 2005 – 2013:

- Report of Traffic Volume through Hai Van Road Tunnel. Hamadeco, Danang 22/10/2013 [28].

Collected data

The Hai Van Tunnel is 6.28 km long and has since 5/06/2005 until 21/10/2013 been used by 11.95 million vehicles – corresponding to a traffic volume of 75 million veh-km. In the same duration the number of fires inside the tunnel has been 42.

The share of fires in HGV is only reported for 2011- 2013. In this period all fires have been in heavy vehicles (including one bus). The share of the traffic with HGVs is not reported.

TABLE 28: REGISTRATION OF FIRES 2005 - 2013 IN HAI VAN TUNNEL IN VIETNAM.

Vehicle type	Number of fires	Traffic volume veh-km in tunnels (2005-2013)
All vehicles	42	$7.5\ 10^{7}$

Results

Based on the analyses the following rates are found.

TABLE 29: FIRE RATE 2005 - 2013 IN HAI VAN TUNNEL IN VIETNAM.

Vehicle type	Fire rate
All vehicles	$5.6\ 10^{-7}$ per veh-km

4.2. TYPES AND SEVERITY OF FIRES

Based on indicators, e.g. personal damage, vehicle damage and tunnel structure (and taking into account the known extreme events): possible distribution of severities and fire developments.

Discussion of the severity of the fires (MW)

In the report Auswertung der ASFINAG-Tunnelbrandstatistik 2006-2012 (Evaluation of the ASFINAG tunnel fire statistics 2006 – 2012 on the Austrian motorway network), [2] the fires in HGVs are roughly estimated in terms of heat release rate. The statistics include also fires which have resulted in a stopped vehicle outside the tunnel. In the group of least severity the heat release rate is estimated 0 – 1 MW; a majority of the fires in this group has had negligible consequences.

TABLE 30: DISTRIBUTION OF FIRE SEVERITIES FROM THE AUSTRIAN STATISTICS

Fire severity	nonHGV	HGV
Outside*	6%	25%
0-1 MW	58%-49%	37%
5MW	36%-45%	15%
30MW		22%
100MW		1%
	100%	100%

** In the Austrian statistics tunnel fires are registered even though the vehicle on fire has come to standstill outside the tunnel just before entering or just after exiting.*

In the fire statistics from the South Korean Expressways, the fire severity in terms of heat release rate has been estimated for all fires. Based on these estimates the distribution shown in table 39 can be established. It shall be noted that the total number of fires is 42 (12 HGV fires and 30 fires in passenger cars and vans), so contributions less than 2.4% (for the total distribution) cannot be represented (respectively 3.3% for non HGV and 8.3% for HGV).

TABLE 31: DISTRIBUTION OF FIRE SEVERITIES BASED ON DATA COLLECTED FROM THE TUNNELS ON THE SOUTH KOREAN EXPRESSWAYS

Fire severity	nonHGV	HGV
1 MW	77%	17%
5MW	23%	42%
25MW		33%
50 MW		8%
100MW		
200MW		
	100%	100%

In the data from Norway only 16 fires (of 85) resulted in personal injury or fatalities, corresponding to 19%. Only 20 (24% resulted in damage on the tunnel), 45 fires (53%) didn't even result in damage to the vehicle.

Based on the above records and indications the best estimate shown in table 40 has been established as an expert judgement. The expert judgment is well in accordance with the statistics collected from the tunnels on the South Korean Expressways

TABLE 32: DISTRIBUTION OF FIRE SEVERITIES BASED ON EXPERT JUDGEMENT.

Fire severity	nonHGV	HGV
1 MW	70%	20%
5MW	25%	31%
25MW	5%	25%
50 MW		16%
100MW		6%
200MW		2%
	100%	100%