Summary:

Vehicle fires in Norwegian road tunnels 2008-2011

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Summary:

Norway is one of the countries that constructs the most road tunnels, and 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, but they have a disaster potential related to vehicle fires. The report maps and describes the characteristics of fires and smoke without fire in Norwegian road tunnels during the last 4 years. 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. 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. 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.

Background and goal

Norway is one of the countries that constructs the most road tunnels. 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. Road tunnels do nevertheless deserve attention from a traffic safety perspective, because of their disaster potential related to vehicle fires.

The goal with this project has been to collect data on fires in Norwegian road tunnels 2008-2011.

Data sources and methods

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

1) "Vegloggen"/"Merkur", are the five Norwegian road traffic centrals' systems for recording road traffic-related events. 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.

"Vegloggen"/"Merkur" generally have good data about the tunnels which 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. The data on use of fire ventilation is also of varying quality. Some regions, however, have done a better job registering this than others.

2) Road traffic central staff. Meetings and discussions with staff at the road traffic centrals served to ensure the quality of our interpretations and to supplement our data.

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.

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. In several cases where we lacked information, we got supplemental or explanatory information, from for example the search engine of "www.google.no".

Quality Assurance. In this project we have received data on road tunnel fires from each region. 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 analyze data in our data analysis programs. We have also received information from fire departments about several of these events. When we had coded all data for a region into a spreadsheet, we sent it back to our contact person at the road traffic central, fire managers and tunnel safety inspectors in the respective region for quality assurance.

Results from Norway 2008-2011

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, 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.

44 % of the fires 2008-2011 occurred in the afternoon. 70 % of the fires occurred between 06 and 18. The majority, or 58 % of the fires occurred in the spring and summer. June is the month with most fires (16 %). November is the month with the fewest fires (4 %).

Most of the fires are registered in the middle zone of the tunnels. 46.3 % of the fires involved a vehicle under 3.5 tonnes. In 38.1 % of the fires there was only one heavy vehicle involved. The other fires involved either multiple or no vehicles.

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 significant proportions of the fires in the eastern western and northern region.

In over 80 % and over 75 % of the cases, the fires involved no harm to people or tunnels respectively. The situations is different with respect to damage to vehicles, where the outcome in 50 % of the cases is recorded as “unclear”. Of the 135 fires and instances of smoke without fire, we know that 16 involved personal injury or death, 40 involved damage to vehicles, and 20 involved damage to the tunnel.

In 30 % of the fires we lacked data on how the fire was extinguished, in 40 % of the cases, the fire services extinguished the fires, and in 27 % of the cases the driver extinguished the fires. In 2 % of the cases other road users extinguished.

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 %).

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 35 %. 27 % 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 %.

Traffic accidents (single vehicle accidents and collisions) seem to be a rarer cause than technical problems when we look at all the 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. 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 S1 shows the causes of fires and smoke without fire for vehicles under and over 3.5 tonnes, in Norway 2008-2011.

Table S1 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
Kollisjon:	20 %	12 %	22
Number of incidents:	76	57	133

Table S1 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 S2 shows the causes of road tunnel fires and instances of smoke without fire, involving personal injury in Norway, 2008-2011.

Table S2: 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 S2 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.

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.

There are thus at least 41 road tunnels in Norway with high gradient. These represent approximately 4 % of the road tunnels in Norway. 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. Undersea tunnels are in average 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.

As we see below, there are a few underwater tunnels in the eastern region, the western region and the central region that contribute to the overrepresentation of the undersea tunnels when it comes to tunnel fires in the period 2008-2011.

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.

Figure S1 shows the involvement of heavy vehicles in fires and instances of smoke without fire in non-undersea tunnel fires and undersea tunnel fires, including fires in non-undersea tunnels with a high gradient, 2008-2011.

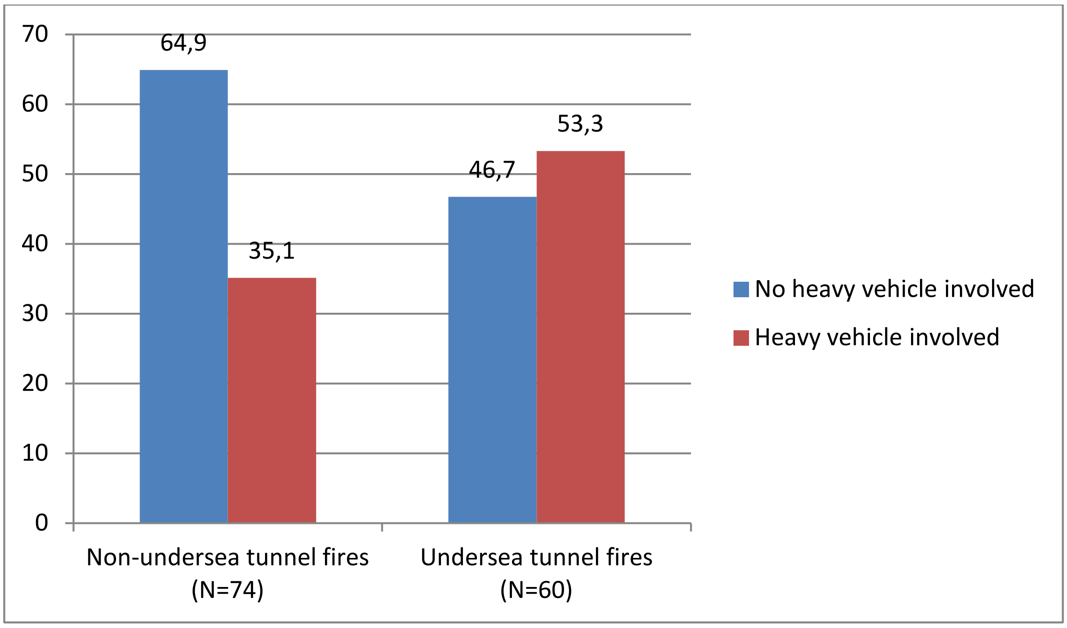


Figure S1 Heavy vehicle involvement in non-undersea tunnel fires (N=74) and undersea tunnel fires and non-undersea tunnel fires in tunnels with a high gradient (N=60), 2008-2011.Percentages based on the number of fires in tunnels without and with a high gradient.

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%).

The considerable proportion of heavy vehicles involved in fires in undersea tunnels 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 S2 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.

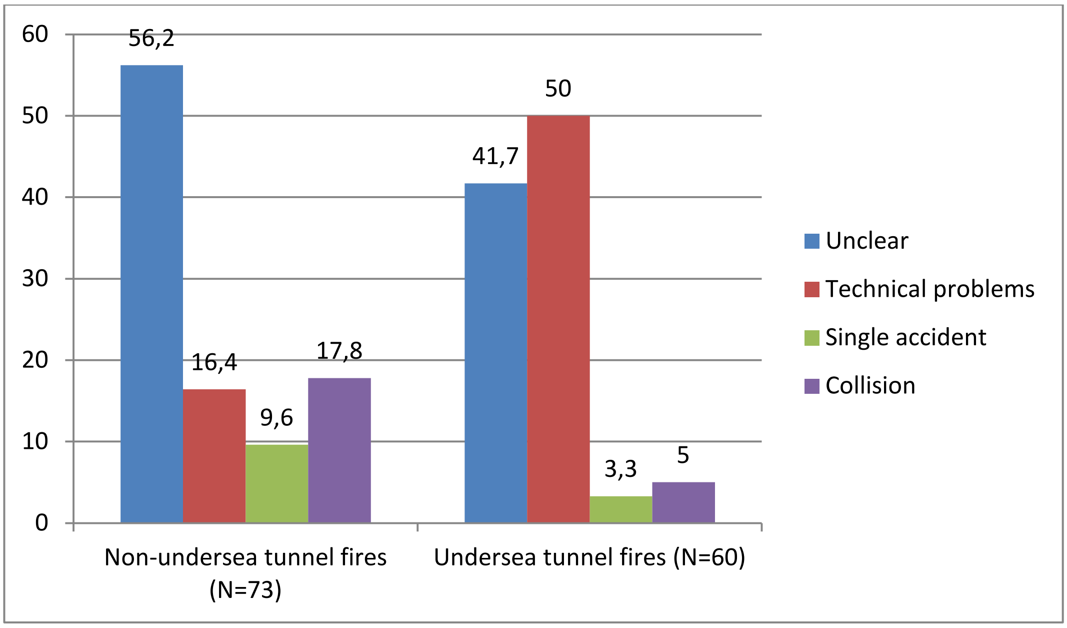


Figure S2 The causes of road tunnel fires and instances of smoke without fire in tunnels without (non-undersea tunnels) and with a high gradient (undersea tunnels), 2008-2011. Percentages based on the number of fires and instances of smoke without fire in tunnels without (N=73) and with (N=60) a high 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 is 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.

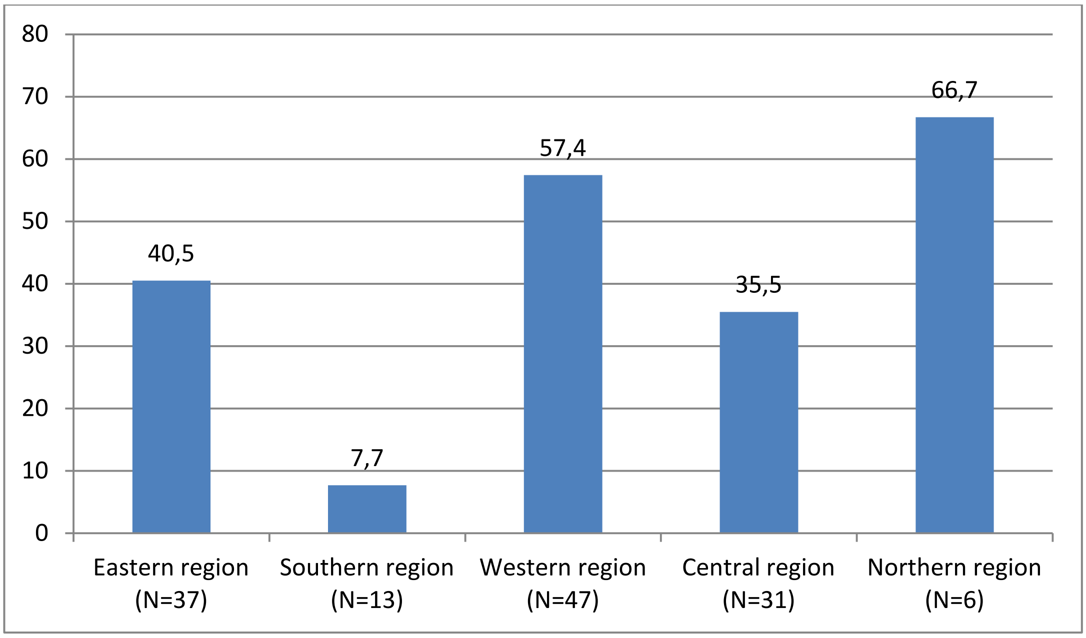
Suggestions for further research

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.

We have found that the undersea tunnels appear to be particularly vulnerable to fire, especially in heavy vehicles. Figure S2 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.



Figur S2 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.

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.