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Vehicle fires in Norwegian road tunnels 2008-2011

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Abstract
Norway is one of the countries that constructs the most road tunnels, and there are well over 1,000 in the country. The aim of the study is to map the prevalence and describe the characteristics of vehicle fires in Norwegian road tunnels 2008-2011. The average number of fires in Norwegian road tunnels is 21.25 per year per 1,000 tunnels, and the average number of smoke without fire is 12.5 per year per 1,000 tunnels. The fires and the instances of smoke without fire do usually not involve harm to people or the tunnels. Of the 135 fires and instances of smoke without fire, we know that 8 involved minor injury to people and that 3 involved serious personal injury and 5 involved death. The present study provides two important findings. The first is the fact that the causes of fires in heavy and light vehicles are different. Technical problems are the most frequent cause of fires and instances of smoke without fire in heavy vehicles, while single vehicle and collisions are the most frequent cause of fires in vehicles weighing less than 3.5 tonnes. The second important finding of the study is that undersea tunnels are substantially overrepresented in the statistics of fires in Norwegian road tunnels. There are 31 undersea road tunnels in Norway. These have a high gradient, defined as over 5 %. In addition, there are 10 tunnels that are not underwater, but still have a high gradient. These 41 road tunnels, which together constitute 4% of road tunnels in Norway, had 44% of the fires and the instances of smoke without fire in the period 2008-2011. Heavy vehicles were overrepresented in these fires, and technical problems were the most frequent cause.

1. Introduction

1.1 Aims and methods

Norway is one of the countries that constructs the most road tunnels (Amundsen & Ranes 1997). There are well over 1,000 in the country. Road tunnels are usually at least as safe as or safer than similar roads in the open air without junctions, exits, pedestrians and bicyclists (Amundsen & Engebretsen 2009). Road tunnels do nevertheless deserve attention from a traffic safety perspective, because of their disaster potential related to vehicle fires.

Road tunnel fires make up a substantial potential for catastrophe on the Norwegian road network. Although international research indicate that vehicle road tunnel fires seldom occur, these incidents constitute a particular risk, as they usually involve substantial release of smoke and heat (PIARC 2008; Stene, Jenssen, Bjørkli & Bertelsen 2003). Although the vehicle accident risk is lower in road tunnels than it is on the remaining road network, the catastrophe potential related to tunnel fire is higher (Jenssen, Bjørkli & Flø 2006: 16). This is indicated by the three catastrophic road tunnel fires in Central-Europe at the turn of the century; in the Mont Blanc tunnel, the Tauern tunnel in 1999 and in the St. Gotthart tunnel in 2001 (Stene, Jenssen, Bjørkli & Bertelsen 2003).

The aim of the study is to map the prevalence and describe the characteristics of vehicle fires in Norwegian road tunnels 2008-2011. The following fire characteristics are examined: 1) time of the fire 2) location of the fire, 3) scope of the fire: people and vehicles involved, personal injuries, vehicle and tunnel damages and for how long was the tunnel closed? 4) how was the fire extinguished?, 5) how was the road traffic centrals alerted about the fire?, 6) cause of the fire and 7) undersea tunnels.

The project is based on the following data sources: 1) “Merkur” (2001-2008) and “Vegloggen” (2008-today), that are the Norwegian road traffic centrals’ (RTC) systems for recording road incidents, 2) road traffic central personnel, 3) Norwegian Public Roads Administration (NPRA) personnel working with road tunnel safety, 4) fire services in all municipalities with road tunnels and 5) news archives

1.2 Previous research on road tunnel accidents and fires

Road tunnels have fewer accidents per vehicle/km than comparable road stretches in the open air, as several accidents occurring out on roads in the open air seldom occur in road tunnels (Amundsen & Engebretsen 2009). The accident severity of the most common road tunnel accident is, however greater than the severity of accidents occurring on open air roads (Nussbaumer & Nitsche 2008).

The vehicle accident risk and severity differs greatly in different tunnel zones (Amundsen & Engebretsen 2009). The vehicle accident risk of the entrance zones of road tunnels (e.g. the first 100 metres) is often 3-4 times higher than it is further into the tunnels, while the accident severity is highest in the central zone of road tunnels. The high entrance zone accident risk is probably due to impaired light conditions in tunnels compared with open air (a “black hole effect”), which make drivers lower their speed, and change lateral position (Amundsen 1994; Sagberg, Hakkert, Larsen, Leden, Schmotzer & Wouters 1999). Road users braking as they enter road tunnels may induce a higher accident risk.

Road tunnels comprise a “poor sensory environment” compared with roads in the open air, and this may lead to, monotony lowered driver attention, disorientation and/or fear (Jenssen et al 2006: 26). The lack of references in road tunnels may also make drivers’ assessments of speed and distances poor. Finally, drivers rate road stretches in the open air higher than tunnels when asked about desirable road environments. Undersea tunnels are rated lowest among road users (Jenssen et al 2006: 12).

Amundsen and Engebretsen (2009) have studied accidents in Norwegian road tunnels 2001-2006 and conclude that the three most common accident types in road tunnels are: collisions between vehicles driving in the same direction 43 % (rear end or changing lanes), single vehicle accidents 35 % and head on collision 15 %. A previous analysis of Norwegian tunnel accident data 1992-96 conclude that rear end collision is the most common road tunnel accident type, occurring twice as often in tunnels as in the remaining road network (Amundsen & Ranes 1997).

Norwegian studies indicate that heavy vehicles are overrepresented in road tunnel accidents. The share of heavy vehicles involved in road tunnel accidents (22 %) is twice as big as the traffic amount and accident share on roads in the open air would imply (Amundsen 1996).

The steep inclination of undersea road tunnels seems to involve a higher vehicle fire risk for heavy vehicles, as their brakes may overheat driving down into tunnels, and as their engines may overheat driving up and out of the undersea tunnels. This argument is underlined in the investigation report of the fire brigade of ”Søndre Follo” (2011) following the Oslofjord tunnel fire 23.06.2011. According to this report, the undersea Oslofjord tunnel experienced 11 fires in the three years preceding the 23.06.2011 fire. Eight of the fires were in heavy vehicles, while three of the fires were in personal cars. Two thirds of the fires in the heavy vehicles were caused by overheated brakes, while one third was caused by overheated engines (Søndre Follo Brannvesen 2011: 9).

SAFETEC’s risk analysis following the 23.06.2011 Oslofjord tunnel fire suggests that foreign lorries seem to have a higher risk of vehicle fires in Norwegian undersea road tunnels (SAFETEC 2011). The foreign lorries have two axles, weaker engines and they are generally older than Norwegian lorries. The demands on the foreign lorries increase when they are used in hilly terrain with heavy loads. This applies to Scandinavian terrain in general, but especially steep undersea road tunnels. Scandinavian lorries are better adapted to the Scandinavian topography. They are equipped with three axles and have more powerful engines, reducing the risk that they are over loaded in hilly Scandinavian terrain. Additionally, Scandinavian lorry drivers are probably more experienced with and more competent with regard to driving on Norwegian roads. As a consequence, they probably apply the brakes more correctly driving downhill in road tunnels, minimizing the risk of overheated brakes (SAFETEC 2011).

A 1992 publication from the NPRA sums up the road tunnel fire research to conclude that the risk of road tunnel fire is 0,01 instances of fire per 1 million vehicle hours. These data indicate that most of the fires occur in cars, and that the fires usually are extinguished by the driver or by other people. The 1992 publication from the NPRA asserts that the most frequent causes of vehicle tunnel fires are defects in the electric system, or the petrol supply. Moreover, it is reported that the fires seldom cause personal injuries (NPRA 1992: 2).

International research indicates that the most common causes of vehicle road tunnel fires are mechanical or electrical defects in vehicles (PIARC 2008: 61).

2. Method

2.1 Road tunnel vehicle fire characteristics

In this study both fires and instances of fire without smoke are included. The Norwegian collegium for fire terminology defines a fire as an “Unwanted or uncontrolled combustion process characterized by release of heat, combined with smoke, flames or glowing.”[1] In order to avoid confusion and minimize our discernments regarding which cases that are fires and not, we define all instances of open flame in vehicles as fires. We have, however, also included instance of smoke without fire that could have turned into fire for three reasons. First, these instances also involve temporarily closed road tunnels. Second, these instances could probably have turned into fires if they had not been extinguished. Third, instances of smoke that were experienced as tunnel fire by road users, but which could not have turned into fire, are not reported in this paper (e.g. fog, exhaust smoke, smoke from defect turbos, smoke from “burning”). These are counted in the study, and distinguished from instances of smoke that could have turned into fires, but they are not reported here.

The study has collected data on the following fire characteristics:

1) time of the fire 2) location of the fire, 3) scope of the fire: people and vehicles involved, personal injuries, vehicle and tunnel damages, and for how long was tht tunnel closed? 4) how was the fire extinguished?, 5) how was the road traffic centrals alerted about the fire?, 6) cause of the fire and 7) undersea tunnels.

2.2 Data sources

In the following we give brief descriptions of the sources we have used to collect data on vehicle fires in Norwegian road tunnels.

1) Our main data sources have been the five Norwegian road traffic centrals’ (RTC) systems for recording road traffic-related events *“Vegloggen”* and *”Merkur”*. Merkur was used from 2001 to 2008, while Vegloggen was used from 2008, and is still used today. There are five road traffic centrals in Norway, corresponding to the five regions of the Norwegian Public roads Administration. The eastern region comprises the following counties: Oslo, Akershus, Hedmark, Oppland and Østfold. The southern region comprises the following counties: Buskerud, Vestfold, Telemark, Aust Agder and Vest Agder. The western region comprises the following counties: Rogaland, Hordaland and Sogn and Fjordane. The central region comprises the following counties: Møre and Romsdal, Sør Trøndelag and Nord Trøndelag. The northern region comprises the following counties: Nordland, Midt Hålogaland, Troms and Finnmark.

[1] http://www.kbt.no/faguttrykk.asp?ID=3418

“Vegloggen”/”Merkur” generally have good data about the tunnels that were struck by vehicle fires, the time when the fires occurred, the number of vehicles involved, how long tunnels have been closed because of fires, harm to people and tunnels induced by the fires, and how the road traffic centrals were alerted about the fires.“Vegloggen”/”Merkur” frequently lack information about where in tunnels the fires occurred, damage to vehicles, how the fires were extinguished and they often also lack data on the causes of the fires.

2) Road traffic central staff. Meetings and discussions with staff at the road traffic centrals served to ensure the quality of our interpretations of the RTC records and to supplement our data (e.g. clarify where in the tunnels the fires occurred).

3) Employees of the Public Roads Administration working on tunnel safety. We communicated with fire and safety inspectors responsible for road tunnels in each region. These supplemented and assured our data.

4) Fire services. Fire services and other emergency services are called out on suspicion of fires in road tunnels and record such call-outs over time. We cooperated with the Directorate for Civil Protection and Emergency Planning (DSB) in our inquiries to the fire services. DSB sent out 192 letters to relevant fire services in all Norwegian municipalities with road tunnels. We received a total of 114 responses. Many of the fire services provided us with fairly detailed accounts of the fires in their municipalities.

5) News Archives. We have also searched news archives to supplement our data collection. Road tunnel fires are extensively covered by local newspapers and often also by the national media. These often include pictures and key details. In several cases where we lacked information, we got supplemental or explanatory information, from for example the search engine of “www.google.no”.

2.3 Data analysis

In this project we have received data on road tunnel fires from each of NPRA’s five regions. Personnel at the road traffic centrals have searched their databases using terms like “smoke”, “fire”, “closed tunnel”. The results have been sent to us as PDF documents. Some of the records did not exist electronically. These were scanned and e-mailed to us.

We have read through the records of a total of 312 events from the road traffic centrals, and coded or standardized each event in spreadsheets to export and analyze data in SPSS. Information was often taken for granted in the records, local names and expressions were used. We contacted road traffic central personnel in order to clarify information. The road traffic central records do, for instance not include detailed data on where in the tunnels the fires occurred. In many cases, the number of a tunnel emergency phone or a fire cabinet that was used is given in the records. When such equipment was used, and the tunnel entrance that was used or the direction of the vehicle struck by fire was known, we were able to determine exactly where in the tunnels, and subsequently in which zones of the tunnels the fires occurred.

We coded all the data for each region into a spreadsheet and sent it back to our contact person at the road traffic central and tunnel safety inspectors in the respective region for quality assurance. A spreadsheet with tunnel fire data, information about the codes and questions regarding lacking information in certain instances of fire were sent. We requested that the personnel would perform a general check on the quality of the coded information. As noted, we have also received information from fire departments about several of these events. This has also served as a quality assurance of our data, as we compared information about the fires that was given in both the records of the road traffic centrals and the fire services.

In our examination of systematic relationships between variables, we have used table analysis, testing significant relationship by means of the chi square test (Hellevik 1994). The chi square test is used to examine a hypothesis that there is no relationship between two variables, by comparing the actual bivariate table with a bivariate table with statistical independence; meaning that there is no relationship between the variables. We choose a significant level of 5 %, which means that if we find a relationship between two variables there is a less than 5 % chance that the relationship is false. Finally, it must be noted that relationships found in bivariate analyses may be due to a "third variable" influencing both variables, falsely making us assume that there is a relationship between the two. Such spurios effects can be controlled for in multivariate analyses. We suggest such third variables (e.g. amount of traffic, number of (undersea) tunnels in a region), when it seems relevant

3. Results: vehicle fires in Norwegian road tunnels 2008-2011

3.1 The prevalence of vehicle fires in Norwegian tunnels

Table 1 shows the prevalence of fire and instances of smoke without fire in the NPRA's five region in 2008-2011.

Table1 Fires in the NPRA's five regions, 2008-2011. (The average number of fires in Norway is given in bold italics).

Year	Event	East	South	West	Central	North	Total
2008	Fire	3	1	10	1	2	17
	Smoke	2	1	7	2	0	12
2009	Fire	7	1	5	8	0	21
	Smoke	3	1	2	2	0	8
2010	Fire	4	0	6	6	2	18
	Smoke	4	2	3	2	0	11
2011	Fire	10	5	7	5	2	29
	Smoke	4	2	8	5	0	19
Total		37	13	48	31	6	135

Average per year:	Fire	6	1,75	7	5	1,5	***21,25***
	Smoke	3,25	1,5	5	2,75	0	***12,5***
Number of tunnels/lines		105	154	540	135	137	***1071***

The data shows that the average number of fires in Norwegian road tunnels is 21.25 per year per 1,000 tunnels, and that the average number of smoke without fire is 12.5 per year per 1,000 tunnels. These events are unevenly distributed in the different regions. The average number of fires per year is 6 in the eastern region, 1.75 in the southern region, 7 in the western region, 5 in the central region and 1.5 in northern region.

The eastern region has 105 tunnels and tunnel lines, the northern region has 154 tunnels and tunnel lines, the western region has 540 tunnels and tunnel lines, the central region has 135 tunnels and tunnel lines and the northern region has 173 tunnels and tunnel lines.

The number of fires and smoke without fire was higher in 2011 than in the preceding years. The explanation is complex. If we only focus on fires, the increase is due to increases in the eastern region and southern region. The increase in the smoke without fire is mostly attributable to increases in the western and central region. We conclude that the increases appear to be the result of random fluctuations, as the result of a chi-square analysis of the relationship between fires and years not are significant. The northern region was excluded from this analysis, as chi-square tests are sensitive to cells with 0.

3.2 The time and locations of the fires

Time of the day. More than 70 % of the fires occurred between 06.00 and 18.00. 6,1 % of the fires took place in the night, between 00.01-06.00, while 26 % of the fires occurred in the period 06.01-12.00. Most of the fires, 45,8 % ,came about between 12.01-18.00. 21,5 % of the fires 2008-2011 occurred in the evening between 18.01-24.00.

Time of the year. The majority, 57,8 %, of the fires occurred in the spring and summer. 26, 7 % of the fires occurred in the spring, 31,1 % in the summer, 23 % in the autumn and 19,3 % in the winter. June is the month with most fires (16 %). November is the month with the fewest fires (4 %).

Location of the fires. We know which tunnels the fired occurred in, but as noted, data on where in the tunnel the fires occurred are fairly scarce. In order to get these data, we generally needed information on: fire cabined or emergency tunnel phone used, tunnel entrance used or the vehicles' direction. As we handed this information to our RTC contact people, estimates of where in the tunnel the fires occurred could be made. Most of the fires are registered in the middle zone of the tunnels. In 33 % of the 135 fires we lacked such data. Most of the fires, 45,2 % occurred in the tunnels' middle zone. 8,1 % occurred in the entrance zone, which defined as the first 100 metres of the tunnel, 3 % occurred in the exit zone, which we defined as the last 100 metres. As the NPRA recommends drivers of vehicles struck by fire to drive out of the tunnel if possible, we also included fires registered outside of the tunnel, if they started inside of the tunnels. 8,9 % of the fires were registered outside of the tunnels.

3.3 Scope of the fires

Vehicles involved. The number and type of vehicles involved in tunnel fires have bearings on the severity of the fires. 46.3 % of the 135 fires involved a vehicle under 3.5 tonnes. In 38.1 % of the fires there was only one heavy vehicle involved. 5,2 % involved one heavy and one light vehicle, 5,9 % involved 2 light cars or more, and in 4,5 % of the fires we lacked information about the vehicle that was struck by fire.

We see that heavy vehicles seem to be overrepresented in road tunnel fires, as indicated in previous research (Amundsen 1996). Moreover, there is a significant relationship between the regions and the extent of heavy vehicles involved in fires in the period 2008-2011. Heavy vehicles are involved in considerable proportions of the fires in the eastern (40,5 %) western (57,8 %) and northern (66,7 %) regions.

The extent of injuries/damages to people, vehicle and tunnels in vehicle fires in Norwegian road tunnels 2008-2011 are given in figure 1:

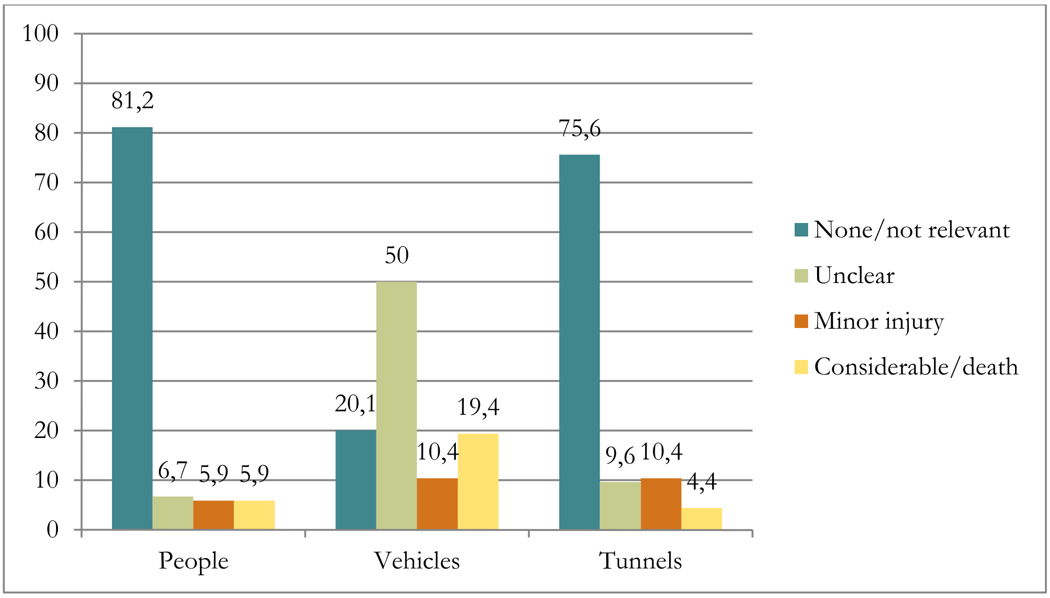

Figure 1 Injury/damage to people, vehicle and tunnels in vehicle fires in Norwegian road tunnels 2008-2011 (N=135).

Personal injuries. In 81,2 % of the 135 fires involved no harm to people. In 6,7 % of the cases, it was unclear whether the fire had lead to injuries. 5,9 % of the fires involved minor personal injury and 5,9 % of the cases involved death/major injury. 3,7 % of the fires involved deaths. Many of the fires are caused by car accidents, and we do not discern between injuries induced by accidents and injuries induced by fires.

Damage to vehicles. 20,1 % of the 135 fires involved no damage to vehicles, 50 % of the fires damage to vehicle was recorded as “unclear”, due to lacking information. 10,4 % of the fires involved some damage to vehicles, and 19,4 of the fires involved considerable damage to vehicles.

Damage to tunnels. 75,6 % of the 135 fires involved no damage to the tunnels, the extent of tunnel damage was unclear in 9,6 % of the cases, 10,4 % of the fires involved some tunnel damage (e.g. melted wires) and 4,4 % of the cases involved considerable tunnel damages (e.g. fire in PE foam, damaged concrete).

For how long were the tunnels closed? When the RTC are alerted about road tunnel fires or smoke in road tunnels, they close the tunnels regardless of the source of the smoke. The RTC records have good data on how long the tunnels were closed because of smoke or fires. We distinguish between eight categories: 1-15 min, 16-30 min, 31-45 min, 46-60 min, 61-75 min, 76-90 min, 91-105 min and 106 min or more. The tunnels are however also partly closed because of fires, and this often happens when the tunnel have been totally closed because of a fire. We do not document the extent of partly closed tunnels in this study, as tunnels are partly closed in many different ways, in these ways are not always sufficiently documented in our data sources: closing one tunnel lie, close one lane if it is possible, decreasing the speed limit, put up a “work sign” and so forth. The length of time the tunnels have been closed due to fire, group themselves into two parts. The first is between 1 and 60 minutes (43 %), and the other is 106 minutes or more (22 %).15 % of the fires involved closed tunnels between 61-105 minutes. We lack data on how long the tunnels were closed in 20,7 % of the 135 fires.

3.4 How was the road traffic centrals alerted about the fire?

As we use the records of the RTC, we focus on how the RTC were alerted about the fires. In case of fires, the RTC are often alerted by several different parties. In our study, however, we focus on the first party to alert the RTC. Several road tunnels are observed by means of cameras that automatically detect differences in light that may be caused by fire. Moreover, RTCs are automatically alerted when fire cabinets are opened, and extinguishers taken out.

We distinguish between six ways that the RTC are alerted about the fires: 1) road users alerting with their phones, 2) road users alerting with emergency tunnel phones, 3) the RTC are alerted by means of automatic alarm (e.g. when fire cabinets are opened and fire extinguishers taken out, or when fires/smoke are detected by means of automatic cameras: ”Automatic Incident Detection” –(AID), 4) fire services, 5) police, 6) Acute medical communication central (AMK)

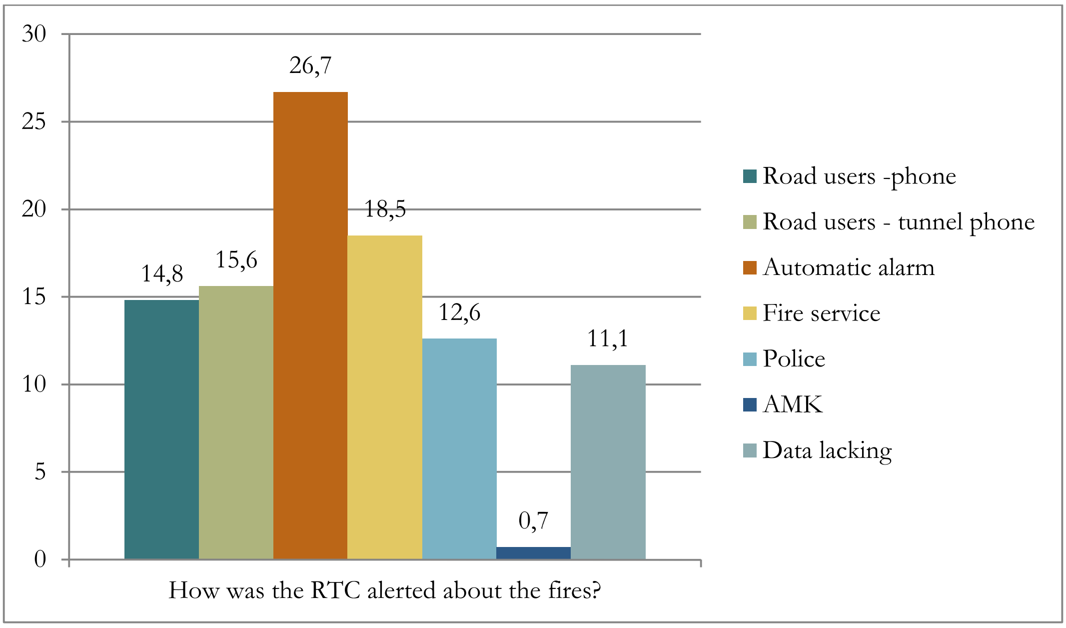

Figure 2 Varsling av vegtunnelbranner og tilløp i hele Norge 2008-2011 (N= 135). Shares.

Road users represent the most frequent actor to warn the road traffic centrals of road tunnel fires. Combining the two options that road users can warn their local road traffic central about road tunnel fires (own telephone and tunnel telephone), we get a share of 30,4 %. 26,7 % of the fires were warned by means of automatic alarm in road tunnels.

The fire warning technology in road tunnels fills an important function. If we combine the shares of automatic tunnel fire detection and warnings communicated by means of tunnel telephone, we get a share of 42 %.

Finally, it is important to remember that in the cases where police and fire services alert RTCs about road tunnel fires, they were usually alerted by road users first. Thus, it seems likely that figure 2 underestimates the role of road users when it comes to giving alerts about road tunnel fires.

3.5 How was the fire extinguished?

We focus on how the fire was extinguished first. In 30,4 % of the 135 fires we either lacked data on how the fire was extinguished or there was no need to extinguish the fire, in 40 % of the cases, the fire services extinguished the fires, and in 26,7 % of the cases the driver extinguished the fires. In 2,2 % of the cases other road users extinguished.

Our data on how the fires were extinguished are somewhat incomplete, as we do not have systematic information on all the parties involved in attempts of extinguishing the fires. The driver, police, ambulance personnel and other road users may be involved in preliminary attempts of extinguishing the fires, in addition to the fire services. It is important to map the efforts of these parties in the case of road tunnel fires. The records of the RTC always include information about fire extinguishers that are taken out of the tunnels' fire cabinets, but little information about fire extinguishers that were in the cars that struck fire, in police, or in the cars of other road users. Finally, extinguishing efforts of the fire services are probably also underestimated in our data, as we focus on how the fires were extinguished first.

3.6 Causes of the fires

The records of the RTC contain little information on the causes of the fires, but on the grounds of the information present in the records, we discern between the following causes: 1) unclear, 2) technical problems, 3) single accident and 4) collisions.

Traffic accidents (single vehicle accidents and collisions) seem to be a rarer cause than technical problems when we look at all the 135 fires and instances of smoke without fire in the period 2008-2011. About half of all instances has an unclear cause. This is probably due to inadequate reporting, and information in the RTC records. The second most common cause is technical problems (32 %), followed by single vehicle accidents (7 %) and collisions (12 %).

The categories of causes are however different when we compare fires and instances of smoke without fire involving heavy vehicles and cars weighing less than 3.5 tonnes. Table 2 shows the causes of fires and smoke without fire for vehicles under and over 3.5 tonnes, in Norway 2008-2011.

Table 2 the causes of fires and smoke without fire for vehicles under and over 3.5 tonnes, in Norway 2008-2011 (N= 133)

Causes	Vehicles <3,5 t	Vehicles >3,5 t	Number of incidents:
Unclear:	52 %	37 %	51
Technical problems:	17 %	49 %	41
Single accidents:	11 %	2 %	9
Collision:	20 %	12 %	22
Number of incidents:	76	57	133

Table 2 shows that technical problems are the most frequent cause of fires and instances of smoke without fire in heavy vehicles, while single vehicle accidents and collisions are the most frequent cause of fires in vehicles weighing less than 3.5 tonnes.

The majority of the fires and the instances of smoke without fire did, as mentioned, not involve personal injuries. It is nevertheless of vital importance to gain insights into the causes of the instances that did involve personal injuries in order to prevent these in the future.

Table 3 shows the causes of road tunnel fires and instances of smoke without fire, involving personal injury in Norway, 2008-2011.

Table 3: The causes of road tunnel fires and instances of smoke without fire, involving personal injury in Norway, 2008-2011 (N= 131)

Causes	**No injury**	**Unclear**	**Minor injury**	**Serious injury/death**	**Number of incidents**
Unclear:	92,4 %	4,5 %	3 %	0 %	66
Technical problems:	95,1 %	0	4,9 %	0 %	41
Single accidents:	37,5 %	0 %	25 %	37,5 %	8
Collision:	18,8 %	37,5 %	12,5 %	31,3 %	16
Number of incidents:	106	9	8	8	131

Table 3 shows that the fires involving personal injury mainly are caused by single accidents and collision. Technical problems caused minor injuries in 4,9 % of the fires, and no serious injuries or deaths. Single accidents caused personal injuries or deaths in 62,5 % of the instances, while collisions caused personal injuries or deaths in 43,8 % of the instances.

3.7 Undersea road tunnels

As noted, the steep inclination of undersea road tunnels seems to involve a higher vehicle fire risk for heavy vehicles, as their brakes may overheat driving down into tunnels, and as their engines may overheat driving up and out of the undersea tunnels. Consequentially, we chose to examine the instances of vehicle fire in the Norwegian undersea road tunnels in the study.

There are 31 undersea road tunnels in Norway: the eastern region has four, the southern region has one, the western region has 7, the central region has 10 and the northern region has 9 undersea tunnels. In addition, there are 10 tunnels that are not undersea, but have a high gradient (defined as over 5 %) in the western region. Since the degree of gradient appears to increase the risk of fire, we include these 10 road tunnels in the analyzes[2].

There are thus at least 41 road tunnels in Norway with high gradient. These represent approximately 4 % of the road tunnels in Norway. Results show that these tunnels had 44 % of the fires in the period 2008-2011. Undersea road tunnels are thus significantly overrepresented in the statistics of fires in Norwegian road tunnels in the period 2008-2011.

It is important to note that undersea road tunnels in average are four times as long as Norwegian road tunnels in general. This is however not sufficient to explain the overrepresentation of undersea tunnels when it comes to vehicle fires.

Heavy vehicles are over-represented in fires in tunnels with high gradient. There is a significant relationship between undersea tunnels (including road tunnels with high gradient) and the proportion of heavy vehicles involved in fires.

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[2] We are thankful to Gunnar Lotsberg of the NPRA for providing us with information about these.

Figure 3 shows the involvement of heavy vehicles in non-undersea tunnel fires and undersea tunnel fires, including fires in non-undersea tunnels with a high gradient, 2008-2011.

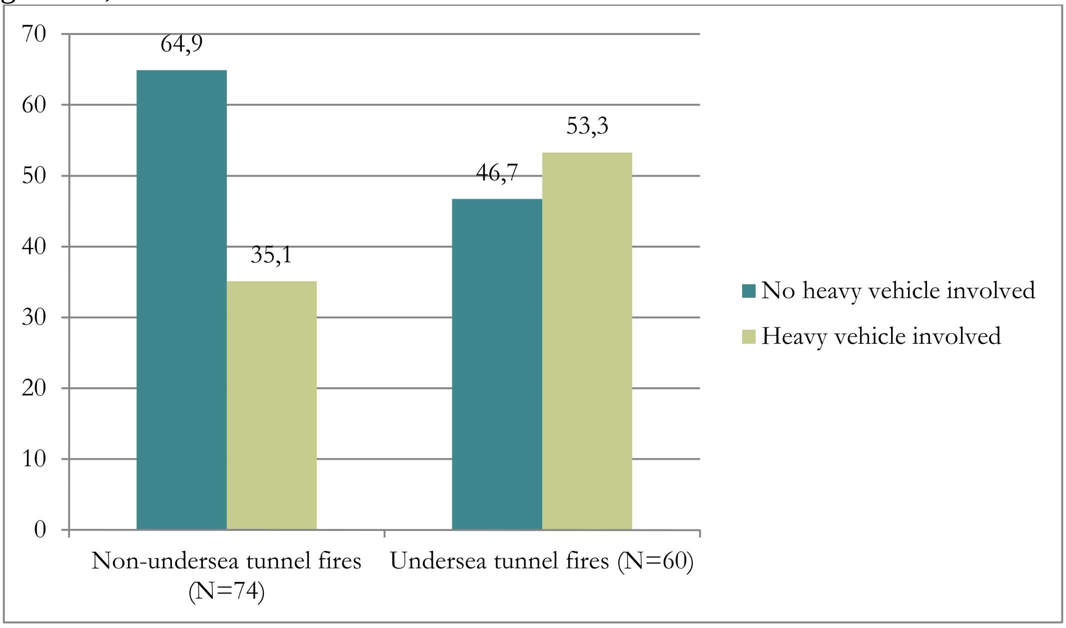

Figure 3 Heavy vehicle involvement in non-undersea tunnel fires (N=74) and undersea/high gradient tunnel fires (N=60), 2008-2011.Percentages based on the number of fires in tunnels without and with a high gradient.

The proportion of heavy vehicles involved in fires in tunnels with high gradient in 2008-2011 was slightly greater than the proportion for no heavy vehicle involved (53% vs. 47%). When it comes to fires in non-undersea tunnels, the proportion of no heavy vehicle involved (65%) was far greater than the proportion of heavy vehicle involved (35%).

Figure 4 shows the causes of fires and instances of smoke without fire in tunnels with and without a high gradient. The percentages are based on the number of fires in tunnels without and with a high gradient, in Norway 2008.

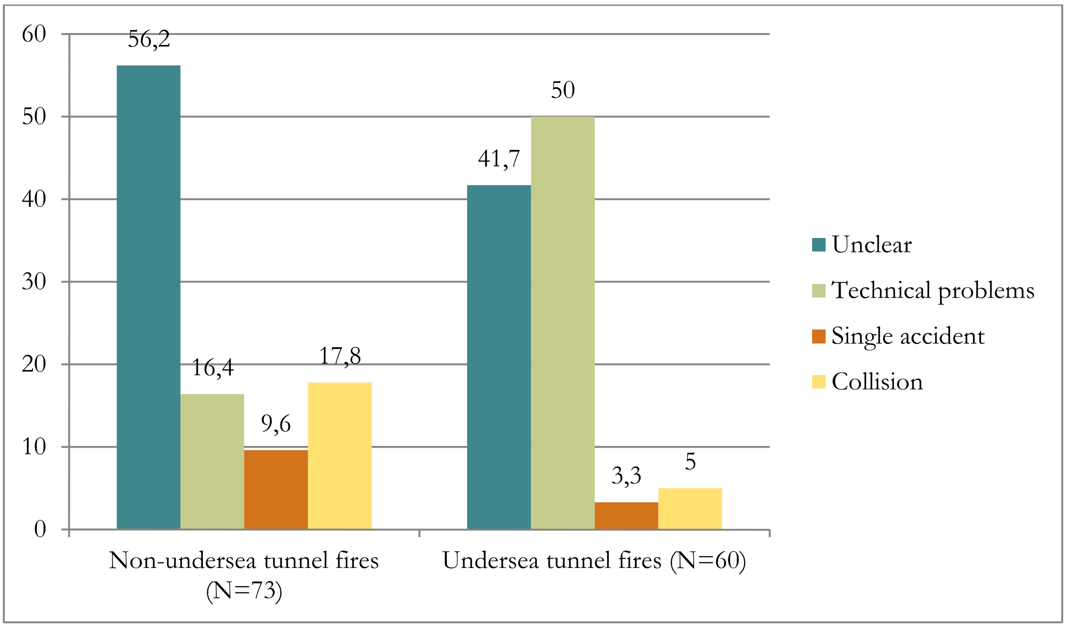

Figure 4 The causes of road tunnel fires in non-undersea and undersea tunnels, 2008-2011. Percentages based on the number of fires in tunnels without (N=73) and with (N=60) a high gradient.

There is a significant relationship between undersea tunnels (including road tunnels with high gradient) and the causes of fires. Although we lack considerable information on the causes of fires, it can be concluded that traffic accidents seem to be a less important cause of fires in undersea tunnels than in other tunnels. By far, the most important cause of fires in undersea tunnels is technical problems.

Technical problems are a three times more frequent cause of fires in undersea tunnels than in other tunnels. Collision is three times more frequent cause of fires in non-undersea tunnels than in undersea tunnels. However, it is difficult to draw conclusions about this, since the cause is unclear in as many as 50 % of the fires.

4. Discussion

The aim of the study has been to map the prevalence and describe the characteristics of vehicle fires in Norwegian road tunnels 2008-2011. The average number of fires in Norwegian road tunnels is 21.25 per year per 1,000 tunnels. The average number of smoke without fire is 12.5 per year per 1,000 tunnels. The fires and the instances of smoke without fire do usually not involve harm to people or the tunnels. Of the 135 fires and instances of smoke without fire, we know that 8 involved minor injury to people and that 8 involved serious personal injury or death. 40 of the 135 fires involved damage to vehicles and 20 involved damage to tunnels.

The present study has provided two important findings. The first is the fact that the causes of fires in heavy and light vehicles are different. Technical problems are the most frequent cause of fires and instances of smoke without fire in heavy vehicles, while single vehicle and collisions are the most frequent cause of fires in vehicles weighing less than 3.5 tonnes.

The second important finding of the study is that undersea road tunnels are substantially overrepresented in the statistics of fires in Norwegian road tunnels. There are 31 undersea road tunnels in Norway. These have a high gradient, defined as over 5 %. In addition, there are 10 tunnels that are not underwater, but still have a high gradient. These 41 road tunnels, which together constitute 4% of road tunnels in Norway, had 44% of the fires and the instances of smoke without fire in the period 2008-2011. Heavy vehicles were overrepresented in these fires, and technical problems were the most frequent cause.

We have found that the undersea tunnels appear to be particularly vulnerable to fire, especially in heavy vehicles. This is in line with the causal picture presented in the report of the "Søndre Follo" fire service on the fire in the "Oslofjordtunnel" 23.06.2011. Previous Norwegian studies also show that the proportion of heavy vehicles involved in tunnel accidents are twice as high as the traffic volume and the proportion of accidents on open roads would suggest.

Figure 5 shows that there are significant differences between the regions with regard to the involvement of heavy vehicles in fires. This should be followed up in further studies.

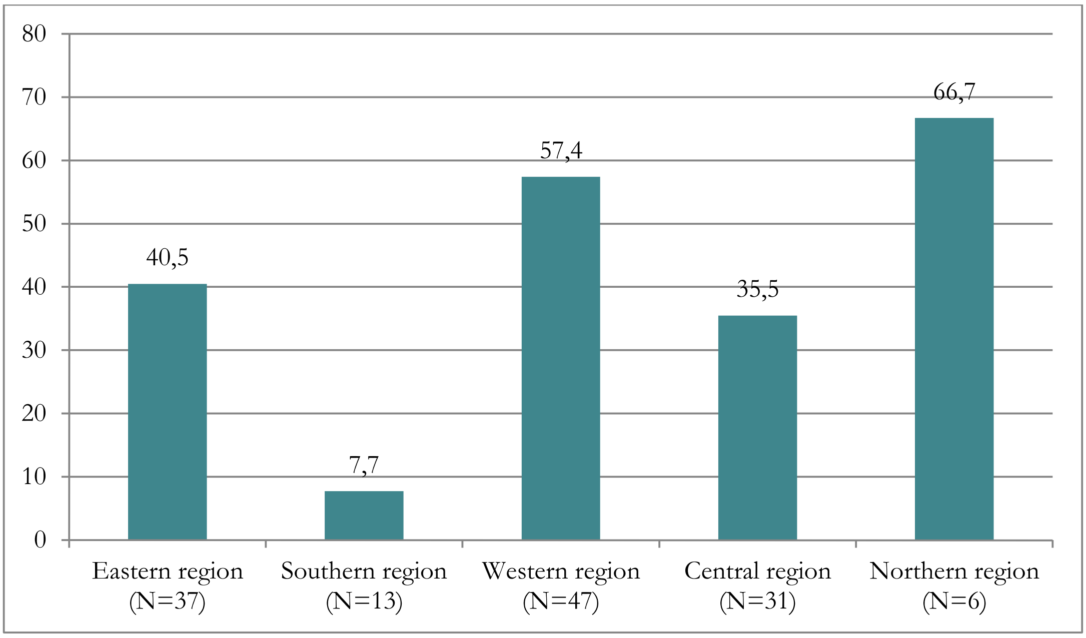

Figure 5 Shares of heavy vehicles involved in road tunnel fires in Norway, 2008-2011 (N=135). Percentages based on the total number of fires in each region.

Further studies should also focus on the following questions: Which undersea tunnels are especially at risk, and why? Are there critical slope gradients, for example in combination with curves that increase or decrease the risk of fire?

There are a few undersea tunnels in the eastern region, the western region and the central region that contribute to the over-representation of undersea tunnels when it comes to fires in the period 2008-2011. Further studies of fires in undersea tunnels could for example focus on the following tunnels "Oslofjordtunnelen" (10 fires), "Byfjordtunnelen" (9 fires), "Bømlafjordtunnelen" (8 fires) and "Eiksundtunnelen" (7 fires).

We do not know the gradient in the shallow underwater tunnels, but an analysis of the relationship between the undersea tunnels' gradient and fire frequency, controlling for traffic volume, and tunnel length could provide answers to whether there are critical gradients increasing the risk of fire.

SAFETEC's (2011) report on the fire in the Oslofjord tunnel 23/06/2011 estimates that particularly foreign (eastern European) heavy vehicles are at risk of fire in Norwegian undersea tunnels. Future studies should therefore examine the shares of fires in heavy vehicles in underwater tunnels involving foreign vehicles. This share should, if possible, be compared with the proportion of foreign heavy vehicles travelling in Norwegian undersea tunnels.

Our data are somewhat lacking when it comes to causes road tunnel fires, and this should be followed up in further studies. How many fires can, for example, be traced to overheating of brakes in heavy vehicles in undersea tunnels, and how many can be traced to engine failure in heavy vehicles in undersea tunnels? These themes can be followed up with a focus on measures to reduce risk factors related to heavy vehicles in undersea tunnels.

Tunnel fires occur rarely, and if we had included all the events that are not ending in fires, and compared the characteristics of them with the characteristics of the fires, we could perhaps have calculated the risk and the risk factors of tunnel fires.

We may, however, still use our data to assess whether some characteristics seem to be overrepresented in road tunnel fires. In this way we may point to specific risk factors related to tunnel fires, such as undersea tunnels, high gradient and heavy vehicles.

The numbers from the study can be used to calculate the risk of fires of vehicles over 3.5 tonnes and below 3.5 tonnes, in road tunnels generally and specifically in undersea tunnels. This can be done by taking traffic volume into the calculations.

Finally, there are several in-depth investigation reports for large tunnel fires. We have used information from such reports in this study. Such reports may for instance provide useful data on the behaviour of road users in road tunnel fires.

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