

Original Research Article**Fire incident data for England road tunnels****Razieh Khaksari Haddad¹, Zambri Harun^{2,*}**¹ London Bridge Associates Limited, London SE1 1TY, United Kingdom² Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, UKM Bangi 43600, Malaysia*** Corresponding author:** Zambri Harun, zambri@ukm.edu.my

Abstract: This paper presents a study carried out to estimate the fire rate in England road tunnels. The result is a dataset of 28 road tunnels and 59 fire incidents. All tunnels studied in this project are continuously monitored by the National Highways, Transport for London, and Fire and Rescue Services. The work presents a hitherto unavailable dataset demonstrating the fire safety rate of these tunnels. The average fire rate was estimated by a safety analysis and the findings indicate that the average fire rate in England's road tunnels is 1.481 per billion veh-km. There is an obvious difference between the number of fire incidents in England road tunnels and the number of fire incidents on England roads. It is also found that the fire rate in England's road tunnels is less than in other European countries considered in this study.

Keywords: fire rate; England road tunnels; National Highways; Transport for London; Fire and Rescue Services

1. Introduction

Road tunnels provide an important role in the transportation system in each country. Tunnels have a dry and well-lit environment while drivers on open roads are exposed to unpredicted weather. Therefore, it is expected that the number of accidents in road tunnels is lower than on roads because the visibility and meteorological conditions are constant in tunnels. Although as it is stated in the Permanent International Association of Road Congresses (PIARC) Technical Committee on Road Tunnel Operation, 2007, the severity of accidental consequences is higher in tunnels. The nature of accidents in tunnels is different from accidents on open roads. The first cause which makes different accidents in road tunnels is driving style. Drivers try to increase their distance from tunnel side walls and decrease their speed as well. This issue is considered more alarming in narrower tunnels and/or with complicated horizontal alignments, as well as in longer tunnels. Another possible reason is the tunnel structure. A tunnel is a confined space and poor visibility occurs due to darkness, especially in the first part of the tunnel and it surprises drivers negatively. This unexpected change in visual condition results in a higher crash rate near the tunnel portal^[1,2].

Moreover, this dark-closed construction can trigger drivers' anxiety. Zhao et al.^[3] measured changes in the pupil and heart rate while driving through the tunnel. This study's results confirmed that drivers feel pressure and mental demand due to the different environments inside the tunnel. There is also a minor effect of temperature change between the inside and outside of the tunnel which might occur in long tunnels. Apart from these negative aspects, drivers desire to drive more carefully in tunnels. The speed limit in tunnels is lower than on open roads. Tunnel lighting during the night also has a positive effect on safety.

1.1. Accidents and fire rate in tunnels

Unidirectional tunnels induce fewer accidents than bidirectional tunnels and the average accident rate is 10 and 8 accidents/billion veh-km for bidirectional (functioning in two directions) and unidirectional tunnels

(operating in a single direction), respectively^[4]. Amundsen and Ranes^[5] studied road tunnel accident (RTA) records of 587 Norwegian road tunnels between 1992 and 1996. According to their analysis, the severity of injury RTAs in road tunnels is greater than in open roads and shorter tunnels have a higher accident rate. This difference between tunnel accident rates and open roads ones is also shown in studies^[6,7].

Swiss road tunnels study carried out by Salvisberg et al.^[8] shows the influence of tunnel traffic known as average annual daily traffic (AADT), and the percentage of heavy goods vehicles (HGVs) on the risk of an accident. Based on their study and Cornelia's study^[9] of Austrian road tunnels, the risk of accidents is higher in tunnels with bidirectional traffic than in tunnels with unidirectional traffic.

It is important to discuss severe accident occurrences as the damages is large and there are injuries and fatalities involved. In Italian tunnels, there is 12 severe accidents/billion veh-km while it is 9 severe accidents/billion veh-km on the corresponding motorways containing the tunnels investigated^[10]. The severity of injuries is lower on open roads than in Chinese freeway tunnels^[11]. Based on the Austrian highway database the risk of being killed in a traffic crash is twice as high in tunnels than on motorways^[9]. In motorways, 3.3% of injury incidents are fatalities, whereas in road tunnels, this percentage increases to 8.2%. It is also proven by Lu et al.^[12] that the percentage of accidents involving fatal and serious injuries in the Shanghai River crossing tunnels in China is 2.4% compared with 1.2% on open roadways. Altogether, the crash severity of road tunnel accidents is greater than the severity of accidents occurring on open-air roads.

However fire incidents cause disastrous consequences, they are less frequent than traffic accidents. Brandt et al.^[13] found that 30% of tunnel accidents result in a fire incident rate in Norway and Switzerland. The statistical data collected between 2002 and 2011 from 96 tunnels in France presents a rate of vehicle fires of 1.1 fires per billion veh-km. Only 10% of these fires were caused by accidents.

In the absence of reliable statistics for tunnel fires in England, estimates of fire frequencies are generally obtained either from international tunnel fire statistics or derived from vehicle fire statistics for England roads as a whole. Since traffic and geometric characteristics, as well as driving styles in other countries, are different from those in England, it was considered worth making an investigation in this paper into fire incidents, especially in England road tunnels.

1.2. Fire incident rate in different zones inside the tunnel

As the behavior of fire and smoke including the maximum temperature of the fire is under the influence of the location of the fire source^[14], the rate of fire occurrence is different in different zones inside the tunnel. With regards to the fire crash rate in different zones inside the tunnel, Amundsen and Ranes^[15] found that the accident rates are higher in the entrance zone of tunnels, 0.3 crashes per million veh-km compare to 0.23 crashes per million veh-km in the first 50 m inside the tunnel, 0.16 in the next 100 m inside the tunnel, and 0.10 in the midzone inside the tunnel. Cornelia^[9] also found that the accident rate near the tunnel portals is higher than in the internal zone of the tunnel. Similarly, the crash rate is lower in the tunnel interior zones and higher in the entry and exit zones in Singapore tunnels. This difference in collision rate between entry and exit zones and the interior zone is due to differences in driver perceptions between open roads and tunnel sections^[16].

On the other hand, Ma et al.'s study^[11] of four Chinese tunnels shows that the rate of crash inside the tunnel is higher than in the portal, as compared to the highest crash rate in access zones (portals) in the Norwegian study^[15].

1.3. Causes of tunnel fires

A vehicle consists of an electrical system, oil circuit system, exhaust system, and various electromechanical functional parts in a compact space, which increases the chance of contact between combustibles and ignition sources. All parts of a vehicle are in danger when they work together^[17].

The main causes of vehicle fires in road tunnels as PIARC 2008 summarised, are mechanical or electrical defects in vehicles^[18]. A road tunnel fire review carried out by the Organisation for Economic Co-operation and Development (OECD) and PIARC also indicates that technical vehicle failure is an important cause of vehicle fire in tunnels^[19]. According to National Cooperative Highway Research Programme, 2006, on the most severe fires, only 10% of fires in road tunnels were caused by an accident^[20]. The aspects related to vehicle fire and smoke without fire incidents in Norwegian road tunnels were examined by Naevestad and Meyer^[21]. According to Naevestad and Meyer^[21], 21% of vehicle fires were caused by a vehicle crash on average. Based on the collected breakdown and fire incident data between 2006 and 2013 from Austrian road tunnels, 90% of fires were caused by technical issues with only 7% derived from collisions^[22].

Zhang et al.^[23] studied the causes of vehicle fire through statistical analysis of defective vehicle recall data caused by fires in China and the United States. Based on their study, 37.24% of the total fires happened because of electrical system defects, 41.03% happened due to defects in the fuel system, and 15.17% from the flammable liquid transportation system.

In regards to psychological reasons for tunnel crashes, Cornelia^[9] found that the most frequent cause of tunnel crashes is lacking vigilance. Other reasons are wrong driving behavior, which results in the inability to maintain a safe distance from the front vehicle, and misinterpretation of road design and layout. Fatalities in road tunnel fires are strongly associated with HGVs; approximately 71% of fatalities in tunnel fires are in fires involving HGVs, 24% regular vehicles excluding trucks and HGVs, and 5% trucks or lorries^[24].

2. England road tunnels

To analyse road tunnel safety in England, fire incident data were gathered from National Highways, Transport for London (TfL), and Fire & Rescue Service for the year 2021 and earlier. The period considered for analysis for each tunnel depended on the available data and the number of years that the tunnel had been in operation. The average period was 10 years.

The basic structure of the data-collecting process is as below:

Step 1: collecting the initial data via the tunnel control centre of the operating body. Different types of equipment such as CCTV, emergency phone calls from tunnel users, and the supervisory control and data acquisition (SCADA) records are used. Operators are in charge of this task.

Step 2: initial collected data is checked to avoid errors, missing data, inconsistencies and deleting false alarms. This stage is the responsibility of authorized bodies except tunnel operators such as tunnel manager or tunnel safety officer.

Step 3: the final collected data is issued either via a report written by the tunnel manager or submission of data in a dedicated data recording system.

At the end, fire incident data for 28 road tunnels on rural and urban roads were collected, which covers 71% of all England road tunnels. The tunnels have a length of between 156 m and 3260 m and a total 999.63 veh/km traffic density, which shows that this database is strong enough. These were all the available fire incident data for road tunnels in England at the time of writing this article.

Since the investigated tunnels are with unidirectional traffic, the AADT refers to one travel direction only and the fire rate is the number of fires per 100 million veh-km. AADT values range from 68 to 133,781 vehicles per day. Traffic flow was extracted from the Road Tunnel Association (RTA) of the aforementioned motorway tunnels. This website contained the annual average traffic for each tunnel.

Table 1 gives the number of fire incidents in each tunnel, duration the information is collected at the same time with reference to the length of motorways, and AADT.

Table 1. Road tunnels included in the dataset and their recorded fire incidents.

No.	Tunnel name	Length (km)	AADT	Duration in which information is collected	Fire incidents
1	Hatfield Tunnel	1.147	80,849	8	3
2	Hindhead Tunnel	1.830	35,000	10	2
3	Blackwall Tunnel-Southbound	1.483	50,000	10	1
4	Blackwall Tunnel-Northbound	1.350	50,000	10	6
5	Tyne Tunnel	1.676	32,877	10	0
6	Bell Common Tunnel	0.505	133,781	10	1
7	Dartford Tunnel	1.430	69,452	10	3
8	Roundhill Tunnel	0.380	40,000	10	5
9	Medway Tunnel	0.725	42,000	10	1
10	Ramsgate Tunnel	0.800	12,000	10	0
11	Rotherhithe Tunnel	1.483	33,000	10	1
12	Limehouse Link tunnel	1.553	65,000	10	5
13	Saltash Tunnel	0.410	40,000	10	2
14	Holmesdale Tunnel	0.684	128,301	10	2
15	Kingsway Tunnel	2.260	42,849	18	12
16	Queensway Tunnel	3.260	42,000	18	0
17	Strand Underpass	0.365	68	20	0
18	Meir Tunnel	0.284	68,493	13	1
19	Southwick Hill Tunnel	0.490	46,877	10	13
20	East India Dock Tunnel	0.350	65,000	10	1
21	Fore Street Tunnel	0.361	60,000	10	0
22	George Green Tunnel	0.295	60,000	10	0
23	Green Man Tunnel	0.170	60,000	10	0
24	Eastway Tunnel	0.290	30,000	10	0
25	Upper Thames St. Tunnel	0.320	30,000	10	0
26	Hangar Lane Tunnel	0.240	60,000	10	0
27	Eltham Tunnel	0.156	60,000	10	0
28	Heathrow Airside Road Tunnel	1.300	1918	10	0

The main objective of this study was to evaluate the fire incident rates of these tunnels to show whether the average fire rate is lower or higher than England road fire rate. This study also allows England fire incident dataset to be compared to datasets for other countries, albeit recognising that there are differences in the data collection methods and the tunnel characteristics in the various datasets.

It is envisaged that the data can be used as a reference during both the operational phase of tunnels (as a means of demonstrating the effectiveness of the fire safety measures deployed) and the development phase of projects. It is planned that the dataset will be periodically refreshed, perhaps every two years and the fire incident data of tunnels located in Scotland and Wales will be collected, to ensure that an up-to-date reference is available.

The analysis was undertaken in the following order:

- 1) Collection of data from tunnel operators and Fire and Rescue Services,
- 2) Review of the data for gaps and inconsistencies,
- 3) Confirmation that the incident was not incorrectly labelled as a fire,
- 4) Interpretation of data to fill gaps (where deemed appropriate),
- 5) Cross-checking of data collected from respective tunnel operators with Fire and Rescue Service data,
- 6) Compilation of a single dataset in spreadsheet format,
- 7) Analysis of the dataset, and
- 8) Presentation of data.

3. Analysing the fire incidents in england road tunnels

Figure 1 shows the number of fires that have been recorded in major England road tunnels. The least number of fires per year was zero recorded in 2005, 2006, 2010, and 2011. The largest number of fires in a calendar year was 10, recorded in 2012.

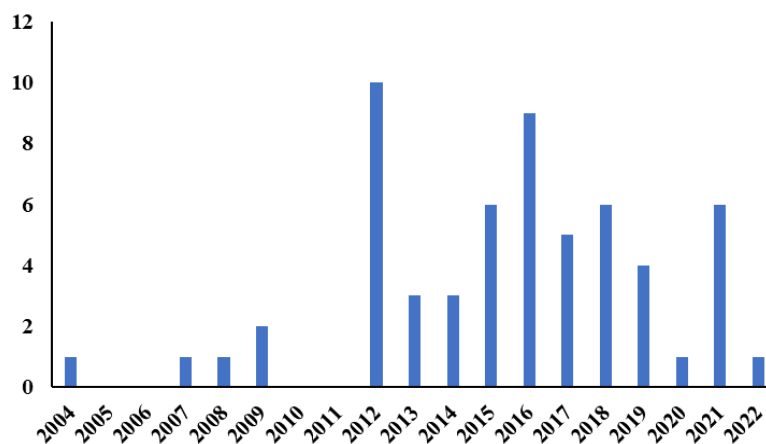


Figure 1. Number of fires per year in England road tunnels.

Table 2 provides the average frequency of fire incidents per year and per 100 million veh-km for all 28 road tunnels. The development of fire to adjacent vehicles is not discussed in this study.

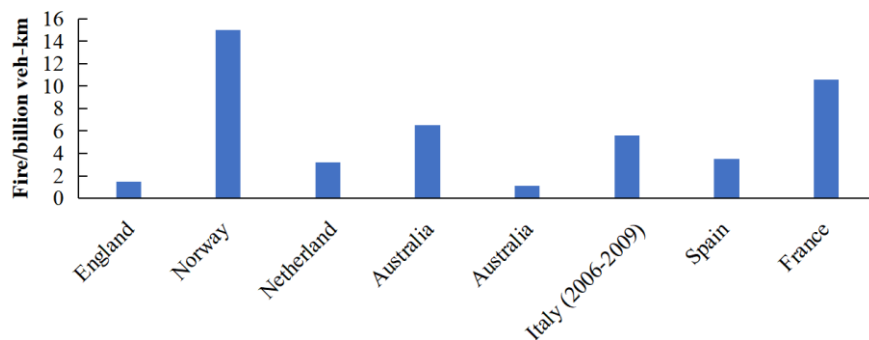
Table 2. Frequency of vehicle fires in England road tunnels.

No. of fires	59
Fire frequency/year	0.194
Fire frequency/billion veh-km	1.481

England road tunnels' average fire rate was compared with Europe, Austria, Australia, Italy, Norway, and Switzerland in fires per billion veh-km in **Table 3** and **Figure 2**.

Table 3. Comparison between England's fire rate and European countries and Australia considered in this study.

	Fire rate/billion veh-km	References
England	1.48	-
Norway	15	[18]
Netherlands	3.2	[18]
Austria	6.5	[18]
Australia	1.1	[25]
Italy (2006–2009)	5.6	[10]
Spain	3.5	[18]
France	10.6	[18]

**Figure 2.** Comparison between England's fire rate and European countries considered in this study.

4. Discussion

There are various parameters affecting the frequency of fire such as^[18]:

- Collision rate
- Gradients in the tunnel
- Gradient on the routes leading toward the tunnel
- Combination of tunnel length and gradient
- Traffic composition

Moreover, there are other factors such as traffic direction, AADT, and HGV proportion in traffic influence fire rate indirectly by affecting on the collision frequency^[8]. Based on this study, collision risk is lower in unidirectional tunnels and it has a direct relationship with AADT. A higher share of HGV leads to a higher rate of collision^[8].

When it comes to gradient, the relationship between fire rate and this parameter relates to the speed difference between fast vehicles such as passenger cars, and slow ones like trucks on uphill/downhill sections, which results in an increase in collision rate and consequently fire rate. Driving uphill put greater strain on the vehicle's mechanical components as well and causes these components to become hot or malfunction, potentially causing a fire to break out.

The gradient of 19 tunnels listed in **Table 1** was investigated. Almost 79% of these tunnels have a gradient of less than or equal to 3%. This could be one of the reasons for the low fire rate in England road tunnels.

Caliendo et al.^[27] used the random-parameters negative binomial (RPNB) model to investigate the crash frequency that occurred in 260 Italian road tunnels over a 4-year monitoring period. Based on their study,

longer tunnels are associated with a greater number of severe accidents because of a decrease in driver's concentration with increasing length. The RPNB regression model proposed by Caliendo et al.^[27] explains why the accident rate in the UK is lower than that in mainland Europe as well since the tunnel lengths in England tend to be shorter and the effect of tunnel length is non-linear.

5. Conclusion

Road tunnels are one of the most complex and critical transportation infrastructures for the urban/rural network. In general, the demands for road and train tunnels have increased due to inter-urban demography changes^[28]. Although the number of accidents in road tunnels is less than on road, the severity of accidents is more especially when it comes to fire incidents. The work presented here represents a dataset of recorded fire incidents in England road tunnels. All tunnels studied in this project are continuously monitored by National Highways, Transport for London, and Fire and Rescue Services. This project is part of the development of a quantitative risk analysis model for England road tunnels and the aim of it is to derive the likelihood of tunnel fires in England road tunnels. The data set consists of 28 unidirectional tunnels, in which 59 fire incidents occurred. Based on the collected data, the average fire rate in England road tunnels is 1.481 per billion veh-km. As well as providing the average fire rate of England road tunnels, this study makes a comparison between England road fire rates and England roads. It is shown that there is a huge difference between these rates. The fire rate in England road tunnels is also less than in other European countries considered in this study.

Author contributions

Conceptualization, RKH and ZH; methodology, RKH; validation, RKH and ZH; formal analysis, RKH; investigation, RKH; data curation, RKH; writing—original draft preparation, RKH; writing—review and editing, ZH; supervision, ZH; project administration, RKH.

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Conflict of interest

The authors declare no conflict of interest.

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