Accident Investigation Board Norway

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REPORT ROAD 2015/02

REPORT ON FIRE IN A HEAVY GOODS VEHICLE IN THE GUDVANGA TUNNEL ON THE E16 ROAD IN AURLAND ON 5 AUGUST 2013

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This report has been translated into English and published by the AIBN to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

Photos: AIBN

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REPORT ON FIRE IN HEAVY GOODS VEHICLE IN THE GUDVANGA TUNNEL

Date and time:	12:00 on 5 August 2013
Location:	The E16 road, the Gudvanga tunnel, Aurland municipality in Sogn og Fjordane county
Road no, main section (Hp), km:	E16 Hp 8 km 9.453
Incident type:	Fire in heavy goods vehicle
Vehicle type and combination:	Polish-registered Renault Magnum tractor pulling a Swedish-registered Krone semi-trailer
Type of transport:	Empty heavy goods vehicle in commercial goods transport

NOTIFICATION OF THE INCIDENT

The Accident Investigation Board Norway (AIBN) received information through the media at approximately 12:30 on 5 August 2013 that a heavy goods vehicle was on fire in the Gudvanga tunnel. Sogn og Fjordane Police District's operations centre was contacted and provided further details about the accident. It turned out that dozens of people were trapped in the smoke inside the tunnel. The AIBN deployed three accident inspectors, who arrived in Lærdal late that evening.

SUMMARY

On 5 August 2013, an empty Polish-registered heavy goods vehicle caught fire in the 11.4 km long Gudvanga tunnel. It is not possible to establish exactly why the vehicle caught fire. In the AIBN's opinion, the factors that may have contributed to the fire are difficult to detect through an ordinary safety check of this vehicle. The driver took the necessary action when he saw signs that something was wrong with the heavy goods vehicle, but he was unable to extinguish the fire using the 6 kg fire extinguisher from his own vehicle.

In the AIBN's opinion, there were failures on four material points when 67 persons were trapped in the smoke in the tunnel and 28 persons sustained acute smoke inhalation injuries:

1. The tunnel was not equipped with any kind of monitoring system or device for counting vehicles that could have provided information about how many vehicles were in the tunnel at all times. The road traffic control centre (VTS) and the fire service thereby did not have an overview of how many vehicles were on the side of the fire towards which the smoke was ventilated.

2. No information was given to the road users that immediate evacuation was necessary. Only those in the immediate vicinity of the fire or who realised what was happening at an early stage managed to evacuate before the tunnel filled with smoke.

3. As a result of the pre-defined strategy for fire-extinguishing and rescue work that is set out in the emergency response plan for the tunnel, the road traffic control centre, immediately after the fire was reported, routinely starting the fire ventilation,[1] so that the smoke from the fire was ventilated 8.5 km in the direction of Gudvangen. The smoke blocked the only possible evacuation route for the road users on the Gudvangen side of the fire.

4. The tunnel's design and technical equipment did not adequately facilitate self-rescue.

The AIBN finds that the conditions in the Gudvanga tunnel were poor in terms of facilitating self-rescue, and believes that this is the most important lesson to be learnt from this incident. The AIBN's investigation, to which SINTEF, Oslo University Hospital and SP Technical Research Institute of Sweden contributed, shows that the road users were in a critical situation. In all, 23 people were seriously injured and 5 very seriously injured as a result of the incident.

The weaknesses that the AIBN has uncovered are, in turn, connected to the safety follow-up of the tunnel on the part of both the tunnel owner (the Norwegian Public Roads Administration – NPRA) and the fire service, and to the general guidelines that apply to emergency response in tunnels. The tunnel's emergency response plan said little about the preconditions for self-rescue and evacuation – the NPRA's safety control had not picked up on safety-critical factors, the drills described in the NPRA's Handbook R511 – Safety management of road tunnels Part 1, had not been implemented, and inspections of the tunnel as a special fire object were inadequate.

In addition, the AIBN sees challenges for the emergency services as regards coordinating, leading and cooperating along so many different interfaces in an emergency. The cooperation was made even more difficult as a result of the communications network that the emergency services were to use being out of action and the fire incident commander not being in the incident command centre.

The AIBN proposes six safety recommendations as a result of the investigation.

[1] The direction and speed of the ventilation described in the emergency response plan in connection with ventilation of the tunnel in the event of fire. This definition is also used by the fire service and VTS.

1. FACTUAL INFORMATION

1.1 Chain of events

1.1.1 <u>The triggering event</u>

At 9:30 on 5 August 2013, a heavy goods vehicle belonging to the Polish transport company P.H.U. KAJ left Bergen bound for Malmø in Sweden. The vehicle had unloaded goods at Hansa brewery in Bergen, and was returning empty together with another Polish heavy goods vehicle that was also going to Malmø.

The drivers of the two vehicles were in radio contact with each other and headed east along the E16. When they approached Vinje, approximately 20 km west of Voss, they stopped because the driver of the heavy goods vehicle that was following the same route as the P.H.U. KAJ vehicle though he saw smoke coming from the other heavy goods vehicle. After a brief stop, they drove on, as they had concluded that what had appeared to be smoke must be steam from the exhaust pipe because the road surface was wet from rain.

Figure 1: Map showing the incident site. Source: Road map, the NPRA

When they arrived at Gudvangen, the two heavy goods vehicles stopped at a petrol station near the entrance to the Gudvanga tunnel. There they had a cup of coffee and topped up their water bottles before continuing along the E16 road and into the Gudvanga tunnel in the direction of Aurland.

Approximately six kilometres after entering the tunnel, the driver of the P.U.H. KAJ vehicle noticed that he was losing engine power. After another two kilometres, he had to stop.

He pulled in to the right, turned on the hazard warning lights and came out of the vehicle. That was when he saw flames below the driver's cabin on the left side. The driver first tried to put out the fire using a 6 kg fire extinguisher that he had in the vehicle, but could not do so before the extinguisher was empty. He then tried to get hold of more fire extinguishers, but none of the other vehicles close by had any available. Nor were there any fire extinguishers in the tunnel near the place where the vehicle had stopped. When interviewed by the police, the driver said that he had asked people in the nearest vehicles to notify the police and the ambulance and fire services.

Figure 2: The heavy goods vehicle in an early phase of the fire. Photo: Monika Blikås

The fire developed rapidly and soon spread to the whole vehicle, filling the tunnel with thick, black smoke. At that stage the driver sought refuge inside a bus that had stopped some way behind the heavy goods vehicle.

1.1.2 <u>Notification of the emergency services</u>

At approximately 12:00, a road user called 110 and notified the emergency communication centre in Sogn og Fjordane (110SF). 110SF immediately (at approximately 12:02) issued a full alert to the fire stations in Aurland and Gudvangen. The duty officer in Aurland confirmed receipt of the alert, was informed that a heavy goods vehicle was on fire and dispatched vehicles and crew to the tunnel immediately. 110SF then notified the health service and the police.

At the same time as 110SF notified the other two emergency services, the Emergency Medical Communication Centre (AMK) in Førde received an emergency call about an incipient fire in a heavy goods vehicle in the Gudvanga tunnel. The caller had been driving from Flåm towards Gudvangen and seen smoke and flames emanating from the heavy goods vehicle as he passed it together with other cars and a Polish coach. The other vehicles had continued towards Gudvangen without stopping.

At approximately 12:03, the NPRA Western Region's road traffic control centre (VTS), which is responsible for controlling the technical installations in the Gudvanga tunnel, was instructed by 110SF to close the tunnel.

The police in Sogn og Fjordane county has registered that the triple notification to all emergency services was received at 12:04. At the same time, 110SF also informed the police that VTS and AMK had been notified.

At 12:05, AMK Førde alerted the ambulance service in Lærdal and informed the municipal medical officer in Aurland of the situation.

At 12:26, the 110 emergency communication centre in Hordaland (110H) was notified of the fire in the Gudvanga tunnel by 110SF. 110H immediately notified the fire services in Bergen and Voss, and they confirmed receipt of the notification at 12:29.

At 12:28, AMK Førde notified AMK Bergen. The air ambulance (SLA Førde) was then notified, and further medical resources from Sogn og Fjordane were called in.

At 12:30, AMK alerted the air ambulance service in Bergen (SLA Bergen) and the ambulance service in Voss. AMK Bergen also contacted the police and fire service in Voss. Between 12:39 and 12:46, Voss Hospital, the municipal medical officer in Voss and Haukeland University Hospital were notified of the possible arrival of patients. Further medical resources from Hordaland county and Voss were then called in.

At 12:35, the police in Voss informed 110H that they were sending a patrol unit to the incident site in Gudvangen. At 12:55, the Voss police notified the local Red Cross, requesting assistance.

A timeline has been compiled of all the times referred to in this report (see Appendix B).

1.1.3 The closing of the tunnel and initiation of fire ventilation[2]

As soon as they were notified of the fire, the VTS operators immediately closed the tunnel manually in accordance with the emergency response plan for the tunnel and VTS's own incident response plan. The tunnel was closed by activating flashing red lights at the tunnel entrances. There were no road barriers installed outside the tunnel.

At 12:05, VTS initiated fire ventilation of the tunnel (described in more detail in section 1.13.4). Immediately afterwards, the fire's location was identified at 3.05 km +/- 250 m from the tunnel entrance on the Aurland side, as the fire extinguisher in fire cabinet BS 133 was removed. The Gudvanga tunnel has longitudinal ventilation and, in accordance with the emergency response plan, the predetermined direction of ventilation in the event of fire is from Aurland towards Gudvangen, at a rate of 1–2 m/sec. This applies regardless of where in the tunnel the incident/fire occurs. The direction of ventilation has been decided on the basis that any direct extinguishing efforts at the scene of an incident/fire will be done by the fire service in Aurland, which has the shortest response time to reach the tunnel and needs to be able to drive through a smoke-free tunnel to the scene of the fire.

This meant that the smoke and ventilation air from the fire were led 8.5 km towards the tunnel opening on the Gudvangen side, and the tunnel filled up with smoke at a rate of around 2 m/sec, see section 1.12.5.

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[2] The direction and speed of the ventilation described in the emergency response plan in connection with ventilation of the tunnel in the event of fire. This definition is also used by the fire service and VTS.

The 'Turn and exit' signs inside the tunnel were not activated by VTS on the basis of the message that was received just after 12:05, as VTS did not receive confirmation of where the fire was from the 110 emergency communication centre/fire service. Such confirmation was not received until the fire incident commander confirmed the site of the fire by removing the fire extinguisher from fire cabinet BS 134 at 12:44.

Figure 3: The heavy goods vehicle after the fire in the Gudvanga tunnel. Photo: the AIBN

1.2 The road users' experience of the fire and the evacuation

According to the NPRA's traffic counts, there were a total of 58 vehicles inside the Gudvanga tunnel at 11:58 – 43 heading towards Aurland and 15 heading towards Gudvangen. Immediately before the tunnel was closed, another 18 vehicles had entered from the Gudvangen side. The AIBN has no overview of the owners or occupants of the vehicles, and has therefore focused its investigation on the road users who did not get out and were trapped in the smoke inside the tunnel.

Neither the police nor the fire or medical services logged the exact number of road users or any exact times during the evacuation of the tunnel. Based on the information received, 67 road users can be accounted for in the tunnel, of which 47 left the tunnel on the Aurland side while 20 came out on the Gudvangen side.

Several road users who placed emergency calls to the emergency services' communication centres in Sogn og Fjordane (the fire, ambulance and police services) described a critical situation for people in the smoke-filled tunnel.

The AIBN has used the services of SINTEF Technology and Society in order to get a better overview of the situation for those road users who were trapped in the smoke. SINTEF conducted interviews/spoke with representatives of 57 of the 67 people who had to be evacuated.

Summaries of the content of the emergency calls made to the emergency communication centres and the SINTEF report are provided in sections 1.2.1 and 1.2.2 below.

1.2.1 Emergency calls from road users

During the period 12:00–13:20, the various emergency communication centres received several telephone calls and emergency calls from road users inside the Gudvanga tunnel.

110SF's log mentions one specific caller (who reported the fire at 12:00) and states that many calls were received from the tunnel during the time that followed. The police logged a total of four callers.

The first emergency call registered by AMK Førde at 12:16 was made by a road user in the tunnel, and concerned the rapid build-up of smoke. The caller was about half-way through the tunnel together with several other cars, and described that they were unable to drive on because of the dense smoke. AMK advised them to remain inside their cars and shut off the ventilation.

The first emergency call registered by the police was received at 12:23. The caller was a German driver accompanied by four passengers, including children. The police operator remaining in contact with this driver until 12:39. The car was travelling from Gudvangen towards Aurland/Flåm. At the request of 110SF, the car had managed to turn around and head back towards Gudvangen, but ended up colliding and was unable to drive on.

The next emergency call from a road user was logged by AMK at 12:24. The caller had trouble breathing, had collided with the tunnel wall and was unable to get anywhere.

At 12:33, the police received an emergency call from a French couple with two children who were trying to leave the tunnel on foot, but had lost their bearings.

Between 12:34 and 13:39, the police were in continuous contact with a Norwegian driver inside the tunnel who had two children in the car. This caller managed to turn the car in the direction of Gudvangen and tried to drive on. The caller informed the police that around 30 people could be seen walking on foot inside the tunnel.

Between 12:38 and 12:39, AMK received another two similar emergency calls.

At 12:46, VTS received its first call from a road user via an emergency phone inside the tunnel.

At 12:53, the police received an emergency call from a caller who was walking along the tunnel wall towards the Gudvangen exit together with a seven-year-old child.

At 12:56, AMK received a call that 24 Chinese tourists had left a tour coach and were walking in the tunnel in the direction of Gudvangen. AMK informed the caller that the fire services were on their way from both ends of the tunnel.

The last call (13:20) to the police came from one of the first cars that had managed to turn and exit the tunnel.

1.2.2 The road users' experience of the time spent in and the evacuation of the Gudvanga tunnel

On assignment for the AIBN, SINTEF Technology and Society has collected information from representatives of 57 of the 67 people who remained inside the tunnel and had to evacuate when they were trapped in the smoke. The information was obtained through conversations, telephone interviews and written feedback. In connection with the assignment, the same framework conditions and the same duty of confidentiality applied to SINTEF's representatives as to the AIBN's own employees in connection with investigations. The assignment was carried out in close dialogue with the AIBN.

This section is based on excerpts from the SINTEF report. A complete description of the road users' experiences is provided in the SINTEF report (Appendix C).

Based on the interviews, the road users' experiences can be divided into three separate periods (highlighted in green, yellow and red in Figure 4). They consist of periods in which the road users

- did not feel that they were in danger
- felt anxious and uncertain
- felt that they were in danger / feared for their lives

These periods can in turn be divided into five phases that describe the road users' experiences. This is illustrated in the diagram in Figure 4.

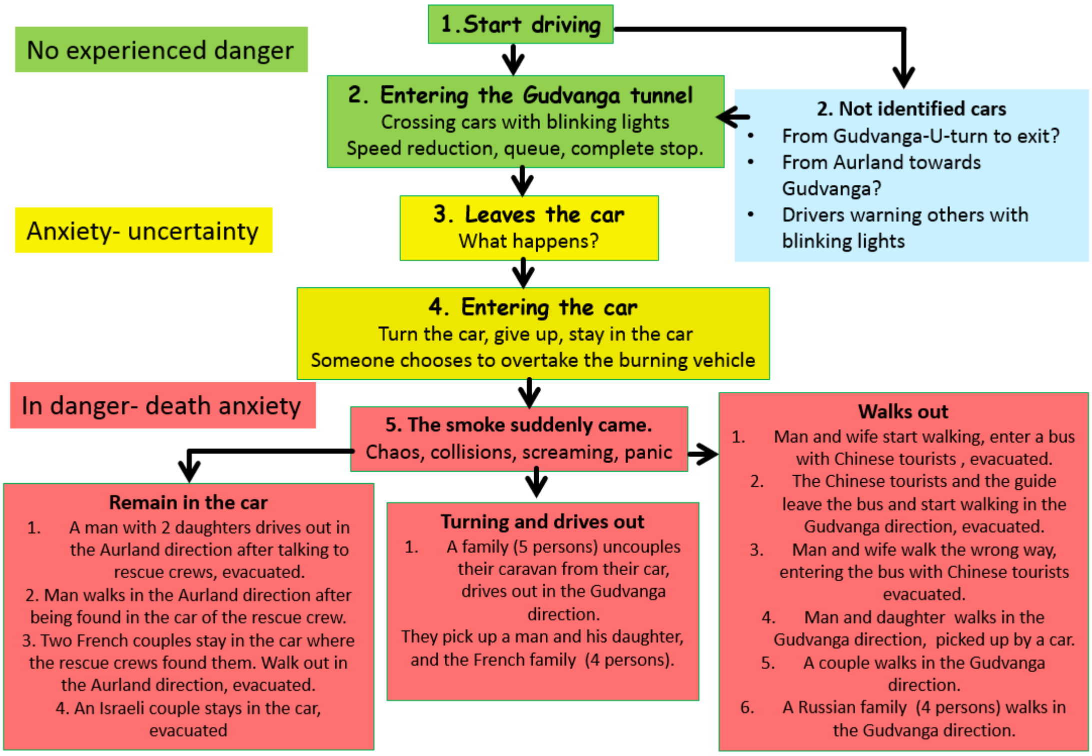


Figure 4: Presentation of the experience periods and most important phases in the road users' behaviour during the fire in the Gudvanga tunnel. Source: SINTEF

Both Norwegian and foreign road users have provided good descriptions of their understanding of the situation during the different phases.

Phases 1 and 2 ('green' period) – the road users did not feel that they were in danger

Several road users were puzzled by the fact that oncoming cars were flashing their lights. Some oncoming cars had their hazard warning lights turned on. The road users gradually noticed that the cars in front were slowing down before coming to a complete stop. They assumed that it was a temporary stop do to the traffic situation. Some of the cars in the queue started to turn and exit the tunnel in the direction from which they had come. At this time, the road users inside the tunnel were not worried at all. Some of the foreign tourists discussed the level of danger associated with long tunnels, but they expected the safety level to be in accordance with European standards.

Phases 3 and 4 ('yellow' period) – the road users felt anxious

The road users started to feel anxious when they understood that something out of the ordinary was going on. The people in the rearmost vehicles left their cars to check what was going on, but none of them could see what had happened. Those who were closest to the heavy goods vehicle saw that it was on fire. Some of them overtook the burning vehicle, while others tried to turn their cars around and head back to Gudvangen. Several of the cars in the queue were towing a trailer or caravan. They found it difficult to turn around or uncouple the trailers. After a while some loud booms were heard, probably from the heavy goods vehicle's tyres exploding due to the heat. This caused more cars to try to turn and drive back the way they had come. Chaos started to develop as most people understood that the situation was getting serious and that it might be difficult to get out of the tunnel.

Phase 5 ('red' period) – felt that they were in danger

The smoke came suddenly, reducing visibility and making it difficult for people to get their bearings. One observer said that '*it was as if the smoke had been let out of a bag, almost like an avalanche*'. At this point, chaos broke out, with cars crashing into each other and the tunnel walls and people shouting and screaming. Many described the situation as one of fear, panic and complete chaos. As the dense smoke built up in the tunnel, some chose to remain in their cars, while others chose to leave their cars to make their way back towards Gudvangen. Those who left their cars used one hand to fumble along the tunnel wall while holding a piece of cloth in front of their nose and mouth with the other. They zig-zagged along due to being disoriented or having completely lost their bearings. They sustained cuts and bruises from the irregular tunnel wall and tripped on the uneven hard shoulder.

They all perceived the situation as very dramatic and used the following terms to describe it:

> *'we did not think we would get out of this alive', 'I feared for my life, but did not panic, and held onto my daughter's hand the whole time', 'there was not enough air and we feared that we would not survive', 'became calmer after a while, but doubted that we would survive', 'we thought our days were numbered', 'we were worn out, supressed our fear and focused on getting out', ' we thought we were doomed, but we got back up on our feet and continued', 'became harder and harder to breathe and we worried that we would not get out alive'.*

One father led his family along with the rest following hand in hand. The father used one hand to feel his way along the tunnel wall while carrying a rucksack in the other. He had several harsh encounters with the tunnel wall. Once, the impact was so hard that he became concussed, threw up, became confused and started to walk in the wrong direction.

One foreign family[3] with three children chose to leave their car to evacuate on foot. Just after they left their car, two of the children (13 and 4 years old) disappeared in the smoke, and their mother and father were unable to find them. The parents placed their third child (10 years old) between them and started walking in the direction of Gudvangen. After walking for just over one and a half hours, and covering a distance of approximately 8 km in conditions of minimal visibility and dense smoke, they came out of the tunnel in Gudvangen. They were covered in soot and completely exhausted. At the time, they did not know the whereabouts of their two other children or how they had fared. They were eventually informed that the children had come out on the Aurland side of the tunnel and were being looked after at Lærdal Hospital.

Many expressed that they had expected to encounter rescue personnel at an earlier stage rather than when they were almost at the tunnel exit. One of the Norwegian couples had spoken with a German family who were shocked by the safety conditions in the tunnel. According to their own descriptions, the majority of those who were trapped in the smoke suffered much stress and were left with strong impressions. Several of the foreign tourists expressed the opinion that

- evacuation rooms should be established
- international tunnel standards must be complied with
- a sufficient supply of oxygen must be available
- those who are evacuated must be assisted by rescue personnel during evacuation and received by professionals outside the tunnel.

1.3 Firefighting and rescue work

1.3.1 The emergency services' response

All the emergency services responded immediately once the fire in the heavy goods vehicle had been reported. The fire service in Aurland requested assistance from the fire services in Lærdal, Voss and Bergen immediately after being called out. Helse Førde health trust also requested assistance from Helse Bergen health trust. The emergency services call-out to the Gudvanga tunnel can be summarised as follows:

- Aurland fire service arrived at the tunnel entrance on the Aurland side with three vehicles and a crew of nine at approximately 12:25. All the vehicles and personnel proceeded straight into the tunnel and arrived at the scene of the fire at 12:30.

- The ambulance from Lærdal arrived at the tunnel entrance on the Aurland side at 12:32. They waited for clearance from the fire service to enter the tunnel.

- A police patrol car in the Lærdal tunnel received information about the fire at 12:13, activated its emergency warning devices and drove at full speed to the

[3] The information we have about this family is not described in the SINTEF report, but taken from other sources to which the AIBN has access.

Gudvanga tunnel. When they arrived at the tunnel entrance on the Aurland side, personnel from AMK had already arrived.

- An incident command centre (ICC) was established outside the tunnel entrance on the Aurland side.
- Scene command for the police and AMK were present in the ICC. There was no representative of the fire service in the ICC, as the technical Supervisor fire chose to be present at the scene of the fire and lead the response team from there, in order to ensure the safety of the emergency responders of the department working inside the tunnel.
- As Voss fire service was not alerted by 110H until 12:29, it did not arrive in Gudvangen until 13:00. Voss fire service's chief officer ordered the crew to wait outside the tunnel, as they were expected to encounter dense smoke and there was a risk that they would collide with vehicles and people on their way out of the tunnel.
- At 13:04, the first ambulance from Voss arrived in Gudvangen.
- The first smoke-diving team from Bergen fire service arrived in Gudvangen at 13:52 and prepared to enter the tunnel. The crew were ordered to hold back until the necessary equipment was in place and ready.
- The second smoke-diving team from Bergen fire service arrived in Gudvangen at 14:00.

1.3.2 Personnel and equipment

In the course of the firefighting and rescue work, the following fire service personnel and equipment were deployed.

Table 1: Overview of response personnel and equipment involved in the firefighting and rescue work

Fire service	**No. of personnel**	**Equipment**
On the Aurland side of the tunnel		
Aurland Lærdal	16 5	Tank truck, rescue vehicle, smoke-divers' vehicle, two smaller vehicles Three fire engines
On the Gudvangen side of the tunnel		
Voss Bergen	14 12	Two fire engines, one all-terrain vehicle (ATV), trailer, air bank Self-contained breathing equipment with 4-hour air supply

The firefighting and rescue work are described in more detail in the following sections.

1.3.3 Firefighting

Aurland fire service entered the tunnel with a crew of nine (chief officer, two drivers and six smoke-divers) and arrived at the site of the fire at approximately 12:30. The smoke-divers' vehicle and fire engine were reversed into the tunnel so that they could evacuate at short notice should anything unforeseen occur. They connected the water from the tanker, and three smoke divers started the work of extinguishing the fire. At the time when work to extinguish the fire began, the fuel filler pipes for both diesel tanks and combustible material in the driver's cab and on the semi-trailer were still burning. At the same time, the heat of the fire caused a lot of rock to fall from the tunnel ceiling. The fire service soon had the fire under control and, at 12:55, reported that the fire was almost extinguished.

1.3.4 Evacuation and rescue

1.3.4.1 *The fire service's response from the Aurland side*

When the heat from the heavy goods vehicle had been sufficiently reduced, three smoke divers started to move people out of the cars closest to the site of the fire. They evacuated 10–15 people, two dogs and a rabbit from the nearest cars. The fire crew then reversed the smoke divers' vehicle with three smoke divers further into the tunnel. Approximately 500 m past the scene of the fire they encountered cars that had collided with each other and/or the tunnel wall. The fire crew evacuated all the road users from these cars. They had to move five cars manually in order to proceed further into the tunnel. Visibility was described by the fire crew as being very poor (0–2 m) and exacerbated by the fact that there was no lighting in the tunnel in the area around the scene of the fire (see section 1.13.5). When passing the burnt-out heavy goods vehicle on their return to the exit, rocks fell from the tunnel ceiling at the scene of the fire, but nobody was hit.

When the tunnel was cleared by the fire service, ambulances and ambulance personnel moved in to the scene of the fire to attend to the people that the fire service had evacuated from the smoke-filled part of the tunnel. The people were transported out of the tunnel where they were attended to by medical personnel who assessed each person's condition and sent those who were in need of further treatment to hospital.

Aurland fire service reinforced its crew with four smoke divers from the rescue vehicle, procured more oxygen from the ambulances that had arrived at the incident site and were ready to reverse back into the tunnel. The smoke divers' vehicle reversed into the tunnel until it reached the part of the tunnel that had lighting. It was then turned the right way around and proceeded in the direction of Gudvangen. There was dense smoke and minimal visibility in the tunnel. Cars and lay-bys were checked for people. They were able to help one or two cars with occupants by escorting them out of the tunnel.

When the crew had proceeded 7 km into the tunnel, they were almost out of breathing air. Visibility was poor and they could not see more than 10–20 m ahead. The emergency communication system did not work at the incident site, but when they got further into the tunnel they were able to communicate with AMK Førde. The smoke diving supervisor announced that they needed more air.

After a while, a pickup from Aurland fire service and a car from Lærdal fire service arrived. The three vehicles then moved further into the tunnel. The crew found some more people approximately 7.6 km in. They were transported to the Aurland side of the tunnel in the pickup.

The smoke divers' vehicle from Aurland fire service was informed on the internal communication channel that there were around 30 people 8 km into the tunnel (these included the Chinese tourists from the tour coach). The smoke divers' vehicle drove on and encountered and picked up 25 people after approximately 8 km. The smoke was dense, but thinning out. The vehicle did not have room for the whole crew in addition to all the evacuees, so two smoke divers from Aurland fire service were left behind in the tunnel. They each carried a compressed air cylinder containing enough air for approximately 30 min. The people who were picked up in the tunnel were transported out and handed over to health personnel. The fire crew then drove back into the tunnel to see if they could find any more people and fetch the smoke divers they had left behind.

At 14:28, Aurland fire service reported that there were no more people in the tunnel. A thorough search of the tunnel confirmed that there were no further people there. When the final search had been completed, the fire service had brought out a total of 47 people to the Aurland side of the tunnel.

1.3.4.2 *The fire service's response from the Gudvangen side*

Three people from Aurland fire service's fire station in Gudvangen were the first to arrive at the tunnel entrance on the Gudvangen side. As they did not have smoke diving equipment, they waited outside the tunnel entrance pending further instructions.

Voss fire service dispatched two fire engines and a crew of 14. The drive from Voss took approximately 35 minutes, and the fire crew arrived at the incident site in Gudvangen just after 13:00. By that time, the fire in the heavy goods vehicle had been put out. Smoke divers with an ATV immediately went into the tunnel. Approximately 1 km into the tunnel, they encountered a wall of smoke and visibility became so poor that they chose to withdraw on grounds of safety. They were afraid that their vehicle would hit somebody inside the smoke-filled tunnel.

At approximately 13:25, Voss fire service's duty officer called the 110 emergency communication centre in Hordaland to report that smoke was starting to well out of the tunnel. At that time they were standing approximately 50-60 m from the tunnel entrance. The fire service crew have described to the AIBN that they felt powerless in this situation where they could not contribute to the rescue effort.

Between 13:46 and 13:58, people started to come out of the tunnel. Three groups of people on foot were the first to arrive. First came a group of three people (two adults and one child) who had become separated from two other children in the chaos inside the tunnel. They were followed by two groups of four and two people, respectively, on foot. Finally, a Volkswagen Caravelle came driving out of the tunnel with 11 people and one dog on board. This brought the total number of people who evacuated to the Gudvangen side up to 20.

At 13:52, a helicopter landed in Gudvangen, bringing smoke divers from Bergen fire service equipped with oxygen respirators for four hours use. The smoke divers encountered problems when assembling their equipment, however. Once these problems had been resolved, two smoke divers were sent into the tunnel on foot, but to no avail because of the visibility conditions in the tunnel.

At 14:00, a Sea King helicopter brought a second smoke diving team from Bergen fire service.

At 14:25, Aurland fire service arrived through the tunnel. A thorough search was then carried out to confirm that there were no road users left in the tunnel.

1.4 Emergency medical response

A total of 67 people were sent to hospital as a consequence of the fire in the tunnel. Voss Hospital received 22 patients, Lærdal Hospital received 19 patients (of whom 12 were transferred to Bergen and 5 to Førde) and Førde Hospital received 25 patients.

1.4.1 The emergency medical response from the Aurland side

A total of 47 people were evacuated to the Aurland side of the tunnel with the aid of rescue crews.

The first ambulance carrying the medical operative leader was dispatched at 12:06. The ambulance arrived at the incident site by the tunnel entrance in Aurland at 12:34 at the same time as two police cars from Lærdal. The next ambulance came from Lærdal and arrived at the incident site at approximately 12:55. At approximately 13:14, an air ambulance helicopter arrived from Førde. Two ambulances from Årdal and Sogndal, respectively, arrived later. In addition to the ambulances and ambulance helicopter, a coach and minibus were also made available to transport patients to hospital.

Once the fire was under control, two ambulances were let into the tunnel as far as the scene of the fire. The scene commander (technical supervisor fire) sent the two ambulances into the tunnel beyond the scene of the fire to pick up road users. However, the two ambulances turned back as they deemed it unsafe to enter the area without protective equipment.

Smoke divers then evacuated the road users inside cars inside the tunnel and transported them to the scene of the fire, where they were transferred to ambulances and transported out of the tunnel. Oxygen was administered to the road users who were transported out of the tunnel by ambulance before they were taken to hospital.

The condition of each patient was assessed as the road users came out of the tunnel, and those who were most in need of medical attention were sent on to the hospitals in Lærdal and Voss.

- Between 12:45 and 13:30, 13 people were evacuated from the tunnel. Nine of them were transported by coach to Lærdal Hospital, two were taken to Lærdal by ambulance, and two were sent directly to Voss Hospital by ambulance helicopter (Førde air ambulance).

- At approximately 13:30, eight people were evacuated from the tunnel. Three ambulances transported them to Lærdal Hospital.

- At 14:10, 24 Chinese tourists were evacuated. They were transferred by Sea King helicopter to Førde Hospital.

1.4.2 The emergency medical response from the Gudvangen side

When the first ambulance from Voss arrived at the incident site at Gudvangen at 13:04, the police and fire service were already there. The ambulance helicopter from Bergen arrived at approximately 13:05. Four more ambulances reached Gudvangen between 13:38 and 15:00.

Because the smoke was being ventilated in the direction of Gudvangen, the ambulance personnel did not proceed into the tunnel from this side. The emergency responders therefore witnessed the smoke that started welling out of the tunnel and the road users that made their way out of the tunnel by their own effort, on foot or by car.

The first road users that emerged from the smoke were covered in soot, apathetic and in urgent need of oxygen. The ambulance personnel immediately started to assess and treat the patients that emerged, and they were transferred to Voss Hospital by ambulance/minibus as quickly as possible. Between 13:50 and 15:10, a total of 20 patients were taken to Voss Hospital.

1.5 Leadership and communication in connection with the rescue work

The fire in the Gudvanga tunnel made great demands of leadership and coordination, as the response had to be organised from two sides. In addition, the response of three different emergency services had to be coordinated. Aurland fire service and Helse Førde health thrust were responsible for the fire and ambulance services on the Aurland side. On the Gudvangen side, Voss and Bergen fire services were controlled by 110SF/Aurland fire service, while the ambulance personnel received their instructions from Helse Bergen health trust.

1.5.1 Leadership

Aurland fire service arrived at the incident site before the police. The chief officer of Aurland fire service, who was also the officer in command of the fire service at the time, therefore assumed command at the incident site until the police arrived. He chose to accompany the crew to the scene of the fire and, in addition to being the officer in command of the fire service he also took over the function as technical supervisor fire from the response team leader (chief duty officer), who was appointed SCBA leader.

When the police arrived (just after 12:30), they took command at the incident site and established an incident command centre (ICC) outside the tunnel entrance on the Aurland side. The police and medical health manager were present in the ICC and coordinated the response of their respective services from there.

The officer in command of the fire service chose to remain at the scene of the fire in order to ensure the safety of the firefighters working inside the tunnel. He acted both as response team leader and as the chief officer (technical supervisor fire) with strategic responsibility. This posed certain challenges, as all communication with those in command of the other rescue services and other fire services had to take place by mobile phone because the radio communication network was not working in the tunnel. The chief fire officer/response team leader made a total of 64 calls during the incident.

As the incident developed, the ambulance crew who were the first to arrive on the Gudvangen side realised that more medical resources were needed. They requested additional resources from AMK Bergen, under whose instructions they were operating. Since AMK Førde, which managed the response effort in the Gudvanga tunnel, had not informed AMK Bergen of the need for more resources, the request was denied. After having spoken with the response personnel on the Gudvangen side several more times, AMK Bergen chose to send more resources even though they had not received a request from AMK Førde.

The ambulance operative leader on the Aurland side wore a vest with the text 'Leder Ambulanse'. Neither the police nor the fire service's operational commanders on the Aurland side wore vests identifying them as operative leaders for their respective services' response efforts. All the services' operational commanders on the Gudvangen side wore vests identifying them as operative leaders.

1.5.2 Communication

As the communication cable running along the tunnel ceiling was destroyed by fire, the communication channel between the incident site and the personnel inside and outside the tunnel on the Aurland side did not work (see section 1.13.6). The chief fire officer therefore communicated with 110 Sogn og Fjordane, and eventually also with the police and the medical operative leader, using his mobile phone.

Already on arrival at the tunnel entrance, the ambulance personnel realised that the communication network had broken down (i.e. channel 37 Aurland). The medical operative leader was in contact with AMK and tried to test the radio communication system, but it did not work. The ambulance personnel and AMK therefore agreed to communicate by mobile phone. The breakdown of the radio communication system also meant that AMK and the medical operations coordinator were unable to establish contact with the fire service inside the tunnel. A police officer managed to contact the fire service's chief officer/response team leader by mobile phone, however. The medical operative leader has also described that it was at times difficult to establish contact with AMK by mobile phone, and that the calls made were answered by different AMK operators.

At the incident site, the medical operative leader was able to establish radio contact with AMK on one occasion, but the information communicated on that occasion did not reach the medical resources outside the tunnel entrance because the communication system did not work there. On a few occasions, the medical operative leader therefore drove the car into the tunnel in order to pass on messages and get an overview of the situation.

In Gudvangen, the communication line between the emergency responders at the incident site and AMK was working, but, according to information received by the AIBN, it was at times difficult to establish contact and to hear what was being said.

1.6 Personal injuries

In all, 15 vehicles carrying a total of 67 people were trapped in the smoke inside the tunnel. They remained in the smoke-filled tunnel for a period of between 50 and 95 minutes before being brought out. Twenty-eight of these people had suffered smoke exposure to such an extent that they needed hospital treatment.

On assignment for the AIBN, Oslo University Hospital has studied the consequences the smoke exposure has had on the health of the 28 people who were admitted to hospital to receive treatment for their smoke inhalation injuries.

The medical assessment was carried out by two specialists in pulmonary medicine and anaesthesiology, respectively, who have broad experience of smoke inhalation injury treatment and clinical toxicology. The work was based on a systematic review of all the medical records and logs kept in connection with these people's stay in hospital. A separate questionnaire survey was also carried out afterwards to quality assure the information.

The conclusions in the report show that:

> *1. Of the road users who were treated for smoke inhalation injuries in hospital after the fire in the Gudvanga tunnel on 5 August 2013, 23 were seriously injured and 5 were very seriously injured.*
>
> *2. Soot and carbon monoxide made a major contribution to the ill health of the road users. No cyanide was found in the blood samples, nor were there any clinical indications of severe cyanide poisoning.*
>
> *3. Young age and good health were probably contributory causes why no lives were lost during the fire.*
>
> *4. The road users who suffered the most serious symptoms were those who had been outside their cars for the longest and experienced the highest degree of physical exertion in the tunnel.*
>
> *5. A longer stay in the tunnel would probably have caused at least five of the road users to be in immediate danger of dying.*

No records are available of pre-hospital treatment of the remaining 39 of the 67 road users who were trapped in the smoke in the tunnel. The report concludes that it must be assumed that a significant number of these people sustained minor injuries.

The report also contains a schematic overview of the scope of injuries in relation to the manner of evacuation. The overview indicates that those who evacuated the whole distance on foot sustained more serious injuries than those who remained in their cars for some or all of the time. A copy of the schematic overview is provided in Figure 5.

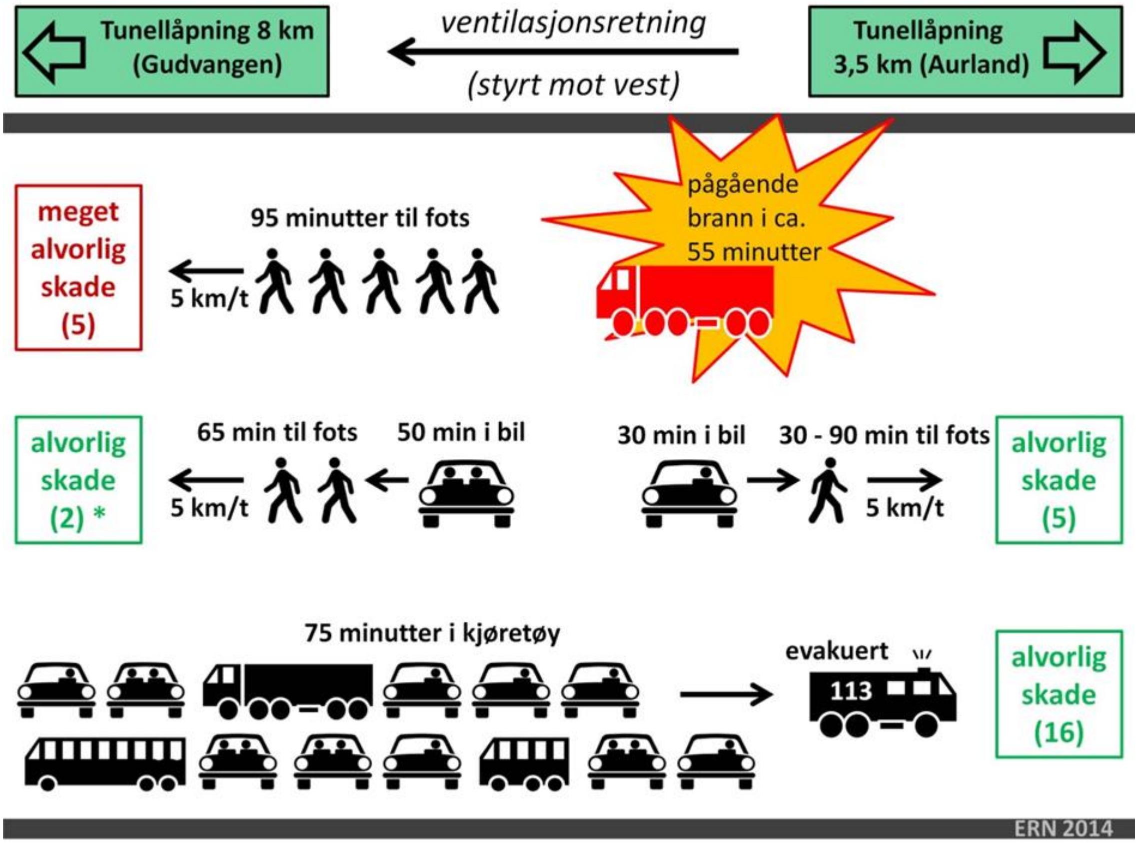


Figure 5: The figure shows the severity of injuries, manner of evacuation and how much time each person spent in the smoke-filled tunnel. Source: Oslo University Hospital

The report concluded that five people were very seriously injured and 23 people were seriously injured (see Table 2).

Table 2: Overview of the severity of injuries for the 28 people who were admitted to hospital after the fire in the Gudvanga tunnel. Source: Oslo University Hospital

Injuries	Number
Minor	None
Serious injuries	23 people
Very serious injuries	5 people

According to the report, the assessment of the severity of injuries was based on the definitions used in Statistics Norway's injury statistics for road traffic accidents. On that basis, according to Statistics Norway's definitions, a total of 28 people were seriously injured in connection with the fire in the Gudvanga tunnel.

The report from Oslo University Hospital is enclosed as Appendix D.

1.7 Damage to vehicles

The fire in the heavy goods vehicle started in the engine compartment on the left side of the engine. It developed rapidly and spread to the whole vehicle in the course of approximately 20 minutes. When the fire service had extinguished the fire after approximately 55 minutes, the whole vehicle was burnt out. Only incombustible materials remained. Figure 6 shows the heavy goods vehicle after it had been pulled out of the tunnel.

Figure 6: The heavy goods vehicle after it had been pulled out of the tunnel. Photo: the NPRA

The other vehicles that were left in the tunnel as the fire developed were covered in soot. Some of them also had internal soot and smoke damage. Several drivers tried to evacuate by driving out of the tunnel. Due to minimal visibility, several cars hit the tunnel wall, which caused extensive external damage to some of them.


Figure 7: One of 16 vehicles that were left in the tunnel, approximately 7.8 km from the tunnel entrance at Gudvangen. Photo: the AIBN

1.8 Other damage and consequences of the fire

1.8.1 Damage to the tunnel structure

All technical equipment and cables in the immediate vicinity of the scene of the fire were destroyed. The rock above the scene of the fire was without protection, apart from a mesh that was bolted to parts of the tunnel ceiling. The heat caused the rock to crack and pieces of rock to fall down.

There was extensive smoke and soot damage to the part of the tunnel that lies west of the scene of the fire (on the Gudvangen side). Cleaning the tunnel in connection with the clearance work represented a challenge, as it was necessary to use chemicals to dissolve the soot, and the wastewater had to be treated as special waste.

As a result of the cleaning work, a lot of moisture penetrated to the technical equipment. This meant that more than just the equipment and installations that were damaged in the fire had to be replaced.

1.8.2 Consequences for traffic

The Gudvanga tunnel was closed for all traffic as a result of the fire. The closing of the tunnel was posted on free-text information signs on the E16 road at Trengereid, Rv 7/E16 at Hønefoss and Rv 7 at Gol. In addition, signs were put up along the Rv 5 road in Sogndal, Kaupanger and Håbakken, Rv 7 at Hol and E 16 at Voss and Vinje. The first signs that were posted were of a temporary nature and contained somewhat incomplete information. The situation was improved when the NPRA produced new and better signs.

Immediately after the fire, the NPRA estimated that the tunnel would remain closed for approximately one week, but it eventually became clear that the tunnel would remained closed for close to one month. As a consequence of the tunnel closing, the traffic between Eastern and Western Norway was diverted to Rv7 across the Hardangervidda mountain plateau and E134 via Haukeli. Traffic between the Bergen area and parts of Sogn used the Rv 13 road over the Vikafjellet mountain.

Several ferry services in the area experienced a great increase in the number of passengers as a consequence of the traffic diversions. For example, the Bruravik–Brimnes ferry service experienced a 38% increase in traffic compared with the previous year (during the period 5–17 August), and the Vangsnes–Hella–Dragsvik ferry service experienced a 57% increase during the period 5–30 August compared with the same period in 2012.

The closing of the tunnel was problematic for commuters and school children as well as the tourist industry. Aurland municipality set up a boat service to transport people between Gudvangen and Aurland, and on 19 August the NPRA put an express boat into service between Flåm and Gudvangen to help with the tourist traffic.

As from 23 August, the tunnel was opened for convoys of buses without passengers and vehicles of more than 7.5 tonnes four times a day. While bus passengers etc. were transferred by express boat. When the lighting installations in the tunnel had been repaired, all types of vehicles were permitted to drive in convoys from 30 August.

The tunnel was opened for all traffic on 5 September 2013, one month after the fire.

1.9 Incident site

The burning heavy goods vehicle stopped in the eastbound lane (towards Aurland) approximately 2 880 m before the tunnel exit on the Aurland side. The heavy goods vehicle had covered a distance of approximately 8 500 m inside the Gudvanga tunnel before it stopped. The driver pulled in on the right-hand side before stopping.

Reference is made to the more detailed description of injuries to road users and damage to vehicles and infrastructure in sections 1.6, 1.7 and 1.8.

The position of the heavy goods vehicle that caught fire and the other vehicles is shown in Figure 8.

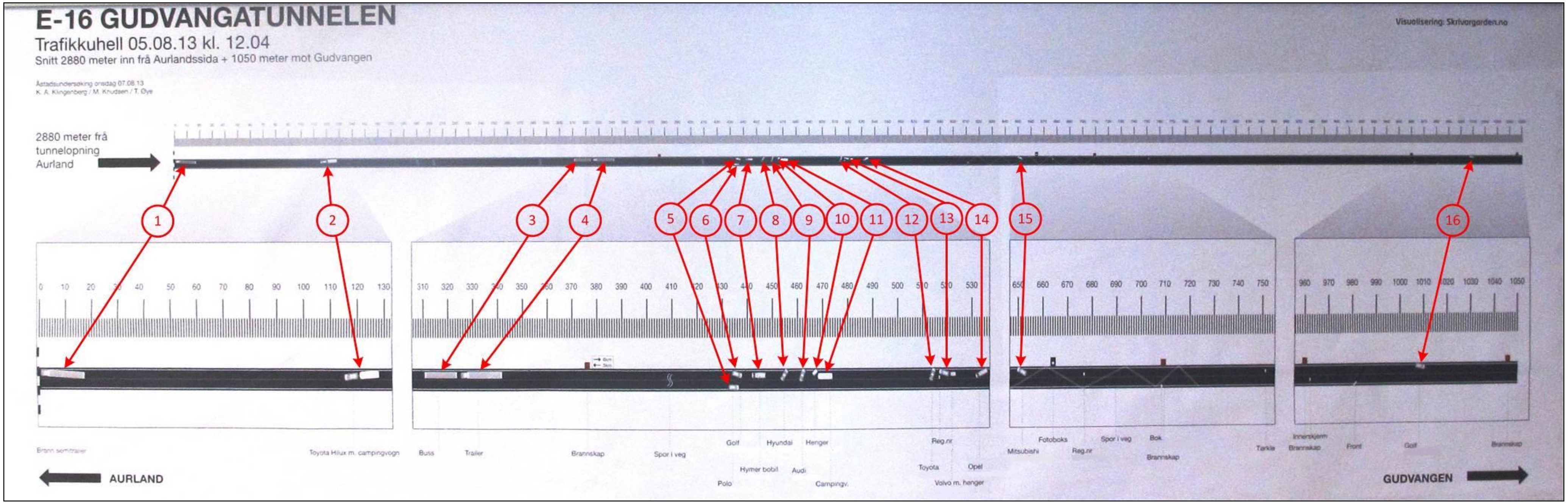


Figure 8: The position of the heavy goods vehicle that caught fire and the other vehicles that were trapped in the smoke inside the Gudvanga tunnel. Source: Skrivargården

Table 3: Supplementary details to the information provided in Figure 8. Source: the AIBN

Position	Vehicle type/nationality		Driver	Passengers	
1	The heavy goods vehicle that caught fire	(Polish tractor and Swedish semi-trailer)	Polish		
2	Van with caravan	(Norwegian)	Norwegian	One Norwegian national	
3	Tour coach	(Slovakian)	Slovakian	24 Chinese tourists	
4	Heavy goods vehicle	(Swedish)	Polish		
5	Passenger car	(Norwegian hire car)	French	Three French nationals	
6	Passenger car	(Norwegian hire car)	Israeli	One Israeli national	
7	Camper van	(German)	German	Four German nationals	(one adult and three children)
8	Passenger car	(Norwegian hire car)	French	Three French nationals	
9	Passenger car	(Norwegian)	Estonian	One Norwegian national	
10	Trailer that had been towed by the car in position 16 – German passenger car				
11	Caravan – had been towed by a Norwegian passenger car that returned towards Gudvangen		Norwegian	Four people	
12	Passenger car	(Norwegian)	Norwegian		
13	Passenger car with trailer	(Norwegian)	Norwegian	One Norwegian child	
14	Van	(Norwegian)	Norwegian	One Norwegian national	
15	Passenger car	(Russian)	Russian	Three Russian nationals	(one adult and two children)
16	Passenger car	(German)	German	Three German nationals	
-	Unknown – drove out of the tunnel unassisted after two hours		Norwegian	Two Norwegian nationals	

1.10 The driver of the heavy goods vehicle

As the driver of the heavy goods vehicle did not want to speak with the AIBN, all our information about him is taken from the statement he made to the police.

The driver of the vehicle was a Polish national, a 28-year-old man holding a class BECE driving licence. He had been issued a class CE licence in November 2006, and had worked as a driver since he obtained his heavy goods vehicle licence. He had been driving to the Scandinavian countries throughout that period. He had had different employers, but had worked for the Polish company KAJ for the past two months.

His most recent journey before the fire broke out started in Malmø at approximately 12:00 on Saturday 3 August 2013, and he arrived in Bergen in the early hours of Monday 5 August 2013. After unloading at Hansa brewery in Bergen, he started the return journey from Bergen to Malmø at approximately 9:30.

1.11 Vehicle and load

1.11.1 <u>The heavy goods vehicle</u>

The heavy goods vehicle consisted of a Polish-registered tractor and a Swedish-registered semi-trailer. It was on an assignment for DSV Road Sweden and was travelling empty to Malmø after delivering its load in Bergen.

1.11.1.1 *Tractor – Renault Magnum 440.19T 4x2*

The tractor was a 2002 model Renault Magnum 440.19T 4x2. It was registered as belonging to the Polish transport company P.H.U. KAJ. The company had used the vehicle since 2007. It bought the vehicle in 2011, after having leased it since 2007.

According to the information given to the police by the owner of the company, the vehicle underwent service and maintenance every 50 000 km. In addition, necessary repairs were carried out as the need arose. The tractor had most recently been approved in an official inspection in Poland (corresponding to the Norwegian periodic roadworthiness test) on 29 March 2013.

1.11.1.2 *Semi-trailer – Krone Profi Liner*

The semi-trailer was a 2009 model Krone Profi Liner. It had three axles and a registered gross vehicle weight of 41 000 kg. The semi-trailer was owned by PNO Sverige Aktiebolag, but it was used by DSV Road Sweden.

1.11.2 <u>Inspection of the heavy goods vehicle after the fire</u>

After the fire, the heavy goods vehicle was inspected by the AIBN together with the National Criminal Investigation Service (Kripos).

The examination of the vehicle showed that the greatest heat had been on the left side of the engine, where no combustible material remained. Most of the aluminium parts in this area had partially melted or burnt up, as had the rubber gaskets for the wheel suspensions, shock absorbers and the left brackets supporting the driver's cabin. There were indications that less heat had developed on the right-hand side of the engine, as the aluminium parts there had not melted. On the right-hand side, the gaskets for the shock absorbers, wheel suspension and mounting brackets for the driver's cabin were also intact.

During the examination to determine the possible cause of the fire, two wear holes were found in the braided protection around the pressure hose feeding oil to the turbo. This line leads from the oil cooler to the turbo and passes through the gap between the intake manifold and the engine block, see Figure 9.

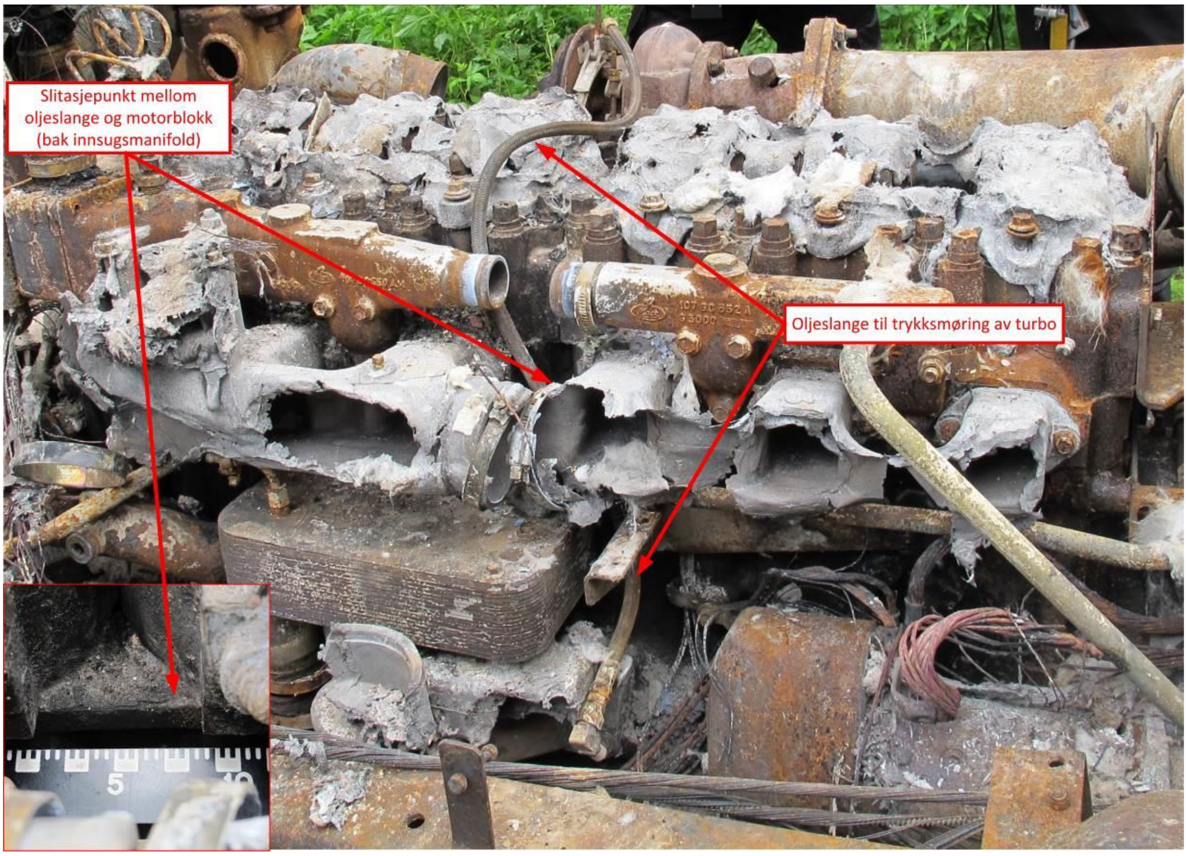


Figure 9: The pressure hose between the oil cooler and the turbo. The inset photo shows the point on the engine block against which the hose had rubbed. Photo: the AIBN

One of the holes in the steel braiding was approximately 10 mm long and 5 mm wide. The other hole was approximately 4 mm long and 1 mm wide. Between these holes, the steel braiding had been partially worn away, but there were no holes in the braiding in this area. The whole length of hose inside the braiding had burnt up.

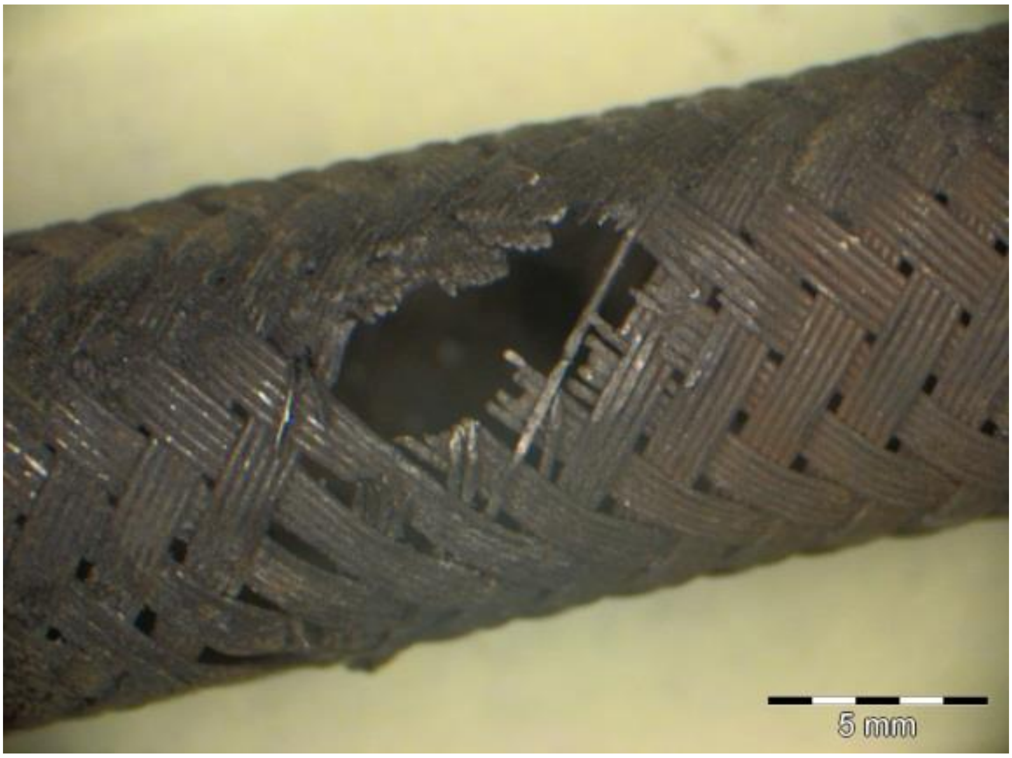


Figure 10: Close-up photo of a wear hole in the braided protection. Photo: the police

The following additional findings were made in the engine compartment:

- Traces of short-circuiting in several of the vehicle's electrical cables
- A hole of approximately 1x1 cm in the throttle housing for the engine brake (on the turbine side of the turbo). The hole was on the side facing the engine.
- Melting damage to the rear part of the dynamo with diode bridge and connections
- When the engine and turbo was removed, moveable parts were not found to have abnormal wear and tear
- The extensive fire damage made it impossible to determine whether there had been any leakage of cooling fluid
- A test of the engine's remaining lubricating oil did not show any signs of cooling fluid in the engine oil

No technical examination was carried out of other parts of the heavy goods vehicle, as it was completely burnt out and deformed due to the heat of the fire.

1.11.3 Calculation of the fire effect on the heavy goods vehicle and load

On assignment for the AIBN, SINTEF NBL AS calculated the fire effect on the heavy goods vehicle that burnt in the Gudvanga tunnel on 5 August 2013 (see Appendix E).

The basis for the calculations was a two-axle tractor of the type Renault Magnum 440.19 T 4x2 towed by a three-axle Krone Profi Liner semi-trailer. The calculations were based on a heavy goods vehicle without load. All combustible material in the heavy goods vehicle was taken into account in the calculations.

There is uncertainty concerning the amount of fuel in the tractor's tanks when the fire broke out. Assuming that both tanks were full (1 200 l) when the vehicle left Malmø, the AIBN has calculated the remaining amount of diesel to around 600 litres. As both tanks were intact after the fire, most of the diesel that burnt must have been burnt off through the fuel fill pipes. However, SINTEF's calculations show that there is a limit to the amount of diesel that the fire could have consumed through the two fill pipes in the course of the 55 minutes that the fire lasted, and believes that the amount might have been around 200 litres.

Based on the above data, SINTEF NBL has estimated the fire effect to be around 25 MW if 200 litres of diesel burnt up. If, on the other hand, the amount of burnt-off diesel was nearer to 600 litres, the estimated fire effect would be 35–45 MW.

1.11.4 Other vehicles

As the other vehicles that were left inside the tunnel after the fire were not involved in the triggering incident (the fire), the AIBN has chosen not to conduct any further examination of those vehicles.

1.12 Weather and driving conditions

The weather in the area between Voss and Gudvangen was cloudy with some rain at the time that the Polish heavy goods vehicle drove into the Gudvanga tunnel. The asphalt road surface in the area was wet.

1.13 The Gudvanga tunnel – design, traffic and safety installations

The Gudvanga tunnel is a single bore tunnel on the E16 between Aurland and Voss. The tunnel is 11 428 m long and was first opened for traffic on 17 December 1991. The tunnel rises at a gradient of 3.5% from Gudvangen towards Aurland. There is a height difference of approximately 300 metres between Gudvangen and the highest point of the tunnel, which is located approximately 300 metres to the west of the tunnel entrance at Langhuso (on the Aurland side). The speed limit at the time of the incident was 80 km/h. Automatic traffic control has been established, with two cameras in each direction.

According to the emergency response plan dated 5 July 2006, the tunnel had safety installations as shown in Figure 11. The tunnel's safety installations are in accordance with the requirements for class B tunnels as described in the 2002 edition of NPRA Manual 021. As no particular requirements had been specified for safety installations at the time when the tunnel was first opened, the NPRA had chosen to equip it in accordance with the requirements that applied to class B tunnels. The reason for this was that these were the requirements that most closely resembled the requirements that applied to similar tunnels at the time when the most recent version of the emergency response plan for the Gudvanga tunnel was prepared, see Figure 12.

1.5 Tryggleiksutrusting

I oppstillinga/oversikta nedanfor har vi lagt handbok 021 *Vegtunneler - normal juni 2002*, til grunn.

Gudvangatunnelen - Tunnelklasse B.

Nr.:	UTRUSTING: ● Krav ○ Vurderast	Tunnel-klasse B	Krav:	Bygt/ Installert:	Kommentar: (Kjeding i retning frå Aurland mot Voss)
1	Havarinisjar	●	Normalavstand 500m ± 50 m	ja	I alt 18 stk havarinisjer. Avstand frå munning til havarinisjer/avstand mellom bygde havarinisjer (m): 900, 400, 500, 500, 700, 400, 700, 1000, 600, 400, 600, 500, 1000, 500, 500, 400, 500, 600, 728.
2	Snunisjer	●	Normalavstand 2000 m ± 100 m.	ja	I alt 6 stk. snunisjer. Avstand frå munning til snunisjer/avstand mellom bygde snunisjer (m): 1300, 2100, 2300, 1500, 1500, 1400, 1328.
3	Straumforsyning	●		ja	Aurland Energiverk
4	Belysning	●		ja	450 stk. 35 W lågtrykksnatrium lamper c/c om lag 25 m. Inngangs-/overgangssoner har ekstra belysning.
5	Ventilasjon	●		ja	90 stk. vifter à 21 kW. Plasserte i 4 stk. grupper à 20 stk. vifter, og 1 gruppe à 10 stk. vifter.
6	Avbrotsfri straum-forsyning	●		ja	For naudskåp, kommunikasjonsanlegg og lys i havarinisjer.
7	Naudtelefonar	●	Normalavstand 500 m. I tillegg 1 stk. utanfor tunnelmunningane.	ja	I alt 20 stk. naudtelefonar. Avstand frå munning til telefon/avstand mellom telefonar (m): 367, 590, 480, 500, 470, 650, 520, 640, 1020, 610, 480, 580, 470, 520, 520, 520, 450, 520, 460, 620, 441.
8	Brannsløkkings-apparat	●	Normalavstand 250 m. I tillegg 1 stk. utanfor tunnelmunningane.	ja	I alt 42 stk. apparat. Avstand frå munning til apparat/avstand mellom apparat (m): 117, 250, 290, 300, 240, 240, 250, 250, 250, 220, 330, 320, 250, 270, 340, 300, 300, 470, 250, 320, 290, 230, 250,. 250, 330, 250, 220, 250, 270, 250, 270, 270, 250, 220, 230, 270, 250, 210, 250, 290, 330, 230, 211.
9	Sløkkevatn	●		nei	Tankvogn.
10	Raudt stoppblinksignal	●		ja	
11	Fjernstyrte bommar for stenging	○		nei	Ikkje i bruk i Sogn
12	Variable skilt	○		nei	
13	Kommunikasjons- og kringkastingsanlegg	●		ja	
14	Mobiltelefondekning i tunnelen	○		ja	Telenor og Netcom
15	Høgdehinder (avvisar)	●		ja	Ved vestlege tunnelportal.

Gjeld punkt 9: *Kompenserande tiltak*: Det er ytt tilskot til Aurland kommune til kjøp av tankvogn med tilstrekkeleg kapasitet, 6 m3.

Gjeld punkt 15: *Kompenserande tiltak*: Ingen.
Retting av avvik: Etablering av høgdehinder ved austlege portal vil bli utført.

Andre opplysningar: Udekka PE-skum: Totalt om lag 151 m2.

Figure 11: This table is from the emergency response plan for the Gudvanga tunnel, and it shows the safety installations that were in place before the fire. The tunnel was equipped with 92 fans (not 90) and 21 emergency telephones (not 20). The PE foam was covered with spray concrete in 2012. Source: the NPRA – Emergency response plan for the Gudvanga tunnel dated 5 July 2006

1.13.1 Tunnel class and tunnel cross-section

The Gudvanga tunnel was planned and constructed in accordance with the regulations and guidelines in force at the time. The tunnel has a 'T8' cross-section and, according to the NPRA's Western Region, it was planned with a 'type C' cross-section as defined in the old standard for road design adopted in 1981. That standard did not include any requirements for emergency lay-bys or U-turn facilities. The work on the NPRA's manual 021 on road tunnels (1992) started before the Gudvanga tunnel was completed, and some emergency lay-bys and six U-turn facilities were therefore blasted more or less in accordance with the requirements set out in the new manual.

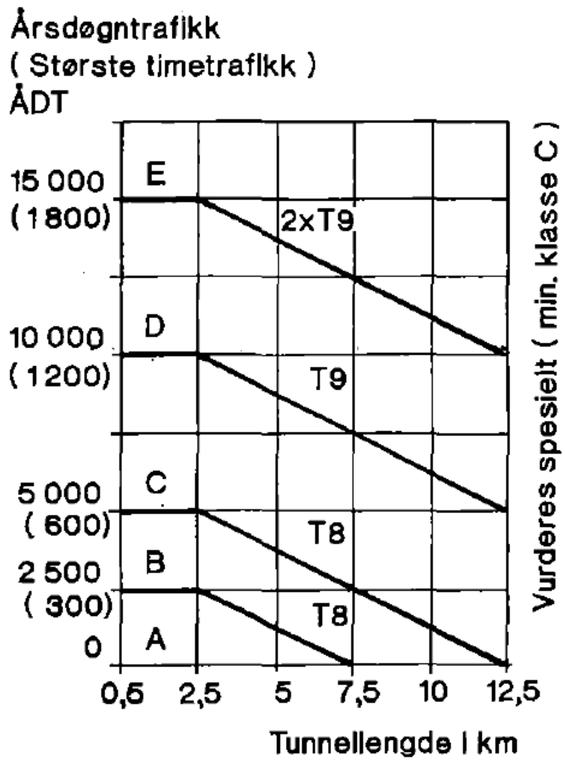


Figure 12: Tunnel classes. Source: NPRA Manual 021 – Road Tunnels (1992)

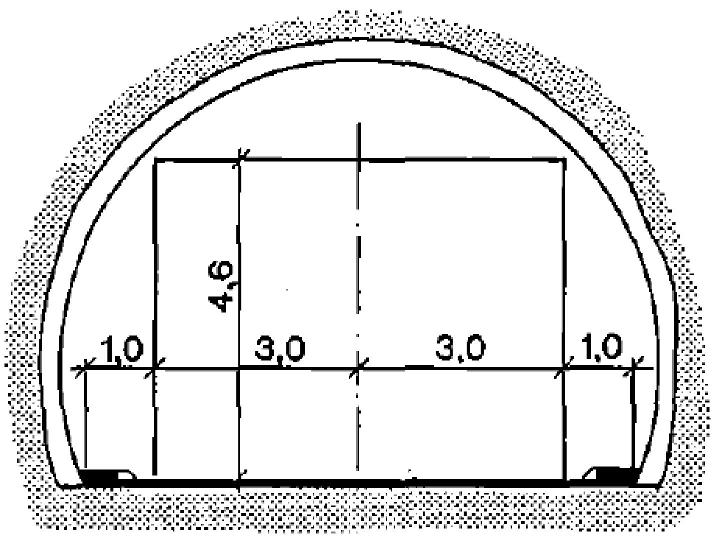


Figure 13: 'T8' tunnel cross section. Source: NPRA Manual 021 – Road Tunnels (1992)

1.13.2 Tunnel structure

Parts of the tunnel (151 m^2 in total) are covered in PE (polyethylene) foam. In 2012, spray concrete was applied to cover the foam. There was no PE foam at the scene of the fire, but the rock above the traffic lane was secured with a mesh and bolts.

1.13.3 Evacuation routes and evacuation lights

It is assumed that evacuation will take place through the tunnel exits on the Gudvangen and Aurland sides, as there are no other evacuation routes from the tunnel. The tunnel had no evacuation lights, but information signs showing the distance to the respective tunnel exits were posted on all the emergency telephone cabinets.

1.13.4 Ventilation

1.13.4.1 *Technical description*

The Gudvanga tunnel has longitudinal ventilation with air intake and discharge through each end of the tunnel. Due to the height difference in the tunnel, the natural draught varies greatly with the time of day and the season, but on the day of the incident, the draught flowed from Gudvangen towards Aurland.

There are a total of 92 fans in the tunnel. They are installed in five groups. The 60 fans closest to Gudvangen have 12 kW motors and push the air with equal thrust in both directions. The 32 fans closest to the Aurland side of the tunnel have 22 kW motors, and their thrust is greater in the direction of Gudvangen. When the fans are reversed to move the air towards Aurland, the thrust is almost halved. Eight of the 92 fans had been out of order all through 2013. Because the ventilation system is old and worn, between five and ten fans are regularly taken down to undergo repairs. Based on experience, the NPRA has found that at least 65 fans must be intact for the system to be able to provide fire ventilation at a rate of 1–2 m/sec as described in the emergency response plan that applied at the time of the incident. If fewer than 65 fans are intact, the tunnel is closed.

In the day-to-day operations, the ventilation level is regulated automatically in accordance with NO_2 levels measured at five measurement points along the tunnel bore. If high NO_2 levels are registered, the fans will start automatically and ventilate the tunnel towards the end with the highest concentration.

Originally, the fans were dimensioned for an annual average daily traffic (AADT) of 1 000 vehicles/day and a maximum hourly traffic of 250 vehicles/hour. The ventilation system was designed to control a fire of 5 MW, but has the capacity to control approximately 20 MW. The fan capacity required to achieve a fire ventilation rate of 1–2 m/sec will vary according to the climatic conditions and traffic volume. At the time of the incident, 26 fans were sufficient to achieve this air velocity.

Noise from the fans makes it difficult to communicate verbally via the emergency telephones in the tunnel. Approximately ten yeas ago, it was decided that the fans should be programmed to stop automatically when the doors to a telephone or fire cabinet are opened. This decision was made based on experience of a similar system in the Lærdal tunnel. The system was configured so that the effect of other fans further away would automatically increase to compensate for the fans that stopped when the cabinets were opened. All the fans start up again at intervals of ten seconds when the doors to the cabinets are closed. If the cabinet doors are left open, the VTS can override the stop function on the orders of the fire service.

1.13.4.2 *Use of the ventilation system in connection with the fire*

In the event of a fire in the Gudvanga tunnel, the ventilation system is normally controlled by VTS in accordance with procedures drawn up in collaboration with the fire service. If required, the fire service can instruct VTS to deviate from the procedure. The fire service can also control the ventilation system from control cabinets outside each end of the tunnel.

Before the fire started, the draught flowed towards Aurland, and the ventilation system was pushing the air in the same direction at almost full capacity (74 of 84 available fans). When VTS was notified of the fire, the ventilation system was set to fire mode, which, according to the emergency response plan that applied at the time of the incident, indicated that the air was to flow from Aurland in the direction of Gudvangen at a rate of 1–2 m/sec. According to information provided by VTS, the fire ventilation controls were programmed to produce an air flow rate of 2.5 m/sec when activated, while full fire ventilation was programmed to produce an air flow rate of 3.6 m/sec.

When the ventilation direction was reversed, 44 of the fans started blowing air towards Gudvangen, while 10 fans continued to blow air towards Aurland. These ten fans continued to blow air towards Aurland for about one and a half hours after the ventilation direction had been reversed towards Gudvangen. When the ventilation direction was reversed, the air flow rate was reduced from approximately 3 m/sec in the direction of Aurland to approximately 2 m/sec in the direction of Gudvangen. During the period between 13:00 and 13:30, the average air flow rate towards Gudvangen was 2.48 m/sec, see Figure 15.

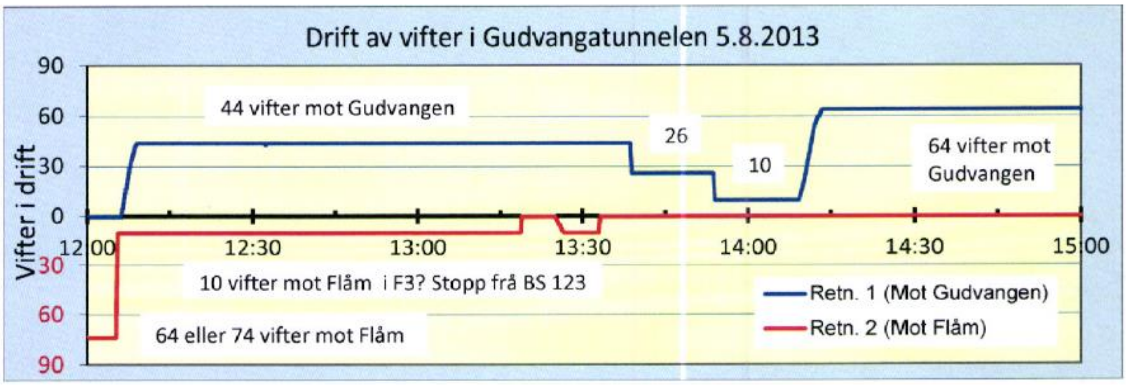


Figure 14: Operation of the fans in the Gudvanga tunnel on 5 August 2013. Source: the NPRA

Between 13:37 and 14:12, first 18 of the 44 fans stopped, and then another 16. The reason why the fans stopped was most probably that the telephone/fire cabinets were opened (see section 1.13.4.1). During a period of around 15 minutes (between 13:54 and 14:09), only 10 fans were working in the direction of Gudvangen. By that time, the 10 fans that had previously blown air towards Aurland had also stopped, see Figure 14. This meant that for a while, the air flow rate towards Gudvangen was as low as approximately 0.8 m/sec.

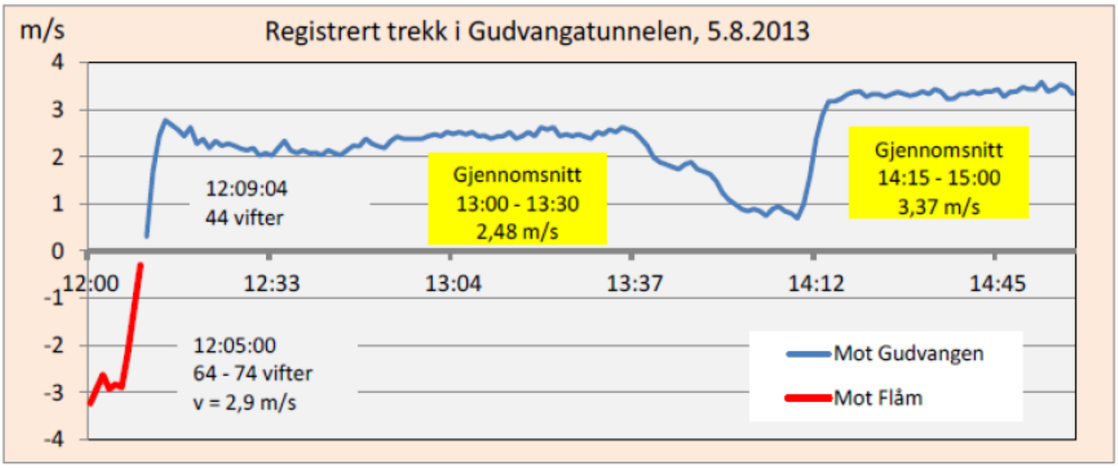


Figure 15: Registered air flow rates in the Gudvanga tunnel on 5 August 2013. Source: the NPRA

At approximately 14:09, VTS began to start the fans manually and, at 14:13, 64 fans were ventilating in the direction of Gudvangen. This brought the air flow rate up to an average of 3.37 m/sec.

1.13.5 Lighting

The tunnel is lit by 450 35 W low-pressure lamps placed at intervals of approximately 25 metres. The entrance/transition zones have additional lighting. Each of the fire cabinets have separate lighting that runs on emergency power in the event of a power failure. These lights will be lit and function as guide lights in the event of a power failure, but, according to the NPRA, they are not sufficient when there is smoke in the tunnel.

At the time of the incident, one of the lighting circuits in the tunnel was switched off due to an earth fault. This meant that a section of approximately 1 000 m, starting approximately 7 km from the entrance on the Aurland side of the tunnel, was unlit. The unlit section was marked with the traffic sign for 'other danger' with a plate underneath bearing the text 'lys mangler' ('no lights ahead').

The lighting above the scene of the fire was intact until the fire melted the cable, which caused the circuit to short and triggered the overcurrent protection. On 5 August 2013, the circuit breakers were triggered at 12:09.

1.13.6 Communication and radio communication system

1.13.6.1 *Radio installations in the tunnel*

Three radio channels have been installed in the tunnel:

- Rescue 2 (joint dual-frequency radio communication channel for all the emergency services)
- HE37 – a joint VHF channel for the medical services and the police
- PK4 – the police

The Gudvanga tunnel also provides radio coverage for the NRK P1 channel, which makes it possible to broadcasts traffic information to road users. Radio break-in messages can either be transmitted from VTS or from the control panel installed on the Gudvangen side of the tunnel. Radio break-in messages can also be transmitted from the technical room by the Flenja tunnel, located approximately 800 m from the entrance to the Gudvanga tunnel.

As described in section 1.5.2, internal communication between the rescue personnel and communication between the rescue personnel and the various operations centres was complicated by the radio communication system not functioning at the scene of the fire inside the tunnel.

The radio communication system in the Gudvanga tunnel is not based on two-way feeding of signals to radiating cable segments.[4] In this type of system, a fault in an amplifier or a broken radiating cable will mean that public announcements cannot be broadcast by radio in all or some parts of the tunnel. The emergency services' communication network will also cease to function in the same sections.

The radiating cables installed under the ceiling are very vulnerable to heat. Assessments made by the NPRA after the fire indicate that the radiating cable between the scene of the fire and the tunnel entrance on the Aurland side failed relatively soon after the fire broke out, and probably before the lighting circuit failed in the same area (at 12:09 on 5 August 2013).

The Gudvanga tunnel has a 1 400 m long mid-section of poor coverage. As several other tunnels in the Aurland district also has poor or no radio coverage, the NPRA Western Region had equipped Aurland fire service with a portable amplifier to compensate for this. The range of such equipment can vary according to where in the tunnel it is used.

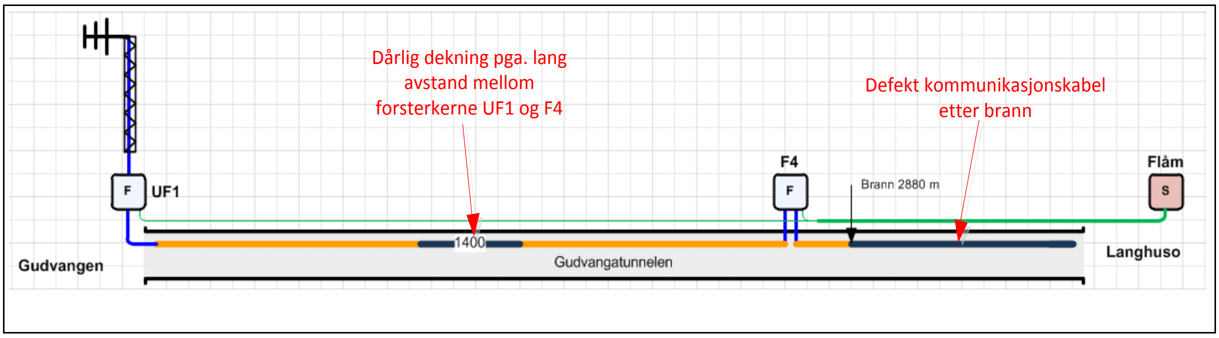


Figure 16: Overview of communication and radio coverage inside the Gudvanga tunnel after the fire on 5 August 2013. Source: the NPRA

1.13.6.2 *Tests of the radio communication system after the incident*

The radio communication system was tested by Mesta Elektro and Aurland fire service on 31 July 2013 (before the incident). The test found the communication system to be in order.

The NPRA carried out another test of the radio communication system on 6 August 2013 (the day after the incident), as it had been reported that the emergency services' communication channel did not work during the rescue operation. The test showed that the emergency services' communication channel was working. Two test calls were made

[4] Communication cable installed under the tunnel ceiling

from the scene of the fire to the police operations centre using VHF handsets. The police confirmed loud and clear receipt.

A further test was carried out of Rescue channel 2 on 8 August 2013. This test was carried out at intervals of 500 metres along the whole distance from the scene of the fire to Gudvangen. Voice transmission was loud and clear, except in the known dead zone midway between the UF1 and F4 radio amplifiers in the technical rooms (see Figure 16). Channel HE37 (fire and medical services) was also tested on 8 August, using the same model and showing the same results. Channel PK 4 was tested, and the transmission from the tunnel to the operator in the police operations centre in Florø was found to be somewhat unclear. According to the NPRA, they have previously received reports that there have been problems related to transmission from outdoor bases to the police's radio communication network and that is believed to be the reason why the sound was unclear in one direction.

1.13.7 Signs, light signals and road barriers

The Gudvanga tunnel is equipped with flashing red stop signals outside the tunnel at each end. The flashing red stop signals can be remotely controlled from VTS, and they were activated when the tunnel was closed after the fire. The tunnel is not equipped with road barriers at the tunnel entrances.

In addition, internally illuminated signs with the text 'Snu og køyr ut –Turn and exit' have been fitted in both directions of travel and are marked with flashing red lights, see Figure 17. These signs are installed in connection with U-turn facilities and can be activated automatically on removal of a fire extinguisher from the tunnel, or manually from VTS. When the tunnel was closed manually from VTS, automatic control of these signs was automatically deactivated. Nor were the signs activated manually from VTS, as no confirmation had as yet been received of where in the tunnel the burning heavy goods vehicle was located.

Figure 17: Sign that can be illuminated when closing the tunnel. Photo: the AIBN

1.13.8 Procedures for closing, evacuation and transmission of radio break-in messages in connection with incidents in the tunnel

The procedures for evacuation and transmission of radio break-in messages in connection with incidents in the tunnel are described in Aurland fire service's procedures for call-outs to tunnels, the instructions for the fire services' 110 communication centre in Sogn og Fjordane county, and the NPRA VTS centre's incident response plan relating to closing of the E16 road/the Gudvanga tunnel.

Aurland fire service and the 110 emergency communication centre in Sogn og Fjordane's documents state the following, among other things:

> *Aurland fire service' procedures relating to tunnel call-outs*
>
> *Checklist on being called out and on arrival:*
>
> - *Has the tunnel been closed? Ensure that it is closed.*
> - *Has the tunnel been evacuated? Request that VTS notify road users by means of a radio break-in message on the P1 channel. Such notification is also possible from the emergency control cabinets in the Flenja, Gudvanga and Lærdal tunnels.*
> - *Are the ventilation fans in operation? Fire ventilation starts automatically on removal of a fire extinguisher. Can be controlled automatically from the emergency control cabinets.*
> - *Is it safe to drive into the tunnel? The fire incident commander gives clearance for other emergency services to drive into the tunnel if there is any doubt based on messages received en route.*
> - *………………….*
>
> *The 110 emergency communication centre in Sogn og Fjordane county – instructions relating to incidents in tunnels*
>
> *Instructions for the emergency communication centre in Sogn og Fjordane in connection with incidents in tunnels*
>
> *On use of the emergency telephone*
>
> - *We take over the call.*
> - *We instruct VTS to close / switch on red lights.*
> - *Ventilation is controlled by them on the instructions of the chief fire officer / emergency response coordinator, communicated via us.*
> - *We notify the emergency services (police – emergency medical communication centre AMK).*
> - *When we receive an emergency call from anyone other than the road traffic control centre via telephone/mobile phone, we notify VTS Lærdal or Bergen.*
> - *…………………..*

The NPRA VTS incident response plan relating to closing of the E16 road/Gudvanga tunnel states that incoming calls to VTS from the tunnel's emergency telephones shall be set up as conference calls with the 110 emergency communication centre in Sogn og Fjordane county. The 110 centre will then take over the communication with the caller as described in the above quote from the instructions for the 110 emergency communication centre in Sogn og Fjordane county.

If accidents or incidents occur in the tunnel and no police or other incident site command are present, the VTS may interrupt the broadcast on NRK P1 with a break-in message to inform road users of incidents in the tunnel. This is done on VTS' own initiative when it is deemed necessary. In the event of fire, there are clear guidelines stating that VTS must receive its instructions from the incident commander and not transmit radio break-in messages unless requested to do so by the incident commander.

Aurland fire service has informed us that they only communicate with the 110 emergency communication centre in Sogn og Fjordane when they are called out to or working at the scene of a fire. The 110 centre is expected to pass on all messages and take responsibility for calling out any extra personnel and equipment when requested to do so by the fire service.

In connection with the fire in the Gudvanga tunnel, Aurland fire service instructed the 110 emergency communication centre in Sogn og Fjordane to inform the road users that were trapped in the tunnel that they should remain inside their cars until they were rescued and breathe through wet clothes.

The AIBN has no information indicating that the 110 emergency communication centre instructed VTS to transmit any radio break-in message. Nor did VTS ask the 110 emergency communication centre whether this should be done.

As described in section 1.13.7, the 'Snu og køyr ut – Turn and exit' sign was not activated because the location of the scene of the fire had not been confirmed.

1.13.9 Traffic volume and composition

The Gudvanga tunnel is equipped with traffic counters to record the traffic volume. Two of these traffic counters are connected to camera boxes (automatic traffic control – ATC) installed inside the tunnel. The counters in the Gudvanga tunnel are not connected to VTS to provide a continuous overview of the number of vehicles that are inside the tunnel at any time.

According to figures provided by the NPRA, the Gudvanga tunnel had an annual average daily traffic (AADT) of about 2 050 vehicles/day in 2012. The traffic volume varies through the year and peaks in July with 3 760 vehicles per day. There is also a marked increase at weekends as a result of weekend travel.

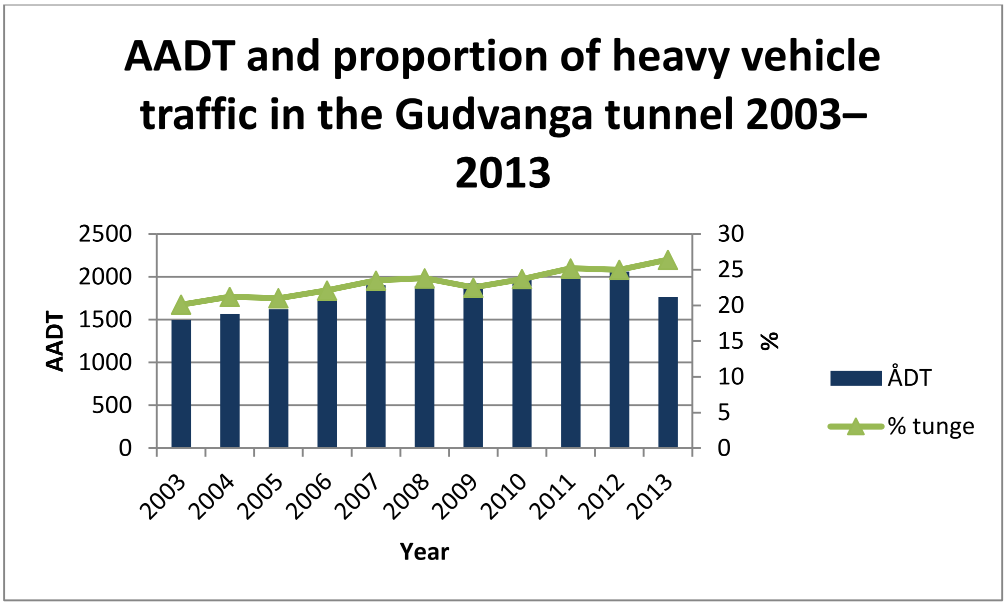


Figure 18: Development in traffic through the Gudvanga tunnel from 2003 to 2013. Source: the NPRA

Figure 18 shows the development in traffic through the Gudvanga tunnel from 2003 to 2013. Calculations show that there has been an increase in traffic of approximately 3.6% over the past decade. The marked drop in 2013 can be ascribed to the closing of the tunnel following the fire. In 2012, 25.2% of the traffic volume that passed trough the Gudvanga tunnel consisted of heavy vehicles.

1.14 Safety follow-up of the Gudvanga tunnel

1.14.1 Emergency response plan for the Gudvanga tunnel

The most recent emergency response plan for the Gudvanga tunnel is dated 5 July 2006 and was drawn up by the NPRA Western Region. According to information obtained by the AIBN from Aurland fire service, the fire service was not involved in the revision of the emergency plan dated 5 July 2006.

Part S1 of the emergency response plan contains information about the technical installations in the Gudvanga tunnel and the use of these installations. Much of this information is included in section 1.13 of this report. The emergency response plan also includes a risk analysis, which is included in part S2 (see section 1.14.2).

The incident response plans for the tunnel and for NPRA VTS are described in separate appendices to the emergency response plan. Appendices describing the emergency response plans for the fire service and AMK are missing from the emergency response plan. The police do not produce incident response plans for individual tunnels, but incorporate the NPRA's emergency response plans in the Rescue Plan for Sogn og Fjordane Police District.

The AIBN has received a copy of Aurland fire service's procedures relating to tunnel call-outs. These procedures deal with tunnel call-outs in general and not the Gudvanga tunnel in particular.

1.14.2 Risk analyses relating to the Gudvanga tunnel

In addition to the risk analysis included in Part S2 of the emergency response plan, a risk analysis was carried out in 2013 as part of the work of upgrading the tunnel in connection with the implementation of the European Tunnel Safety Directive. Among other things, both risk analyses describe the problems relating to fires, smoke and ventilation/smoke control.

1.14.2.1 *The 2006 risk analysis – part S2 of the emergency response plan*

The risk analysis from 2006 includes sub-sections on general considerations, dangerous goods, design scenarios/undesirable incidents, the frequency of incidents and a risk matrix. It also discusses the NPRA's measures to prevent and reduce the scope of damage/injuries in connection with fires and accidents.

The following is reproduced from the risk analysis:

> *2.1 General*
>
> *…*
>
> *The consequences of a vehicle fire are potentially more serious in a tunnel than outside. Rapid build-up of smoke will make it difficult for people to get their bearings and get out of the tunnel. The fire service will be working under difficult conditions due to severe heat development, high smoke temperature and orientation problems. Even using smoke diving equipment, the fire service will only be able to fight a fire in the ventilation direction (with the draught coming from behind).*
>
> *…*
>
> *2.6.2.1 Measures to reduce the scope of damage/injuries*
>
> *1. Measures that enable road users to extinguish a fire*
>
> *Fire extinguishers have been installed in the tunnel at intervals varying between approximately 210 and 470 metres. There are a total of 42 fire extinguishers.*
>
> *2. Measures that enable rapid notification, rapid closing and communication with the 110 emergency communication centre and VTS:*
>
> *Emergency telephones have been installed in the tunnel at intervals varying between approximately 450 and 620 metres. There are a total of 20 telephones. The emergency telephones put the caller in direct contact with the 110 emergency communication centre. A flashing red stop signal has also been installed outside the tunnel entrance at each end to prevent more road users from being involved in the fire.*
>
> *3. Measures to ensure safe and efficient evacuation of people threatened by smoke or fire:*
>
> *Fans have been installed – fire ventilation. The fire ventilation can be started and controlled both from the road traffic control centre (VTS) and from the emergency control cabinet. The tunnel has U-turn facilities and emergency lay-bys so that it is possible for vehicles to turn around inside the tunnel. Signs bearing the text 'Snu og kjør ut / Turn and exit'.*

4. Measures to facilitate the fire service's efforts in the tunnel:

Fire ventilation has been installed so that the smoke can be ventilated in one direction.

1.14.2.2 *The risk analysis of April 2013 – 'E16 Gudvangatunnelen. Risk analysis of road tunnel' (Høj 2013)*

The risk analysis was conducted by the Swiss consultancy firms HOJ Consulting and Matrisk on assignment for the NPRA Western Region.

Chapter 12 of the risk analysis discusses ventilation and smoke control, and the consequences of different scenarios in the event of a fire in the Gudvanga tunnel. The following is quoted from Section 12.4 of the risk analysis:

12.4 Special conditions relating to ventilation of tunnels with two-way traffic

12.4.1 Situation

What is special about ventilation in connection with a fire in a tunnel with two-way traffic is that there must be expected to be vehicles (and, hence, people) on both sides of the fire. As the tunnel is more than 11 km long, a considerable number of people can potentially gather inside before the tunnel is effectively closed. Effective fire notification (for example by means of video surveillance, AID, smoke detectors, telephones, mobile network coverage etc.) is in any case important so that VTS can be informed about the fire and close the tunnel. (It is important to facilitate rapid action and to have in place effective means of closing the tunnel (stop light system, various signs and barriers)……………….

The following is described under the heading 'Ventilation strategies':

Ventilation strategies

Generally speaking, there are three strategies for ventilation of a two-way tunnel: high flow rate, no flow rate and low flow rate. These three strategies are illustrated in Figure 12.2.

The direction of ventilation should not be reversed, as this can cause the tunnel cross section to fill up with smoke during the period when the ventilation is being reversed. If people flee in the direction that is free of smoke before the flow direction is reversed, the smoke plume will catch up with them once the ventilation has been reversed, exposing them to critical smoke concentrations. By reversing the ventilation, one is effectively cutting off the road user's possibility of escape.

The following is quoted from section 12.6 of the risk analysis:

………… It is only advisable to reverse the ventilation if 1) this operation can be carried out in an early phase before the fire has had time to develop to any significant degree and before evacuation has been initiated, or if 2) this operation is not carried out until everybody has evacuated to a safe area. In order to ensure that this is the case, there must, as a minimum, be video surveillance of the tunnel, but, even with such equipment, it is difficult to make absolutely sure that the ventilation does not put those who are fleeing from the fire at risk.

1.14.3 Overview of fires and incipient fires in the Gudvanga tunnel

The NPRA Western Region have recorded two incipient fires during the period 2002–2013. The first occurred on 8 June 2008 and the second one on 28 March 2011. Both incipient fires were in vehicles with a registered heavy vehicle weight of more than 3 500 kg. Since neither the NPRA nor the Directorate of Civil Protection (DSB) had a system for separate registration of fires in tunnels, it has not been possible to get an overview of any fires or incipient fires in the Gudvanga tunnel before 2002.

In an extended report on the fire in the Gudvanga tunnel on 5 August 2013 ('Utvidet rapport – Trailerbrann i Gudvangatunnelen 05.08.2013') prepared by Aurland fire service, it is stated that 10 fires have occurred in the Gudvanga tunnel since 2001, without any specification of when they occurred.

1.14.4 Exercises in the Gudvanga tunnel

The NPRA manual on safety management of road tunnels ('R511 – Sikkerhetsforvaltning av vegtunneler – 2007' – HB R511) describes how exercises in tunnels are to be held. According to the manual, the intention behind exercises is to learn how to improve response capabilities for the next time an incident occurs. HB R511 does not list evacuation and self-rescue as items to be covered by exercises in tunnels.

HB R511 states that rescue exercises must be carried out so that all the respective rescue services can practice cooperating at the tunnel incident site. Full-scale exercises shall be organised every two years, while table top or simulation exercises should be organised in the years when no large-scale exercises are held.

According to information from the NPRA, four exercises were held in the Gudvanga tunnel before the fire on 5 August 2013 (January 2004–November 2009). A review of the documentation from these exercises shows that they consisted of function tests of some of the equipment that is installed in the tunnel. Under the Regulations of 26 June 2002 No 847 relating to fire prevention measures and inspection (the Fire Prevention Regulations), regular exercises must be conducted for 'special fire objects', and they must reflect the risks associated with such objects. Tests carried out by the NPRA can meet some of the requirements set out in Section 3-3 'Training and fire exercises' of the above-mentioned Regulations. The emergency services have not participated in these tests.

In an extended report on the fire in the Gudvanga tunnel on 5 August 2013 ('Utvidet rapport – Trailerbrann i Gudvangatunnelen 05.08.2013') prepared by Aurland fire service, one coordination exercise is reported to have been conducted in the Gudvanga tunnel before it opened in 1991, in addition to one in the Flenja tunnel. According to information provided in a separate memo from Aurland fire service, which was sent to the AIBN in February 2015, several coordination exercises, communication exercises and orientation exercises were held in the Gudvanga tunnel before the fire on 5 August 2013, but there is no specification of when these exercises took place.

1.14.5 Supervision of the Gudvanga tunnel as a special fire object

In addition to organising the emergency response effort when a fire occurs, the Aurland fire service is also responsible for inspecting special fire objects (see the Act relating to the Prevention of Fire, Explosion and Accidents involving Hazardous Substances and the Fire Services' Duties connected with Rescue Operations). The Gudvanga tunnel, like most of the other tunnels that are part of the road network in Aurland municipality, is defined as a special fire object.

The most recent fire inspection report available for the Gudvanga tunnel is dated 12 March 2010 and was prepared after a system inspection of all the tunnels in Aurland municipality in November 2009. As far as the Gudvanga tunnel was concerned, all the technical requirements defined by the fire service were met at the time of the inspection, with the exception that there was an area of 151 m^2 of uncovered PE foam in the tunnel. However, this area was covered with spray concrete in 2012, see section 1.13.2.

In August 2011, another fire inspection was carried out of the tunnels in Aurland municipality. After sending repeated reminders, the NPRA has still not received any report from this inspection. Nor has the AIBN received a copy of the final report requested from Aurland's municipal administration.

1.15 Technical registration systems

As the heavy goods vehicle was completely burnt out, it was impossible to download any data from the vehicle's tachograph or other electronic control or storage units.

1.16 Medical matters

The AIBN does not know of any medical matters relating to the driver that were of significance to the incident. A blood test of the driver found no alcohol or narcotics.

1.17 Special examinations and evaluations

1.17.1 Engine temperature recording during test driving of a Renault Magnum

On 15 October 2013, the AIBN recorded the engine temperature during a test drive in a heavy goods vehicle of the same type as the vehicle that caught fire in the Gudvanga tunnel.

The purpose of this test was to study the surface temperatures that were registered at various points in the engine compartment when driving uphill, and to find out whether these temperatures were sufficient to ignite oil vapour in the engine compartment. Surface temperatures were registered on the turbo (hot part), the dynamo, at the wear point on the oil line that led from the oil cooler to the turbo, and at a point that registered the temperature in the engine compartment. The temperatures were continuously recorded during the whole test drive.

The test drive started at Alnabru in Oslo and followed the E18 to Kjellstad in Lier, before returning to Alnabru. On the drive from Lysaker in Bærum to Kjellstad and back, the heavy goods vehicle was driven at the speed limit of 80 km/h.

When driving from Asker towards Lierskogen, there is an uphill section of road of approximately 6 km with a height difference of about 180 m. The gradient varies between 2% and 3.5%. The temperatures that were recorded are shown in Figure 19.

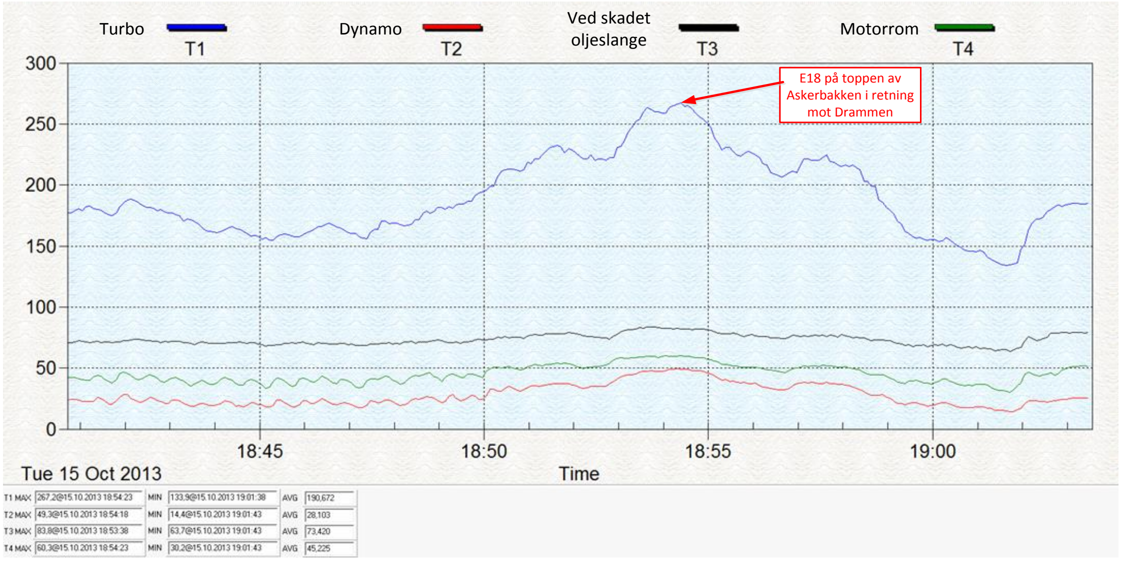


Figure 19: Recorded temperatures when driving in the direction of Drammen. Source: the AIBN

When driving from Kjellstad in Drammen towards Oslo, there is an incline of approximately 4 km with a height difference of around 200 m. The gradient along this section varies between 4.5% and 5.7%. The temperatures that were recorded along this incline are shown in Figure 20.

The records show that the temperature on the turbo varied as the engine load increased, while the temperatures at the other measuring points varied very little with variations in the engine load. When reaching the top of the Askerbakken hill (Figure 19), the turbo's temperature had risen to approximately 270^{o} C, and at the top of the Lierbakken hill (Figure 20) it was almost 300^{o} C.

In addition to recording the temperatures, it was also desirable to detect any other factors in the engine compartment that might contribute to the outbreak of fire when driving uphill/at high engine load. Two video recording points were therefore mounted, focusing on the dynamo and turbo. The video records showed no sparks from the dynamo or glowing turbo during the test drive.

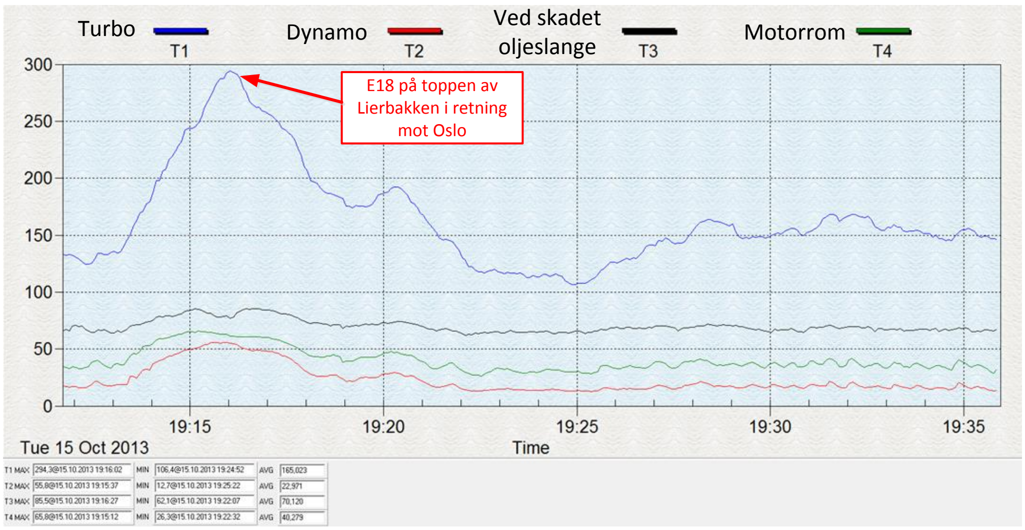


Figure 20: Recorded temperatures when driving in the direction of Oslo. Source: the AIBN

1.17.2 Report from SP Technical Research Institute of Sweden on smoke fumes produced in connection with fire in a heavy goods vehicle

On assignment for the AIBN, SP Technical Research Institute of Sweden in Borås in Sweden considered and answered some general questions about:

1. what fumes are present in the smoke from a fire in a heavy goods vehicle

2. how smoke from a heavy goods vehicle on fire spreads inside a tunnel without mechanical ventilation

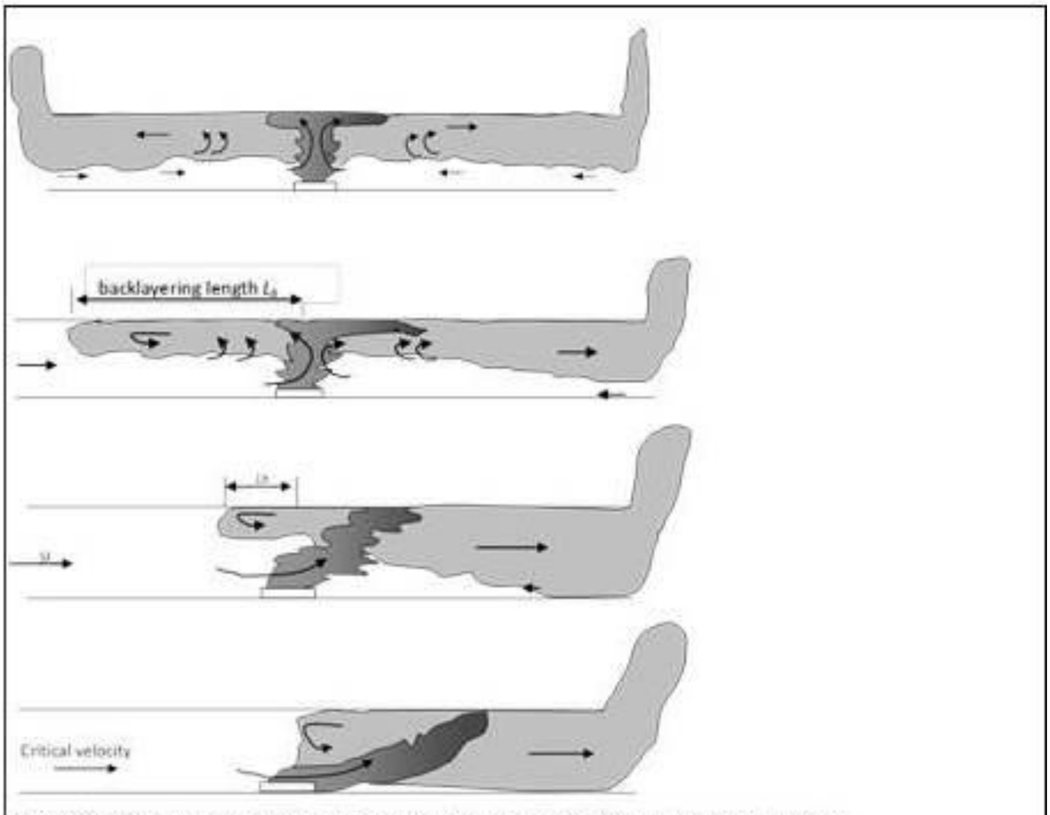
3. the smoke intensity from an empty heavy goods vehicle compared with a fully loaded heavy goods vehicle (gross mass 40 tonnes)

4. why the smoke spreads unevenly and some areas of the tunnel have denser smoke (smoke plugs) than others

5. SP's assessment of ventilating the smoke to provide access for the fire service from the smoke-free side while road users on the other side of the scene of the fire risk becoming trapped in the smoke inside the tunnel.

The report provides an overview of the fumes that normally develop in connection with a fire. These include cyanide gas (HCN) in addition to CO and CO_2.

Fire and smoke development will, according to the report, depend on the velocity of the air flow in the tunnel. Scenarios for air velocity and the spread of smoke are shown in Figure 3 in the report, which is reproduced below (Figure 21).



Figur 3 Skiktning av rök i tunnel vid olika lufthastigheter u (från överst och nedåt u=0.3 m/s, u= 1m/s, u=2 m/s och slutligen u=3 m/s) (Ingason, 2012).

Figure 21: Example of the spread of smoke at different air velocities. Source: SP Technical Research Institute of Sweden

An assessment has also been made of why the smoke intensity differs in different parts of the tunnel bore when there is mechanical ventilation. This happens when the direction of ventilation is reversed. This will push the smoke that is on one side of the fire back across the scene of the fire so that it is mixed with the smoke from the fire. This will increase the smoke concentration for a limited period and produce a 'smoke plug' that will move through the tunnel. This will increase the concentration of smoke fumes. Staying in this part of the smoke for around five minutes can lead to unconsciousness.

The report includes the following mechanical ventilation strategy description:

> *A fundamental principle for bi-directional tunnels (traffic in both directions) should be to ensure minimum ventilation during evacuation so that the smoke spreads slowly inside the tunnel and people downstream and upstream of the fire have a chance to escape. This can be achieved by mechanical or natural ventilation depending on the weather conditions at the tunnel portals. Then, when evacuation has been completed and in order to help the rescue service to reach the fire, the ventilation can be turned on in one direction to enable the rescue service to enter through a smoke-free environment; 3 m/sec will normally be sufficient to produce favourable conditions upstream of the fire, see Figure 3. The equipment that is installed in many tunnels from which information can be obtained about the number of vehicles and their position in the tunnel can be used as a basis for the rescue service's decisions. These decisions should be made in consultation with the road traffic control centre.*

Caution should be exercised when it comes to changing the ventilation flow in a tunnel after a fire has broken out. The most important reason for this is that if there are people in the tunnel upstream of the fire, the ventilation flow should not be reversed as this will cause more smoke in the tunnel for a longer period and produce higher concentrations in the smoke plug. In other words, it will lead to higher smoke fume concentrations for those people who were previously upstream of the fire when the old smoke and the newly emitted smoke catches up with them.

For more information about the contents of the report, see Appendix E.

1.17.3 Evaluations by other parties

1.17.3.1 *The Directorate of Civil Protection and Emergency Planning's (DSB) report on the fire in the Gudvanga tunnel*

In its report, the DSB has considered several important issues relating to the fire-fighting and rescue efforts in the Gudvanga tunnel. They included planning and existing plans, notification and call-out of response personnel. Ventilation and smoke control were also considered in the report. In addition, assessments were made of communication, the communication system and incident response leadership.

The report concluded that it is important to have good emergency and incident response plans for response efforts in long tunnels. The DSB is of the opinion that the NPRA's emergency response plan provides a basis for drawing up incident response plans for incidents in tunnels. Such incident response plans must be prepared by the fire and rescue service, and should have been prepared by Aurland fire service.

As regards response efforts at the incident site, the report states that the effort to extinguish the fire was in accordance with normal practice, but that the strategic leadership of the efforts was lacking. This was due to inadequate incident response planning and division of functions, and unclear organisation. The DSB believes that the preparation of incident response plans would have identified the problems associated with commanding operations from inside the tunnel, as the chief fire officer chose to do.

The ventilation functioned as planned in relation to the response personnel. They had a clear view of the scene of the fire and could initiate extinguishing as planned. However, it has been questioned whether the chief fire officer should have chosen to reverse the ventilation when he had located the scene of the fire. In the DSB's opinion, the decision to retain the direction of ventilation as described in the emergency response plan was in line with applicable guidelines and recommendations. According to the DSB, one important function of fire ventilation is to thin out the smoke by supplying fresh air. This facilitates self-rescue. The DSB claims, however, that a higher ventilation rate would have caused the smoke plug to move faster and be out of the tunnel in half the time.

The DSB does not find that the incident has uncovered any weaknesses in the regulatory framework relating to smoke and ventilation control in tunnels. However, the DSB states that fires in long single bore tunnels are complex incidents, and feels that there is a need to look more closely at strategies for rescue efforts in tunnels.

1.17.3.2 *The NPRA's evaluation of the fire in the Gudvanga tunnel*

The NPRA Western Region conducted an evaluation following the fire in the Gudvanga tunnel on 5 August 2013. The report was issued on 15 November 2013 and included the following conclusions:

- The safety installations in the Gudvanga tunnel are in accordance with the requirements that applied when the tunnel was constructed.
- The emergency response plan that applied to the Gudvanga tunnel on 5 August 2013 was dated 5 July 2006. It contained some minor errors relating to the number of fans and emergency telephones in the tunnel. It also stated that there was uncovered PE foam in the tunnel. At the time of the incident, it had been covered with spray concrete.
- The fire ventilation is pre-set to flow in the direction from Aurland towards Voss. It is up to the chief fire officer to decide whether this should always be the case. In the event of a fire, it is the chief fire officer who controls the ventilation. This can be done by making a request to VTS or from the emergency control panel outside the tunnel. This was not used during the fire. It is possible that the fire service is not sufficiently familiar with the control panel.
- The velocity of the fire ventilation air was in accordance with the emergency response plan, and the ventilation worked in accordance with the requirements. It is up to the chief fire officer to decide how much air should be supplied to the scene of a fire on the basis of fire-technical considerations.
- It has emerged that the emergency communication network did not work during the fire. In the tunnel section between the scene of the fire and the tunnel portal on the Aurland side, this was because the communication cable was destroyed by the fire. In the rest of the tunnel, where the communication cable was intact, one possible explanation is that the communication equipment was used incorrectly. The emergency communication network has worked normally in tests that have been conducted after the fire.
- Aurland municipality has mobile communication equipment that is designed for use in tunnels. This equipment was not brought along to the fire.
- There was an area of poor coverage. This was known and has now been remedied.

1.17.3.3 *Extended report on the fire in the Gudvanga tunnel on 5 August 2013 prepared by Aurland fire service ('Trailerbrann i Gudvangatunnelen 05.08.2013')*

Aurland fire service prepared a report following the fire in the heavy goods vehicle in the Gudvanga tunnel on 5 August 2013.

In addition to the fire service's response efforts in connection with the fire on 5 August 2013, the report contains a description of the structure, technical installations and emergency response plans for the Gudvanga tunnel.

The report concludes that the fire service's overall response efforts were satisfactory with respect to both response leadership and the firefighting and rescue work carried out by the fire service's response personnel inside the tunnel.

The report recommends that further consideration should be given to the following:

- The ventilation during normal operation and the fire ventilation should have the same direction
- The consequences of the reduction in the ventilation rate when doors to fire cabinet are opened
- Changes to the fire ventilation velocity
- Collaboration between the fire service and VTS relating to use of technical equipment in the tunnel

1.18 Regulatory framework and guidelines

1.18.1 Laws:

The most important Norwegian laws regulating the framework for the construction, use, operation, supervision, control and fire preparedness in road tunnels are:

- Act of 21 June 1963 No 23 relating to roads (the Road Act)
- Act of 18 June 1965 No 9 relating to road traffic (the Road Traffic Act)
- Act of 14 June 2002 No 20 relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire service (the Fire and Explosion Act).
- Act of 27 June 2008 No 71 relating to planning and the processing of building applications (the Planning and Building Act)

Regulations, standards and guidelines have been adopted pursuant to these acts.

1.18.2 Regulations, standards and guidelines

The following regulations, standards and guidelines are relevant in connection with this investigation:

- Regulations of 15 May 2007 No 517 on minimum safety requirements for certain road tunnels (the Tunnel Safety Regulations)
- Regulations of 26 June 2002 No 729 relating to organisation and dimensioning of fire services
- Regulations of 26 June 2002 No 847 relating to fire prevention measures and inspection (the Fire Prevention Regulations)
- Regulations of 6 December 1996 No 1127 relating to systematic health, environmental and safety activities in enterprises (Internal Control Regulations)

- NPRA Manual 021 – Road Tunnels (1992) and NPRA Manual 021 – Road Tunnels (2002). The manual has the status of a standard and was issued pursuant to the Road Act.

- NPRA Manual 163 – Water and frost protection in tunnels (2006). This manual has the status of a guideline.

- NPRA Manual 269 – Safety management of road tunnels Part 1 (2007). This manual has the status of a guideline. The current version of Manual R511.

1.19 Authorities, organisations and leadership

1.19.1 The Norwegian Public Roads Administration (NPRA)

The NPRA is an administrative agency under the Ministry of Transport and Communications. The agency is organised with two administrative levels: the Directorate of Public Roads and five regional offices. The NPRA is responsible for planning, construction, operation and maintenance of the national road and county road networks, and for approval and supervisory activities relating to vehicles and road users. The NPRA also prepares provisions and guidelines for road design, operation and maintenance, road traffic, road user training and vehicles.

The road traffic control centres (VTS) are NPRA entities that function as points of contact with road users. There are five road traffic control centres in Norway, located in Oslo, Bergen, Porsgrunn, Trondheim and Mosjøen, respectively. Among other things, the road traffic control centres are charged with traffic monitoring and control of tunnels and road sections in their respective areas.

The NPRA Western Region is responsible for operation and maintenance of the Gudvanga tunnel, and has responsibility for the road traffic control centre in Bergen.

1.19.2 The fire and rescue service

In Norway, the fire and rescue service (the fire service) is the responsibility of the municipal authorities. The Directorate of Civil Protection and Emergency Planning (DSB) guides the municipal authorities through the Act of 14 June 2002 No 20 relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire service (the Fire and Explosion Act). The purpose of this Act is to safeguard life, health and material assets. The fire and rescue service is expected to carry out preventive work, including inspections, put out fires and provide technical rescue resources in connection with fires and other accidents. Many municipal authorities enter into different forms of cooperation, for example by establishing inter-municipal companies (IKS).

The fire service is organised in accordance with the Regulations relating to the organisation and dimensioning of fire services based on the number of inhabitants in the municipality and on the types of risk that exist there.

1.19.2.1 *Aurland fire service*[5]

Aurland fire service does not have an officer on duty at the station 24/7, but is based on call-out personnel who are part-time fire service employees. Aurland has two fire stations (Aurland and Gudvangen) in addition to a fire depot in Undredal.

Aurland fire service is the fire service in charge in the event of a fire or an accident in the Gudvanga tunnel. According to the tunnel's emergency response plan (dated 5 July 2006), the response time is approximately 20 minutes during the day and approximately 25 minutes at night. When necessary, Aurland fire service can request assistance from the fire services in neighbouring areas, including Voss, Bergen, Lærdal and Årdal.

As described in section 1.14.5, Aurland fire service is also responsible for inspection of tunnels classified as 'special fire objects' in Aurland municipality.

1.19.2.2 *Voss fire service*

Voss fire service does not have an officer on duty at the station 24/7, but has 7 full-time and 41 part-time employees. Voss has three fire stations, located in Voss, Vossestrand and Evanger, respectively.

1.19.2.3 *Lærdal and Årdal fire service*

Lærdal and Årdal municipalities have a joint chief fire officer. The fire station in Lærdal is located at Bergo, and there is a fire depot at Frønningen. The fire service has four response team leaders and 16 crew, organised in duty teams.

Fire and rescue services in Årdal municipality are provided by Hydro Aluminium's company fire service for Årdal Verk. Årdal has three fire stations (Årdal, Øvre Årdal and Årdalstangen) in addition to a fire depot in Offerdal.

1.19.3 The Norwegian Directorate for Civil Protection and Emergency Planning (DSB)

The DSB is an administrative agency under the Norwegian Ministry of Justice and Public Security. The DSB's responsibilities in the civil protection area include national, regional and local security and emergency response, fire and electrical safety, industrial and business safety, hazardous substances, product safety and consumer safety. The DSB is also responsible for the Civil Defence. The agency was established in 2003 as a continuation of the Directorate for Fire and Electrical Safety (DBE), which was established in 2002 by a merger between the Product and Electrical Safety Inspectorate and the Directorate of Fire and Explosion Prevention.

Together, the DSB and the NPRA have prepared some guidelines for case processing and ensuring fire and electrical safety in road tunnels: 'Retningslinjer for saksbehandling og ivaretakelse av brann- og elsikkerhet i vegtunneler' (in Norwegian only). These guidelines are primarily addressed to those who plan, construct and operate road tunnels,

[5] Information about the fire services has been obtained from the respective municipalities' websites and http://www.brannstasjoner.com/news_1.html (viewed on 14 March 2014).

to those who carry out fire safety inspections in road tunnels and to those who will respond in the event of a tunnel fire or accident.

1.20 Other information

1.20.1 Report on fire in the Oslofjord tunnel on 23 June 2011

On 23 June 2011, a fire broke out in a Polish heavy goods vehicle in the Oslofjord tunnel. The heavy goods vehicle was passing through the tunnel from Hurum towards Drøbak.

Approximately 5.5 km into the tunnel, and approximately 1.8 km before the exit on the Drøbak side, the heavy goods vehicle stopped because a fire had started in the engine. Søndre Follo fire service entered the tunnel from the Drøbak side to put out the fire. In order to provide good visibility for the firefighting efforts, the ventilation air was set to flow towards the Hurum side. This caused 5.5 km of the tunnel to fill up with dense, black smoke. Several road users had problems evacuating, and nine persons were trapped in the smoke. It took approximately two hours before they were evacuated by the rescue crews. The following is quoted from the summary in the report:

> *The danger to road users was exacerbated by the tunnel's safety equipment and emergency preparedness solution not being sufficiently designed for self-rescue. There was only one escape tunnel (3480 metres away from the location of the fire) in addition to the tunnel exits and no smoke-proof evacuation rooms. In addition, many road users did not receive information from the VTS via radio in time to turn/evacuate before being trapped in the smoke.*
>
> *The fire extinguishing from the Drøbak side functioned in a satisfactory manner and as expected. The rescue effort from the Hurum side encountered major problems due to the smoke development, risk of collisions and the distance to the fire location. 25 of 34 road-users exited the tunnel under own power. Nine road-users were later evacuated from the tunnel by rescue crews. The overview VTS had through CCTV monitoring of the tunnel and direct contact with road users in the SOS boxes, in addition to the emergency services' fire and rescue efforts, saved lives that day.*
>
> *Through this investigation, the AIBN has identified five important safety problems that have contributed to weakening system safety in relation to the Oslofjord tunnel, and which resulted in road users becoming trapped in the smoke:*
>
> *a) The Oslofjord tunnel's safety level, through its emergency preparedness solution and safety equipment, was not satisfactory seen in relation to traffic growth and composition.*
>
> *b) The fire and rescue preparedness for the Oslofjord tunnel was not designed, equipped or organised in relation to what can be expected as regards location and size of fires in the tunnel.*
>
> *c) Sufficient documentation for the use of longitudinal ventilation in tunnel fires and how to effect evacuation when the tunnel is filled with smoke is not available.*
>
> *d) The preconditions for the self-rescue principle were not sufficiently present in the Oslofjord tunnel's safety equipment and emergency preparedness solution.*

e) The Norwegian Public Roads Administration's safety management of the Oslofjord tunnel had not captured the relevant risk situation, and the risk-based approach to safety and preparedness was deficient.

Based on this investigation, the AIBN is concerned that the fire risk in single-bore tunnels is only countered with prioritisation which ensures a minimum safety level. The decision base for what the acceptable safety level is should be based on an assessment of the real risk situation in the specific tunnel and impact analyses of near-fires, in addition to learning from monitoring and supervision.

In several respects, the sequence of events of the fire in the Oslofjord tunnel resembles what happened during the fire in the Gudvanga tunnel. For more comprehensive information about the fire in the Oslofjord tunnel and the safety recommendations that were made in connection with the investigation, see Rapport VEI 2013/05 om brann i vogntog på RV 23, Oslofjordtunnelen, 23. juni 2011.

1.21 Implemented measures

After the incident, physical measures have been implemented in the tunnel in addition to measures relating to firefighting and rescue work.

1.21.1 Measures implemented by the NPRA

In connection with repairs to the Gudvanga tunnel, the NPRA has made some upgrades in relation to the previous standard. According to the NPRA Western Region's evaluation report after the fire in the Gudvanga tunnel on 5 August ('Brann i Gudvangatunnelen 5. august 2013'), the following upgrades were made before the tunnel was reopened on 5 September 2013:

- All ex cables in the tunnel have been replaced.
- Equipment has been installed so that there is no longer a dead zone for radio communication.
- New fibre-optic cables have been installed throughout the tunnel in preparation for the installation of a new emergency communication system. The transition to the new emergency communication system was scheduled to take place in the first quarter of 2014, but was postponed, and the system will not be put into operation until the second quarter of 2015.
- The tunnel walls have been painted white to provide better optical guidance and better lighting in the tunnel.
- Extra lighting has been fitted inside the tunnel portal on the Aurland side.
- The eight fans that were out of order have been repaired, so that all 92 fans were in working order when the tunnel was reopened.
- New barriers have been installed, and cameras have been installed by the technical rooms and by the barriers.

- The worn-down profiles of the tunnels longitudinal road markings have been renewed to provide better visual guidance.

- The battery units for the emergency power supply (UPS) have been replaced.

- The speed limit has been temporarily lowered to 70 km/h pending clarification regarding reprogramming of the ventilation system.

The emergency response plan for the Gudvanga tunnel has been revised. The plan, dated 1 September 2014, includes the following description under the heading Fire ventilation:

> *Good ventilation is a precondition for the fire service being able to carry out effective firefighting inside a tunnel. The smoke must be removed between the scene of the fire and the tunnel entrance through which the fire service is to enter before the fire service and other rescue personnel can do anything.*
>
> *The Gudvanga tunnel is located in Aurland municipality. It is the Aurland fire service that is responsible for firefighting and rescue work in the tunnel.*
>
> *Good fire ventilation makes it possible to reach and work at the scene of the fire. Fire ventilation is important in order to ensure that the fire service have fresh air behind them.*
>
> ***The fire ventilation is pre-set to flow in the direction from Aurland towards Voss. This was decided in consultation with the chief fire officer.***
>
> *The fire ventilation can be operated in four steps (92 fans in all):*
>
> *Step I: 16 fans in operation*
>
> *Step II: 34 fans in operation*
>
> *Step III: 65 fans in operation, producing an air flow rate of 2.6 m/sec*
>
> *Step IV: 84 fans in operation, producing an air flow rate of 3.6 m/sec*
>
> ***During a fire**, step III will normally be used, i.e. 65 fans producing a flow rate of at least 2.5 m/sec. This is intended to ensure that the fire service has fresh air behind them when they arrive at the scene of the incident. Any backflow of smoke must be avoided.*
>
> ***After the fire has been extinguished** As soon as the fire has been extinguished, the fire ventilation should be set to step IV, i.e. maximum fire ventilation, which produces a flow rate of 3.6 m/sec or more. The chief fire officer on duty/ fire incident commander will notify the 110 emergency communication centre when this should be done. The 110 emergency communication centre will pass on the message to VTS. Alternatively, the VTS can be contacted directly by calling 57 65 95 11 or 55 16 10 81.*
>
> *It is very important to activate maximum fire ventilation once the fire has been extinguished, as this will increase the amount of oxygen and dilute the smoke. It improves the situation for people in the smoke-filled area and greatly facilitates the fire service's efforts………*

The NPRA has drawn up plans and set aside NOK 350 million for improvement work in the Gudvanga tunnel to bring it into line with the safety requirements set out in the Tunnel Safety Regulations. The improvement work will be carried out by 2019.

1.21.2 Measures implemented by Aurland fire service

Aurland fire service has implemented the following measures after the fire in the Gudvanga tunnel on 5 August 2013:

- A mobile fan has been bought for use in tunnels without ventilation.
- An amplifier has been installed in the rescue vehicle for use in areas with poor radio coverage.
- Revised requirements have been submitted in connection with the revision of the emergency response plan for the Gudvanga tunnel.
- The incident response plan for road tunnel incidents ('Innsatsplan – rutine og prosedyre ved utrykning til vegtunnel' – in Norwegian only) in Aurland municipality has been revised. The plan was prepared in order to facilitate rapid and effective response to incidents in tunnels and to safeguard the response personnel in connection with such assignments. The plan contains no description of how road users are to be evacuated other than that VTS should be asked to notify road users by transmitting a radio break-in message on the NRK P1 channel. The revised plan has retained the same ventilation strategy as the previous plan.

1.21.3 Measures implemented by the DSB

The DSB has implemented the following measures after the fire:

- In cooperation with the NPRA, the DSB has organised five one-day seminars (in all road regions) focusing on safety in connection with firefighting and rescue work in tunnels. The target group comprised all fire and rescue services.
- The DSB has carried out an evaluation of the fire service's response in connection with the firefighting and rescue work. A report with recommendations was submitted in August 2014, and is referred to in section 1.17.3.1 of this report.
- The DSB has initiated work to evaluate guidance material, and to consider whether a change in work procedures can improve the quality of the fire service's rescue response efforts.

2. ANALYSIS

2.1 Introduction

The AIBN has investigated the sequence of events, contributory factors and consequences of the fire in the Gudvanga tunnel, in which 28 persons were seriously injured.

The analysis starts with an assessment of the triggering event, including a discussion of factors that may have contributed to the fire in the heavy goods vehicle.

This is followed by an analysis of the safety level in the tunnel. The analysis looks at how the tunnel's design, technical installations and safety equipment functioned during the fire. This is followed by an assessment of how this affected the road users' self-rescue and the firefighting and rescue work.

The tunnel was constructed in accordance with the requirements that applied at the time of its construction (1991). The AIBN has chosen to limit the investigation to an analysis of how the actual safety of the road users was affected by existing equipment and plans, and not analyse it in relation to acts and regulations.

With the assistance of SINTEF and Oslo University Hospital, a detailed investigation has been carried out of the road users' experiences and injuries. The analysis discusses the preconditions for the self-rescue principle, and the mental stress suffered by the road users who were trapped in the smoke in the tunnel. An assessment is also made of the smoke inhalation injuries suffered by those involved.

The fire and rescue efforts have been an important focus in this investigation. The analysis starts with a discussion of firefighting and rescue strategy and the prioritisation that caused 8.5 km of the tunnel to become filled with smoke, making it very difficult for 67 people to evacuate. It goes on to consider the organisation, dimensioning and strategic leadership of the fire service's response.

This is followed by an overall assessment of all the emergency services' efforts in connection with the incident. This part includes notification, emergency medical response, and cooperation and information flow between the emergency services.

Finally, an assessment is made of how the safety in the Gudvanga tunnel was followed up, which in turn affected the safety level in the tunnel and the emergency response strategy at the time of the incident. This includes a discussion of how inspections and exercises were conducted and of the NPRA's safety management of the tunnel.

The final section concerns the overriding guidelines that apply to tunnel safety.

2.2 Assessment of the triggering event

The technical investigation carried out after the fire (see section 1.11.2) identified several factors that may have contributed to the outbreak of fire in the heavy goods vehicle's tractor. The following findings were made:

- Wear damage on protective braiding around the oil line between the oil cooler and turbo.

- Traces of short-circuiting in several of the vehicle's electrical wires.
- A hole in the throttle housing for the engine brake (on the turbine side of the turbo). The hole was on the side that faced the engine.
- Melting damage to the rear part of the dynamo with diode bridge and connections.

Any shorting of electrical wires would generate enough heat for the insulation or adjacent materials to catch fire. The shorting, if any, may also have generated enough heat to ignite any combustible vapours or atomised particles of combustible liquid.

In the AIBN's opinion, the wear found on the oil line may have contributed to atomised oil being sprayed into the engine compartment and being ignited by sparks produced by short circuiting, an inflow of hot exhaust through the hole in the turbo or hot surfaces on the engine's turbo.

Temperature measurements made by the AIBN on the same type of heavy goods vehicle (see section 1.17.1) show that the turbo temperature can rise to around 300 ^{o}C during normal driving up inclines that resemble the conditions in the Gudvanga tunnel. Temperatures at this level are sufficient to ignite atomised engine oil with a temperature of between 70 ^{o}C and 90 ^{o}C. In connection with a fire in a train on the Brattsberg line in Skien in 2010, wear on an oil line was mentioned as a contributory cause of the outbreak of fire in the train. More detailed information about that fire can be found in the AIBN's RAIL Report SHT rapport JB 2011/06.

Based on the technical examination, the AIBN finds it to be impossible to determine exactly why the fire broke out in the heavy goods vehicle, but it believes that the above-mentioned factors may have contributed to the outbreak of fire.

In the AIBN's view, the factors that may have contributed to the fire would be difficult to detect during an ordinary safety inspection of the vehicle. The position of the worn oil line means that the problem could only be detected by someone with special knowledge of this problem area, knowledge that the AIBN does not feel a driver can be expected to have. The same applies to the possibility of detecting possible shorting of electrical circuits. The AIBN has neither found any indication of changes having been made to the electrical system that would increase the risk of short-circuiting, nor of the condition of the vehicle's original electrical installations being such that the driver should have been aware of the risk of short-circuiting or fire.

The investigation has shown that the driver acted when he received information that there could be something wrong with the heavy goods vehicle. He stopped at Vinje when he was informed that smoke was allegedly emanating from the vehicle. When he noticed that the vehicle was starting to lose power in the Gudvanga tunnel, he also stopped and immediately tried to put out the fire, but was not able to extinguish it. In the AIBN's view, this shows that the driver took action as necessary when he received indication that something was wrong, and that he acted in accordance with what can be expected of a professional driver.

Furthermore, the AIBN is of the opinion that, given the nature of the triggering event that caused the fire in the heavy goods vehicle in the Gudvanga tunnel, it is difficult to completely eliminate this type of incident. The tunnel owner and the fire service must therefore focus on minimising the consequences for road users if such a fire occurs. In its further analysis of the incident, the AIBN has therefore chosen to focus on aspects that reduce consequence.

2.3 The Gudvanga tunnel's technical installations and safety equipment

The Gudvanga tunnel was opened for traffic in December 1991 and, as regards structural design and safety, it was built and equipped to meet the requirements that applied at that time. The 11.4 km long single bore tunnel has no escape routes or evacuation spaces other than the tunnel portals. In this section, we discuss the tunnel's safety level in the form of technical installations and safety equipment that, in the AIBN's opinion, had a direct impact on the rescue work and the evacuation of road users on 5 August 2013.

2.3.1 Fire extinguishing equipment

The NPRA equips tunnels with fire extinguishers to enable road users to put out any fires themselves. In accordance with the emergency response plan, the Gudvanga tunnel is therefore equipped with 42 6 kg fire extinguishers placed at intervals of between 250 and 300 m.

In the case of both this fire and the fire in the Oslofjord tunnel, the driver was unable to extinguish the fire using a 6 kg fire extinguisher taken from his own vehicle. Since the heavy goods vehicle in the Gudvanga tunnel had stopped midway between two fire extinguishers in the tunnel, it was not possible for the driver to get a fire extinguisher from the tunnel to continue his efforts to put out the fire. In the case of the fire in the Oslofjord tunnel, the driver was able to use one of the tunnel's fire extinguishers in addition to his own, but was nevertheless unable to stop the fire from developing.

It is the AIBN's opinion, based on the two above-mentioned incidents, that the fire extinguishing equipment was not dimensioned to be able to stop the type of fire that occurred in this incident and in the Oslofjord tunnel. It should be considered whether there are other extinguishing agents, forms of equipment or methods that are more appropriate to extinguishing such fires at an early stage.

2.3.2 Monitoring and traffic control equipment

The Gudvanga tunnel was not equipped with any kind of CCTV monitoring or vehicle counters that provided VTS with continuous information about how many vehicles were in the tunnel at any time. The tunnel was in fact equipped with vehicle counters, but the data were not available to VTS as real-time data that could have provided such information.

Hence, VTS had no overview of the number of vehicles and positions of the vehicles inside the Gudvanga tunnel – not at the time when the heavy goods vehicle caught fire, and not during the evacuation of the tunnel. This meant that VTS in the Western Region lacked an overview corresponding to the one that VTS Eastern Region had when the fire broke out in the Oslofjord tunnel, and that probably helped to save lives. If such equipment had been in place in the Gudvanga tunnel, it could have provided information of importance to the rescue and evacuation work as regards the location and scope of the fire, and the number and positions of vehicles.

When the 110 emergency communication centre was notified of the fire, it immediately communicated the information to VTS, which immediately closed the tunnel by activating the flashing red lights outside the tunnel. The tunnel is not equipped with road barriers. Even though it cannot be documented that anyone entered the tunnel after it was closed, the AIBN assumes, on a general basis, that fewer motorists will enter a tunnel that is closed with both flashing lights and road barriers. The AIBN takes a positive view of the fact that the NPRA, in connection with the repairs that were made to the Gudvanga tunnel after the fire, installed barriers that are activated automatically when the tunnel is closed.

In connection with this fire, the Gudvanga tunnel was manually closed by VTS on the basis of a message from 110 Sogn og Fjordane. The 'Turn and exit' signs were therefore not activated automatically. Nor were they activated manually from VTS, as the scene of the fire had not been confirmed at the time. In the AIBN's opinion, the type of variable sign in question provides a possibility to notify road users who are inside the tunnel of the need to evacuate. However, the requirement for the exact scene of the fire to be located by the incident emergency responders first means that the solution is not very efficient.

2.3.3 Fire ventilation

After closing the tunnel, VTS immediately started the fire ventilation so that the smoke from the fire was ventilated over a distance of 8.5 km towards Gudvangen. This was done so that Aurland fire service, which is the closest fire service to the tunnel, could enter from the smoke-free side and extinguish the fire. At the same time, the smoke was thinned out with fresh air, making it less harmful.

SINTEF NBL has estimated a fire effect in the heavy goods vehicle of approximately 25 MW, which is slightly in excess of what the ventilation system was designed to deal with.

The fire ventilation rate was not programmed in accordance with the emergency response plan. The emergency response plan prescribed a fire ventilation rate of 1–2 m/sec, while the programmed rate was 2.5 m/sec. The AIBN was surprised to learn that the fire ventilation was not programmed to operate at the rate stipulated in the emergency response plan.

When the ventilation direction was reversed, 44 of the fans started blowing air towards Gudvangen, while 10 fans continued to blow air towards Aurland. Due to a control system error, VTS was unable to stop the ten fans that were blowing in the opposite direction to the fire ventilation until 13:30, i.e. after one and a half hours.

Measurements of the tunnel's ventilation rate show that, in the initial phase, after the ventilation system had been set to blow in the direction of Gudvangen, the average air velocity reached approximately 2.5 m/sec, after which it dropped to 0.8 m/sec during the period between 13:54 and 14:09. The reason for this was that a number of fans had stopped.

VTS brought the situation under control after approximately two hours. By that time, the ten fans that had blown in the opposite direction to the fire ventilation had been stopped, and the fans that had stopped as a result of the fire door cabinets being opened had been restarted.

The AIBN considers it important that fire ventilation systems work as intended, and takes a critical view of the fact that it took almost two hours before VTS were in control of the ventilation system.

The AIBN questions whether a ventilation system with control faults and failing fans is acceptable in an 11.4 km long single bore tunnel that has, at times, a very heavy traffic load. The AIBN also takes a critical view of the planned strategy for smoke control and firefighting defined in the emergency response plan for the Gudvanga tunnel. This is discussed in more detail in section 2.5.1.

2.3.4 Information to road users

Information to road users could have been transmitted by radio in connection with the evacuation of the Gudvanga tunnel, as the tunnel had the equipment to transmit radio break-in message via NRK P1 (see section 1.13.6). As a consequence of a communication failure between VTS, the 110 emergency communication centre in Sogn og Fjordane county and Aurland fire service, this possibility was not utilised during the fire. The AIBN sees this as a serious failure.

The AIBN considers it unfortunate that the request for the transmission of a radio break-in message made by the fire service to the 110 emergency communication centre in Sogn og Fjordane county was not passed on to VTS. At the same time, the AIBN is of the opinion that the VTS should have had a better dialogue with the 110 emergency communication centre in Sogn og Fjordane on this point.

The AIBN would also like to point out that radio break-in messages are most important to the evacuation of road users during the time before the fire ventilation is started and the tunnel fills up with dense smoke. In connection with the fire in the Oslofjord tunnel, a radio break-in message was not transmitted until approximately 9 minutes after the fire had broken out and approximately 6 minutes after fire ventilation had been started. Hence some of the road users did not receive the message in time to turn their vehicles around before they were trapped in the smoke. Radio break-in messages can also be used to provide road users with important information as the incident develops, for example to tell them to remain in their cars and to inform them that rescue personnel are on their way.

The AIBN has been informed that the NPRA is in the process of considering the possibility of sending text messages to road users in defined areas in the event of such tunnel incidents. In the AIBN's opinion, this would constitute an effective information channel that would reach most of those affected, as the majority of both Norwegian and foreign road users now have mobile phones. In the AIBN's view, the introduction of such a scheme should be considered.

2.3.5 Lighting

Parts of the tunnel were in complete darkness over a distance of approximately 1 000 m due to a fault in the electrical system (see section 1.13.5). Since the unlit section was approximately 4 km from the scene of the fire in the direction of Gudvangen, the AIBN does not believe that it had any direct impact on the incident. When those who were evacuating reached the unlit part of the tunnel, the tunnel was already filled with smoke and any lighting would therefore have had little effect. The AIBN would nevertheless like to point to the general importance to road users of a well-lit tunnel should an incident occur.

2.3.6 Radio communication equipment for communication between the emergency services

As the radio system in the Gudvanga tunnel did not have two-way feeding of signals to radiating cable segments, the fire caused the communication network between the scene of the fire and the tunnel entrance on the Aurland side to fail. The communication network, which was very sensitive to heat, probably failed before the lights failed. Nor was the radio communication system working outside the tunnel, as it was connected to the communication cable inside the Gudvanga tunnel.

In the AIBN's opinion, the failure of radio communications inside and outside the tunnel had a direct impact on the work at the incident site. In connection with this incident, the mobile phone network worked so that information could nevertheless be transmitted to and from the firefighters inside the tunnel, but the information flow was significantly impeded.

The incident shows the importance of an intact radio communication system when such incidents occur. The communication system would have been functional during the incident had radiating cables with two-way feeding of signals been in place.

In connection with the repairs to the tunnel after the fire, a new communication cable was installed in preparation for the new emergency communication network. Pending such time as the latter is put into operation, the NPRA has chosen to not install a new amplifier to provide two-way feeding of signals to the existing radiating cable segments throughout the tunnel, as the new emergency network will provide for this.

According to information received from the Directorate for Emergency Communication (DNK), the emergency communication network in the Gudvanga tunnel will not be put into operation until the second quarter of 2015, even though the plan was for it to be operational from the first quarter of 2014. Until then, the existing radio network will work in the same way as it did before the fire and, in the event of a similar incident, it may fail just as it did during the fire on 5 August 2013.

2.3.7 Overall assessment of the Gudvanga tunnel's technical installations and safety equipment

In the AIBN's opinion, regardless of the requirements and guidelines that apply to the tunnel's design, technical installations and their operation, all the factors considered in this main section had an impact on the outcome of the incident in the Gudvanga tunnel on 5 August 2013. There was inadequate fire extinguishing equipment, control faults in a ventilation system that did not work in an optimum manner, and a vulnerable radio communication network without redundancy. Furthermore, there were no possibilities for traffic control in the form of road barriers and signs, no equipment for monitoring and keeping an overview of vehicles in the tunnel, and limited evacuation possibilities. In addition, the possibility of transmitting a radio break-in message to the road users was not used during the fire.

In the AIBN's opinion, the NPRA should map the robustness of other tunnels in the event of a fire in light of the weaknesses identified during this investigation.

Safety recommendations are submitted on these points.

2.4 Consequences for the road users

The AIBN would like to draw attention to the efforts made by individual road users in connection with the evacuation of the tunnel. Their contribution may have saved lives in the chaotic situation that arose.

2.4.1 The self-rescue principle

The self-rescue principle is a guiding principle for what the authorities expect of road users in an evacuation situation. According to this principle, the road users shall get out of the tunnel through their own efforts, either by car or on foot. Reference is made to the report on the fire in the Oslofjord tunnel, where this is also discussed. In the AIBN's opinion, the conditions in the Gudvanga tunnel did not facilitate self-rescue. The AIBN believes that this can be explained by several factors that, together, contributed to the problems, traumas and injuries suffered by the road users as a consequence of the fire.

The immediate impression on driving through the tunnel before it was cleared of vehicles after the fire was that many road users did not become aware of the danger until it was too late. All the vehicles that were left in the tunnel – vehicles at right angles to the direction of travel and pointing the wrong way, vehicles that had collided with each other or run into the tunnel wall, and vehicles with significantly body damage – bear testimony to the chaos that arose as a consequence of the fire and smoke in the tunnel.

The AIBN's assessment is that the pre-defined strategy for firefighting and rescue work that is enshrined in the emergency response plan and the incident response plans for the tunnel had a strong impact on the situation. At the time when the ventilation was set to blow towards Gudvangen, neither VTS nor the fire service had any overview of how many vehicles were on the side of the fire towards which the smoke was ventilated. This means that the fire ventilation was started before the road users became aware of the critical situation and understood that they had to evacuate.

It has subsequently been ascertained that there were 58 vehicles inside the Gudvanga tunnel when the fire broke out. Some of these vehicles had already passed the place where the heavy goods vehicle stopped, or they passed the vehicle without hindrance in an early phase of the fire. Of those who could not get past the burning heavy goods vehicle, only those who understood the situation at an early stage were able to evacuate before the tunnel was filled with smoke.

There were signs in the tunnel that could have been used to inform the road users of the need to turn around, and it would have been possible to provide verbal information by transmitting radio break-in messages. This was not done, and the road users in the tunnel were not assisted in their self-rescue by being provided with the necessary information. In the AIBN's opinion, there is potential for improvement in terms of equipment, utilisation of the possibilities that the available equipment represents, and the procedures for communicating information to road users in connection with tunnel fires.

Many of the vehicles that were left in the tunnel had first tried to turn around to head back towards Gudvangen. As there were no U-turn facilities or emergency lay-bys near to where the vehicles stopped, several had been unable to turn around. Several cars had run into each other or into the tunnel wall when the smoke created conditions of minimal visibility. Several road users therefore left their vehicles behind and started to walk through the tunnel. This also became difficult on account of the lack of facilities for people on foot in the form of evacuation lights or handrails along the tunnel walls.

After a while there was zero visibility on the Gudvangen side of the tunnel, and those who were in this part of the tunnel found it difficult to breathe and impossible to find their bearings. The smoke blocked the only possible evacuation route for the road users on the Gudvangen side of the fire.

The AIBN is of the opinion that conditions in the Gudvanga tunnel did not facilitate self-rescue, and that it was largely left up to the road users who were trapped in the smoke to take responsibility for their own safety. The AIBN considers this an important lesson to be learnt from this incident. The incident shows that there is a strong conflict between the planned strategy for firefighting and rescue work and the self-rescue principle. This is discussed in more detail in section 2.5.1.

2.4.2 How the road users experienced the incident

In order to get a better overview of the situation for those road users who were trapped in the smoke in the tunnel, SINTEF Technology and Society conducted an extensive study on assignment for AIBN (see Appendix C). The sum of information obtained by SINTEF describes the critical situation in which the road users found themselves, their experiences of the situation and the traumas they suffered. In the AIBN's view, the information gives a good picture of the poor safety conditions in the Gudvanga tunnel at the time of the incident.

The AIBN considers it important that those who are responsible for tunnels and rescue work, whether at the local or national level, learn from these impressions in their work to follow up this report.

2.4.3 The road users' state of health after their stay in the smoke-filled tunnel

No road users have lost their lives as a consequence of fires in Norwegian road tunnels, and this may give the impression that such fires are not critical. However, the results of the investigations into both the Gudvanga and Oslofjord tunnel incidents show that road users who were trapped in the smoke suffered serious/very serious injuries even though large volumes of fresh air were supplied when the fire ventilation was activated.

In the AIBN's opinion, the consequences for the 67 people in the tunnel, of whom 23 were seriously injured and 5 very seriously injured and potentially at immediate risk of losing their lives, show that this was an extremely serious situation. This is confirmed in Oslo University Hospital's report from its analysis of 28 cases of acute smoke inhalation injuries ('En retrospektiv analyse av 28 tilfeller av akutt røykskader' – see Appendix D). In this case, the time spent in the smoke-filled tunnel was just within the limit of what the road users could withstand without immediate danger to their lives. Young age and good health probably contributed to prevent lives from being lost during the fire.

The smoke inhalation injuries suffered by the 28 people who were seriously or very seriously injured are not included in Statistics Norway's road traffic accidents statistics. Nor are there any systematic records of this type of injuries in the Directorate of Health's register of personal injuries. The smoke inhalation injuries that people suffered in the Gudvanga tunnel in connection with the fire are therefore not included in the statistics.

The AIBN is of the opinion that personal injuries in tunnels should be systematically registered, so that this information can be used in connection with preventive work.

One safety recommendation is submitted on this point.

2.4.4 Recommendations to road users in the event of fire in a tunnel

Oslo University Hospital's report shows that the situation was most serious (including five critically injured persons) for the road users who evacuated in the direction of Gudvangen, i.e. those road users who made their way towards Gudvangen on foot and were not picked up by the rescue crew. It was most critical for those who had spent most time in the tunnel after leaving their cars. This shows that, in this fire, the best course of action would be for the road users to remain in their cars as long as possible, and preferably until they were found by rescue crew.

This may not have been the best solution had the circumstances been different, but it is important to keep this information in mind when making recommendations about what people should do when they find themselves surrounded by smoke.

2.5 The fire service's firefighting and rescue work

This main section assesses the incident response efforts in connection with the fire-fighting and rescue work. It includes a discussion of priorities in the work, organisation and dimensioning, and strategic leadership of the fire service's response.

2.5.1 Prioritisation in the firefighting and rescue work

The AIBN is concerned about the fact that all the fire service and NPRA's systems, routines and procedures are based on giving priority to extinguishing the fire without making further assessments of the situation and giving more consideration to the evacuation of the road users in the tunnel. The result was that the smoke was ventilated towards the side on which most of the road users found themselves, which was also the side with the longest evacuation route.

In the AIBN's view, the fire service and the NPRA should have had another strategy for the firefighting and rescue work to start with. Their first priority should have been to get an overview of the scene of the fire, the spread of smoke, and the number of vehicles and road users in the tunnel. On the basis of such information, the ventilation system could have been used in such a way so as to help the road users to evacuate rapidly and safely before the smoke spread too far in the tunnel.

On the basis of its investigations into the fires in the Oslofjord and Gudvanga tunnels, the AIBN is of the opinion that decisions on firefighting and rescue work should be based on observations and specific assessments of the fire and the tunnel in each case, and not on pre-defined strategies.

The AIBN realises that it can be challenging for the fire service to change its procedures from having a pre-defined ventilation direction and ventilation rate to making decisions according to the specific situation. It requires essential information about the incident to become available very quickly. Those who make decisions about rescue efforts in an early phase also risk making what can afterwards prove to be sub-optimal prioritisation, particularly in the case of a fire in a long single bore tunnel. In the AIBN's opinion, this strategy should nevertheless be considered, as fire incidents in tunnels are very seldom identical and cannot all be dealt with in the same way.

The firefighting and rescue work should be organised on the basis of local information about the scene and scope of the fire, and the number and positions of vehicles/road users in the tunnel. It is therefore crucial that tunnels are equipped to make necessary information readily available to response personnel in the acute phase and enable critical information to be effectively communicated to road users at an early stage to assist them in their self-rescue.

Both the Technical Research Institute of Sweden and the HOJ Consulting and Matrisk consultancy firms have considered the problems relating to smoke control in their reports. It is pointed out in both reports that priority should be given to the rescue phase, and that the initial response efforts during the first 10–15 minutes after the outbreak of a fire are decisive for the evacuation of road users. The reports describe how the air velocity in the tunnel should be kept to a minimum during this period in order to prevent the smoke from spreading. The AIBN is of the opinion that assisted rescue, as described in HOJ Consulting and Matrisk's report (Høj 2013), should be a guiding principle during this period. The DSB has also mentioned this on page 159 of DSB Report HR2296 on the national risk situation in 2014 ('Nasjonalt risikobilde 2014'), where a fire scenario, including in the Gudvanga tunnel, is discussed.

The AIBN is of the view that the NPRA and the fire service together should prepare procedures to ensure more rapid identification of the scene of the fire. The evacuation of road users should also be prioritised by optimum use of available equipment and personnel, for example by correct use of existing systems for transmitting radio break-in messages and variable signs that can guide road users out of the tunnel.

In the case of incidents in the Gudvanga tunnel, the AIBN is of the opinion that Aurland fire service should equip its personnel stationed in Gudvangen so that they can enter the tunnel and escort road users on that side of the scene of the fire to the exit before the smoke spreads.

2.5.2 Strategic leadership of the rescue work

When Aurland fire service arrived at the Gudvanga tunnel, the police were not present and the fire service's operational commander assumed the function of incident commander. When the police arrived, they took command of the incident site and established an incident command centre (ICC) outside the tunnel on the Aurland side. After that, the police and medical health manager were present in the ICC, but the technical supervisor fire was absent as he continued to function as operative leader inside the tunnel in order to ensure the safety of the emergency responders.

In the AIBN's opinion, the fire service should have considered appointing another person to act as operative leader or technical supervisor fire, so that the fire service could also be represented by an expert in the ICC set up outside the tunnel.

Furthermore, the AIBN is of the opinion that there was insufficient communication between the fire service's operative leader in the tunnel, who also acted as fire technical leader, and the police, medical service and VTS, as well as with the fire service on the Gudvangen side of the tunnel. The AIBN finds that the absence of a fire operative leader in the ICC made it more difficult to get a complete overview of the situation, which in turn meant that the police and medical service encountered challenges relating to communication and organisation of the work at the incident site. The AIBN also believes that a fire operative leader in the ICC would have been able to keep a better overview of all the fire services' response teams and could have obtained up-to-date information about conditions on the Gudvangen side of the tunnel.

In the AIBN's opinion, the shortcomings of the incident response plan for the tunnel contributed to this situation. It also illustrates the importance of good plans and of having a shared understanding of all rescue work in connection with fires in tunnels.

2.5.3 Organisation and dimensioning of the fire service's firefighting and rescue efforts

The AIBN finds the rescue work that was carried out inside the Gudvanga tunnel praiseworthy. When the fire service deemed the fire to have been sufficiently suppressed, they searched further into the tunnel and efficiently brought road users to safety as they were found. The fire service's response personnel put themselves at great risk. The personnel showed good improvisation skills and praiseworthy efforts when they filled up their vehicles with road users who had been trapped in the smoke to bring many as possible to safety, while leaving their own personnel in the tunnel.

A total of 47 operational response personnel from the fire services in Sogn og Fjordane and Hordaland counties participated in the incident response efforts. The AIBN finds that this should be sufficient to both extinguish the fire and evacuate 67 people from the tunnel. The AIBN believes that the rescue and evacuation work could have been speeded up somewhat had more vehicles and response personnel participated at the Aurland side. Due to the build-up of smoke and poor visibility on the Gudvangen side of the tunnel, half the response personnel on that side had to remain passive.

After careful consideration, the operational scene command in Sogn og Fjordane county decided to send two smoke diving teams from Bergen fire service to Gudvangen to participate in the search and rescue work in the Gudvanga tunnel. The AIBN's assessment is that this was not a well-thought-through decision, as Voss fire service had already pulled out of the tunnel due to insufficient visibility and considered it unsafe to be inside the tunnel. The AIBN is of the opinion that the smoke divers from Bergen fire service should have been flown to the Aurland side and entered the tunnel from there.

The AIBN believes that a good incident response plan and better strategic leadership of the fire services' response efforts could have identified this option.

Aurland fire service did not bring the portable amplifier intended for use in tunnels when called out to the fire in the Gudvanga tunnel. Even though the effect of an amplifier might vary according to which part of the tunnel it is used in, the AIBN finds that it is important to have procedures in place to ensure that equipment that can contribute to efficient rescue efforts is always brought along when the fire service is called out. The AIBN takes a positive view of the fact that an amplifier has been installed in the rescue vehicle for use in areas with poor radio coverage.

2.6 The emergency services' response and cooperation during the rescue work

This section contains a discussion of the other emergency services' response to the incident and of internal and inter-service cooperation in connection with the rescue work.

2.6.1 Notification of the emergency services

Notification of the emergency services (fire and ambulance) on the Aurland side of the tunnel in Sogn og Fjordane county was efficient and timely. The emergency services on the Voss side, on the other hand, were only notified after 25 minutes. In the AIBN's opinion, this delay was undesirable. In the case of an accident or fire in a tunnel, the incident response crews on both sides should be automatically notified in order to ensure efficient and appropriate rescue work.

In this particular case, the delay did not have any bearing on the seriousness of the incident and scope of the injuries/damage, as the smoke from the fire was ventilated towards Gudvangen and parts of the tunnel were already filled with smoke. The response personnel from Hordaland would not have been able to enter the smoke-filled part of the tunnel in which road users were trapped even if they had arrived 25 minutes earlier. Had the fire ventilation not been started immediately, or had it blown the air in the opposite direction, the resources from Hordaland would have been crucial to the effort to evacuate and assist the road users in the tunnel.

2.6.2 Emergency medical response

The emergency medical response seems to have been satisfactory and resources sufficient. The prioritisation of patients also seems to have functioned well. Oxygen was administered as the patients were evacuated, and they were transferred to hospital as quickly as possible using the best available means of transport.

The AIBN observes that in the case of a tunnel fire, the need for medical resources may differ greatly between the two sides of the tunnel, and it should therefore be possible to run the two sides as separate incident sites with different resource requirements. The ambulance personnel from Voss requested more resources from AMK Hordaland, but their request was initially denied because no such instructions had been received from AMK Førde, which was in charge of the operation. The need for more resources was not recognised until it was confirmed by the air ambulance doctor. In the AIBN's opinion, it should be considered whether the respective emergency medical response centres (AMK) should be allowed to make independent decisions based on how the situation is assessed by operational medical personnel on each side of the tunnel.

2.6.3 Cooperation and information flow between the emergency services

The length of the tunnel and the number of road users who were in the tunnel at the time of the incident meant that there was a great need for emergency responders from all the emergency services (the police, medical and fire services) and from two counties (Sogn og Fjordane and Hordaland). A total of five different emergency communication centres were involved in coordinating the response efforts. The AIBN finds that this particular fire illustrates the challenges involved in coordinating, leading and cooperating along so many different interfaces in an emergency.

The cooperation was made even more difficult by the communications network that the emergency services were to use being put out of action. This had consequences for the emergency services on the Aurland side of the tunnel in particular. On the Gudvangen side of the tunnel, communication and cooperation between the emergency services seems to have functioned, though many of the personnel remained passive witnesses to the whole incident.

The AIBN considers it extremely important in connection with such incidents to know where the road users are and how many they are, in order to be able to organise the rescue work efficiently. The lack of CCTV monitoring made this difficult in the Gudvanga tunnel, but the emergency communication centres had some notion of the scope based on the calls they received from road users in the tunnel. However, there was no coordination between the different emergency services' operations centres concerning the different emergency calls they received. Each emergency communication centre was therefore left with an incomplete picture of the critical situation in the tunnel. In the AIBN's opinion, a better overall picture of this and similar situations could provide a better basis for decisions concerning the different emergency services' response and priorities.

The AIBN cannot see that the information from the emergency calls was passed on to the emergency responders so that they could plan their efforts and the deployment of resources as they proceeded through the tunnel. One specific example to illustrate this is that AMK Førde and the police operations centre were notified about the Chinese tourists on foot in the tunnel at 12:56 and 13:06, respectively. Nevertheless, the fire service was unprepared when they encountered the tourists in the tunnel at approximately 14:10, and therefore had to leave their own personnel in the tunnel to make room for the tourists in their vehicles.

The AIBN would like to have seen better control and organisation at the incident site, including a formalised overview of when the road users came out of the tunnel and who they were. This must be seen in conjunction with the fact that the overall picture of the scope of injuries/damage and the number of people involved remained unclear throughout the incident.

2.6.4 Overall assessment of the emergency services' efforts

In the AIBN's opinion, the investigation has shown that internal and inter-service cooperation and information flow between the emergency services were less than optimal. The AIBN would have liked to have seen a coordination of the emergency services' incident response plans, as well as emergency services response exercises in the Gudvanga tunnel, for the purpose of ensuring optimal notification, incident site command, information sharing, organisation and dimensioning. The lessons that can be learnt from the Gudvanga tunnel should be transferred to other tunnels where it is necessary to cooperate along different interfaces.

One safety recommendation is submitted on this point.

2.7 Safety follow-up in the Gudvanga tunnel

As tunnel owner, the NPRA has a clear responsibility for following up safety in the Gudvanga tunnel. In its report after the fire in the Oslofjord tunnel, the AIBN discussed the NPRA's safety management and found the risk-based safety management to be inadequate. In this incident, the AIBN again finds that the NPRA has lacked awareness of the risk factors relating to tunnel fires and the measures necessary to reduce the risks. The fires in the Oslofjord and Gudvanga tunnels give a particularly good indication of the major accident potential of a fire in a heavy goods vehicle inside a long single bore tunnel with subsequent build-up of smoke. The AIBN would like awareness of this to permeate the administration of tunnels.

2.7.1 Fire inspections

Both Aurland fire service's inspections of the Gudvanga tunnel (2009 and 2011) were systems inspections, in which emergency response plans and documentation relating to the tunnel infrastructure and technical installations were reviewed. They did not involve any on-site inspection of the Gudvanga tunnel. The AIBN therefore finds that the nature of the inspections of the Gudvanga tunnel was not appropriate to identifying the safety-critical factors in relation to self-rescue that became evident during this incident.

2.7.2 Drills/exercises

According to the information received from Aurland fire service, one coordination exercise was conducted in the Gudvanga tunnel before the opening in 1991, and one in the Flenja tunnel. According to a memo from Aurland fire service, which was sent to the AIBN in February 2015, several other exercises had also been held in the Gudvanga tunnel before the fire on 5 August 2013, but there is no specification of when these exercises took place. In addition, the NPRA has conducted several tests of technical equipment during the period 2004–2009. There is no documentation to show that the above-mentioned exercises and tests were conducted in accordance with the manual on safety management of road tunnels (HB R511).

The AIBN considers exercises to be an important aspect of following up safety in tunnels. By conducting scenario-based exercises, it is possible to gain a picture of the actual conditions and identify any weaknesses in both procedures and equipment. The AIBN believes that exercises combined with on-site inspections of the tunnel could have identified several of the safety-critical factors in the Gudvanga tunnel relating to the possibility of evacuation, radio communication equipment, options for traffic control and information to road users, and issues relating to smoke control. The AIBN is also of the opinion that there is too little emphasis on self-rescue and evacuation in the HB R511 manual's chapter 16 on training, drills and exercises.

2.7.3 Risk assessments

The risk analysis completed in April 2013 (see section 1.14.2.2) identified several of the issues that became apparent during the fire some months later. The purpose of the risk analysis was to meet the requirements of the Tunnel Safety Regulations and to follow up by further upgrading the tunnel accordingly. The risk assessment provided the NPRA Western Region with the necessary knowledge about the safety situation in the tunnel, including that the chosen firefighting and rescue strategy, which involved the use of fire ventilation, was not recommended.

The risk analysis identified the exact same critical scenario that arose in connection with the incident. The AIBN believes that it would have been possible, based on the risk analysis, to identify strategic and operational measures and implement them in the tunnel. At the same time, the AIBN recognises that the report was produced for a different purpose. The NPRA Western Region was also in the process of planning upgrades to the tunnel in accordance with the findings of the risk analysis, though no binding progress schedule had been adopted at the time of the incident.

2.7.4 Learning from experience

The incident in the Gudvanga tunnel also shows that the ability to learn from experience has been inadequate in the NPRA, i.e. the incident-based safety management has failed. There have been few previous incidents in the Gudvanga tunnel, but the AIBN feels that lessons should then be learnt from incidents in other tunnels and other regions. In the present case, weaknesses corresponding to those that were identified in connection with the incident in the Oslofjord tunnel manifested themselves in the Gudvanga tunnel more than a year later. The AIBN's report on the incident in the Oslofjord tunnel had not been published at the time of the fire in the Gudvanga tunnel, but both the NPRA and the DSB were well aware of the issues discussed in that report.

In connection with the fire in the Oslofjord tunnel, the smoke divers found themselves unable to enter the smoke-filled tunnel entrance. In the Gudvanga tunnel, it once again became clear that the chosen ventilation strategy made it impossible to carry out firefighting efforts from one end of the tunnel and search and rescue work from the other. A further lesson to be learnt from the fire in the Oslofjord tunnel is that road users must be given an opportunity to evacuate before the tunnel fills up with smoke.

2.7.5 Emergency and incident response plans

In principle, emergency response plans consist of an agreement between the tunnel owner and the fire service concerning the division of responsibility and response in the event of an accident in the tunnel, and it is a very important document in terms of ensuring good emergency preparedness and response in the event of a fire. However, the AIBN finds that, like the emergency response plan for the Oslofjord tunnel, the emergency response plan for the Gudvanga tunnel primarily dealt with the technical installations in the tunnel and said little about the preconditions for self-rescue and evacuation of road users. The emergency response plan did not describe any specific measures to prevent road users from becoming trapped in smoke or measures to facilitate self-rescue. The AIBN sees the emergency response plan for the Gudvanga tunnel and the incident that followed as examples of inadequate planning.

Aurland fire service is responsible for preparing an incident response plan for the Gudvanga tunnel as a 'special fire object'. The plan is meant to be an extension of the emergency response plan that the NPRA has prepared for the tunnel. The investigation has shown that Aurland fire service had prepared general procedures for call-outs to tunnels, but had failed to prepare a specific plan for responding to incidents in the Gudvanga tunnel. In the AIBN's opinion, Aurland fire service's general procedures for responding to incidents in tunnels did not meet the requirements that apply to an incident response plan. The AIBN considers it essential that Aurland fire service prepare an incident response plan for the Gudvanga tunnel so that the safety of road users can be properly safeguarded.

The AIBN takes a critical view of the fact that the updated emergency response plan for the Gudvanga tunnel and Aurland fire service's general procedures for tunnel call-outs involve an unchanged ventilation strategy. Nor do the new emergency response plan or the general procedure for tunnel call-outs mention any measures to evacuate road users before starting fire ventilation.

2.7.6 Overall assessment of safety follow-up

The AIBN finds that the weaknesses identified in this investigation as regards the preconditions for applying the self-rescue principle are related to the overall follow-up of safety in the tunnel on the part of both the NPRA and the fire service. The tunnel's emergency response plan said little about the preconditions for self-rescue and evacuation. The NPRA's safety management had failed to identify safety-critical factors. Exercises as described in HB R511 were not held and the fire service's inspection of the tunnel as a special fire object was inadequate. Nor did Aurland fire service have any specific incident response plan for the Gudvanga tunnel.

One safety recommendation is submitted on this point.

2.8 Overall guidelines for tunnel safety versus the self-rescue principle

In light of the present incident and the reports from SINTEF, Oslo University Hospital and the Technical Research Institute of Sweden, the AIBN finds that there is a need to reassess the fundamental principle underlying fire ventilation in the Gudvanga tunnel and other long road tunnels. The knowledge that is presented in this report indicates that the use of fire ventilation should be thoroughly reviewed, and that new plans and tunnel monitoring measures should be established. In addition, the options and procedures for providing information to road users in tunnels must be reviewed.

The investigation has found weaknesses in the NPRA's follow-up and use of technical installations and safety equipment in the Gudvanga tunnel. Weaknesses have also been found in the fire service's inspection of the tunnel with respect to detecting that the tunnel and the plans did not facilitate self-rescue. Similar weaknesses have previously been identified relating to safety management and inspection of the Oslofjord tunnel. The AIBN is therefore of the opinion that the Directorate of Public Roads and the DSB together must assume a leading role in the work to remedy these weaknesses.

The investigations have shown that smoke control and evacuation of road users from long single bore tunnels are more demanding than indicated in the emergency response plans for the tunnels. Decisions in connection with firefighting and rescue work should be made on the basis of on-site observations and assessments of the fire, tunnel and traffic situation in each case, and not on the basis of pre-defined strategies.

The AIBN finds that there is a need for closer collaboration between the DSB, the fire service and other fire expertise in considering the strategy for applying the self-rescue principle in tunnels. In order to be able to make correct and effective decisions, the level of expertise relating to evacuation and smoke control in road tunnels should be increased through interdisciplinary collaboration and, if necessary, supplemented by external expertise.

At the same time, the NPRA must focus on the emergency response plans for tunnels and on the preconditions for self-rescue in each specific tunnel. In tunnels with a minimum of equipment, the focus must be on compensatory operational and strategic measures, including good emergency and incident response plans, rescue exercises and procedures for cooperation between the emergency services. Such compensatory measures were not in place in the Gudvanga tunnel.

3. CONCLUSION

3.1 Key investigation results of importance to safety

In the AIBN's opinion, there were failures on four material points when 67 persons were trapped in the smoke in the 11.4 km long tunnel and 28 persons were seriously injured:

1. The tunnel was not equipped with any kind of monitoring system or device for counting vehicles that could have provided information about how many vehicles were in the tunnel at all times. The road traffic control centre (VTS) and the fire service thereby did not have an overview of how many vehicles were on the side of the fire towards which the smoke was ventilated.

2. The road users received no information that immediate evacuation was necessary. Only those in the immediate vicinity of the fire scene or who realised what was happening at an early stage managed to evacuate before the tunnel was filled with smoke.

3. As a result of the pre-defined strategy for firefighting and rescue work that is set out in the emergency response plan for the tunnel, the road traffic control centre routinely started the fire ventilation immediately after the fire was reported, so that the smoke from the fire was ventilated 8.5 km in the direction of Gudvangen. The smoke blocked the only possible evacuation route for the road users on the Gudvangen side of the fire.

4. The tunnel design and safety equipment did not adequately facilitate self-rescue.

The requisite conditions for the self-rescue principle were thereby not present, and the AIBN believes that this is the most important lesson to be learnt from this incident.

3.2 Investigation results

3.2.1 <u>The fire</u>

a) It has not been possible to establish exactly why the heavy goods vehicle caught fire. In the AIBN's opinion, the factors that may have contributed to the fire are difficult to detect through an ordinary safety check of the vehicle.

b) The driver took necessary action in response to the indication that something was wrong with the heavy goods vehicle. He tried to put out the fire using a 6 kg fire extinguisher from his own vehicle.

c) SINTEF NBL has estimated the fire effect on the vehicle to be around 25 MW, assuming that 200 litres of diesel was burnt off. The tunnel's ventilation system was designed to control a fire of 5 MW, but has the capacity to control approximately 20 MW.

3.2.2 <u>The tunnel's safety equipment and fire ventilation</u>

a) The fire extinguishers in the tunnel were not appropriate to preventing the fire from developing.

b) Immediately after VTS was notified of the fire at 12:03, the tunnel was closed by the flashing red lights outside the tunnel entrance being activated. The tunnel was not equipped with road barriers at the time of the incident.

c) VTS started fire ventilation as a matter of routine so that the smoke from the fire was ventilated over a distance of 8.5 km in the direction of Gudvangen. This was in accordance with the guidelines in the emergency response plan, which stated that the fire service closest to the tunnel should enter from the smoke-free side to put out the fire, and that the smoke should be diluted with fresh air so that it was less harmful to the road users. At the same time, it spread the smoke to areas of the tunnel that could otherwise have remained free of smoke for a longer period.

d) The fire ventilation rate was not programmed as described in the emergency response plan. The emergency response plan prescribed a fire ventilation rate of 1–2 m/sec, while the programmed rate was 2.5 m/sec.

e) The fire ventilation did not meet the requirement in the emergency response plan for an air velocity of 1-2 m/sec. At one point during the period between 13:54 and 14:09, the air velocity in the direction of Gudvangen was as low as about 0.8 m/sec.

f) There were signs in the tunnel that could have been used to instruct road users to turn around, and it would have been possible to provide verbal information by transmitting radio break-in messages. These possibilities were not used, which meant that the road users were not given information that could potentially have helped them in their self-rescue efforts.

g) The Gudvanga tunnel did not facilitate self-rescue with respect to design, technical installations and safety equipment. The road users had no other escape routes than via the tunnel exits in the 11.4 km long tunnel.

h) The radio communication system in the Gudvanga tunnel was sensitive to heat and did not enable two-way feeding of signals to radiating cable segments. When the system failed, it had a direct impact on the work at the incident site.

3.2.3 Self-rescue and consequences for the road users

a) Of those who could not get past the burning heavy goods vehicle, only those who understood the situation at an early stage were able to evacuate before the tunnel was filled with smoke.

b) The basis for applying the self-rescue principle was not present, as the road users' only evacuation route on the Gudvangen side of the fire was blocked by smoke, without the road users having been given information or a chance to evacuate the tunnel.

c) Few U-turn facilities/emergency lay-bys and minimal visibility made it difficult to evacuate by car. Those who evacuated on foot found it difficult to breathe and became disoriented.

d) SINTEF's report draws a serious picture of the critical situation in which the road users found themselves, their experiences of the situation and the traumas they suffered.

e) The incident caused 28 cases of acute smoke inhalation injuries, and the report by Oslo University Hospital concludes that 23 were seriously injured and 5 were very seriously injured.

f) During the present incident, the period of time spent in the tunnel was just within the limit of what the road users could withstand without immediate danger to their lives. Young age and good health probably contributed to this.

g) The smoke inhalation injuries suffered by the 28 people are not included in Statistics Norway's statistics of road traffic accidents. Nor are there any systematic records of this type of injuries in the Directorate of Health's register of personal injuries.

h) The situation was most serious for the road users who made their way towards Gudvangen on foot and were not picked up by the rescue crew and who remained in the tunnel outside their vehicles for the longest time.

i) In this fire, the best course of action would be for the road users to remain in their cars for as long as possible, and preferably until they were found by rescue crew. This may not necessarily have been the best solution had the circumstances been different.

j) Use of text messages to road users in defined areas in the event of such tunnel incidents is potentially an effective information channel.

3.2.4 Firefighting and rescue work

a) The fire service operated on the basis of a predefined fire ventilation direction and velocity and gave priority to putting out the fire over evacuating road users.

b) The fire was extinguished within 25 minutes.

c) The fire service's subsequent rescue work inside the tunnel was efficient, and the response personnel acted at great risk to themselves.

d) The fire service had to leave behind some of their own personnel in order to make room for the tourists from the coach that was left behind in the tunnel.

e) As a consequence of a communication failure between VTS, the 110 emergency communication centre in Sogn og Fjordane county and Aurland fire service, the possibility of transmitting a radio break-in message was not utilised.

f) The response personnel on the Gudvangen side had to remain passive because of the smoke. In the AIBN's opinion, the smoke divers from Bergen fire service should have been flown to the Aurland side and entered the tunnel from there.

3.2.5 The emergency services' response and cooperation

a) The emergency services in Hordaland that were to cover the Gudvangen side of the tunnel were only notified after 25 minutes. In the AIBN's opinion, this delay was undesirable, though with the chosen firefighting and rescue strategy, it did not have any bearing on the seriousness of the incident and scope of injuries/damage.

b) The emergency medical response was satisfactory and resources were sufficient. The patients were prioritised and oxygen administered as they were evacuated, and they were transferred to hospital as quickly as possible using the best available means of transport.

c) No fire incident commander was present in the ICC to keep an overview of the situation, and there was no coordination and forwarding of information from incoming emergency calls to the response personnel in the tunnel. The AIBN finds that this made it more difficult to keep an overview of the situation and involved challenges relating to communication and organisation of the work at the incident site.

d) There are challenges involved in notifying, coordinating, leading and cooperating along so many different interfaces in an emergency (involving the emergency services from two counties and a total of five emergency communication centres).

e) The AIBN would have liked to have seen a coordination of the emergency services' incident response plans, as well as emergency services response exercises in the Gudvanga tunnel, for the purpose of ensuring optimal notification, incident site command, information sharing, organisation and dimensioning.

3.2.6 Safety follow-up and plans

a) The AIBN's investigations into the incidents in the Gudvanga and Oslofjord tunnels show that there is a conflict between the pre-defined strategy for the fire service's firefighting and rescue work, which involves use of fire ventilation as defined in the emergency response plan, and the self-rescue principle.

b) The emergency response plan for the Gudvanga tunnel primarily dealt with the technical installations in the tunnel and said little about the preconditions for self-rescue and evacuation of road users. The emergency response plan did not describe any specific measures to prevent road users from becoming trapped in smoke or measures to facilitate self-rescue. Aurland fire service has prepared general procedures for call-outs to tunnels, but has not prepared any specific plan for the Gudvanga tunnel to be enclosed with the emergency response plan.

c) It has not been documented that full-scale or functional/simulation exercises as described in HB R511 have been conducted in the Gudvanga tunnel, whereby safety-critical factors could have been identified and addressed to enable self-rescue.

d) The risk analysis that HOJ Consulting and Matrisk carried out for the NPRA, completed in April 2013, identified the exact same critical scenario that arose in connection with the present incident (Høj 2013). The NPRA Western Region was in the process of planning upgrades to the tunnel in accordance with the findings of the risk analysis, but no immediate action had been taken.

e) The investigation has identified weaknesses in the NPRA's safety management relating to the Gudvanga tunnel as regards follow-up of safety-critical factors, learning from experience and plans to facilitate self-rescue.

f) The nature of the inspections of the Gudvanga tunnel as a special fire object was neither appropriate to identifying the safety-critical factors that manifested themselves in this incident, nor to ascertaining that the tunnel and plans did not facilitate self-rescue.

4. SAFETY RECOMMENDATIONS

The investigation of this accident has identified several areas in which the AIBN deems it necessary to submit safety recommendations for the purpose of improving road safety.[6]

Safety recommendation ROAD no 2015/02T

The investigation of the fire in the Gudvanga tunnel on 5 August 2013 uncovered weaknesses in the tunnel's design and safety equipment that had a direct bearing on the rescue work and evacuation of road users. They include under-dimensioned fire extinguishing equipment, a ventilation system with a control fault, a vulnerable communications network without redundancy, inadequate traffic control, monitoring and overview of vehicles in the tunnel, and limited aids for evacuation.

The Accident Investigation Board Norway (AIBN) recommends that the Norwegian Public Roads Administration improve the safety equipment in Gudvanga tunnel in order to ensure its robustness and satisfy the requisite conditions for self-rescue.

Safety recommendation ROAD no 2015/03T

The investigation of the fire in Gudvanga tunnel on 5 August 2013 revealed that road users were not given information that could potentially have helped them in their self-rescue efforts. Information signs and radio alerts were not used. Only those in the immediate vicinity of the fire scene or who realised what was happening at an early stage managed to evacuate before the tunnel filled with smoke. The AIBN believes that giving road users information is essential in order to comply with the self-rescue principle.

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration and relevant fire services improve information for road users in the event of a fire in Gudvanga tunnel. Signs, radio alerts and text message notification should be considered, among other things.

Safety recommendation ROAD no 2015/04T

The investigation of the fire in Gudvanga tunnel on 5 August 2013 revealed that five people were severely injured and 23 seriously injured by the smoke. That is much more serious than was first assumed. The smoke injuries are not registered in Statistics Norway's injury statistics for road traffic accidents or in the Norwegian Directorate of Health's register of personal injuries. The AIBN believes that personal injuries in tunnels should be systematically registered, so that this information can be used in connection with preventive work.

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration take steps to ensure that Statistics Norway and/or the Directorate of Health include personal injuries as a result of exposure to smoke in connection with tunnel fires in relevant accident statistics.

[6] The investigation report is submitted to the Ministry of Transport and Communications, which will take necessary measures to ensure that due consideration is given to the safety recommendations, cf. the Regulations of 30 June 2005 on Public Investigation and Notification of Traffic Accidents etc. Section 14.

Safety recommendation ROAD no 2015/05T

In connection with the fire in Gudvanga tunnel on 5 August 2013, the smoke was ventilated from the fire scene towards the tunnel opening in Gudvangen before the road users had a chance to evacuate from the tunnel. This resulted in 67 people becoming trapped in the smoke and 28 people suffering serious smoke injuries. The AIBN believes that the requisite conditions for the self-rescue principle were not met through the pre-defined strategy for fire extinguishing and rescue work as defined in the tunnel's emergency response plan. Corresponding findings were also made in connection with the fire in the Oslofjord tunnel on 23 June 2011.

The Accident Investigation Board Norway recommends that the Directorate for Civil Protection (DSB) and the fire service, in consultation with the Norwegian Public Roads Administration, revise the strategy for fire extinguishing, rescue and smoke control in long single-lane tunnels, so that, as far as possible, the fire ventilation does not come into conflict with the road users possibility of rescuing themselves.

Safety recommendation ROAD no 2015/06T

The investigation of the fire in Gudvanga tunnel on 5 August 2013 shows that the emergency services face challenges as regards notifying, coordinating, leading and cooperating along so many different interfaces in a crisis situation. The cooperation was made even more difficult as a result of the communications network that the emergency services were to use being put out of action and the fire incident commander not being in the command centre. The AIBN has identified a lack of coordination of the emergency services' response plans in the Gudvanga tunnel with respect to ensuring optimal notification, incident site command, information sharing, organisation and dimensioning.

The Accident Investigation Board Norway recommends that the emergency services involved (the fire service, health service, police) in the Gudvanga tunnel coordinate the plans for notification, incident site command, information sharing and for ensuring sufficient resources.

Safety recommendation ROAD no 2015/07T

The investigation of the fire in Gudvanga tunnel on 5 August 2013 has shown that the requisite conditions for self-rescue were not present. The weaknesses are related to inadequate safety follow-up of the tunnel. The tunnel's emergency response plan and the Road Traffic Centre's and fire service's incident response plans/procedures for call-out to the tunnel said little about what was necessary to enable self-rescue and evacuation. Aurland fire service had not prepared an incident response plan for the Gudvanga tunnel. Drills described in HB R511 were not held and the fire service's inspection of the tunnel as a special fire object was inadequate.

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration Region West and Aurland fire service cooperate on updating and coordinating the emergency response and incident response plans for Gudvanga tunnel in order to improve the possibility of self-rescue, and carry out inspections and scenario-based drills in Gudvanga tunnel.

Accident Investigation Board Norway

Lillestrøm, 11 March 2015

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APPENDICES

Appendix A: Safety recommendations

Appendix B: Time line for the report

Appendix C: Report by SINTEF Technology and Society on the road users' experiences

Appendix D: Report by Oslo University Hospital on health effects (In Norwegian)

Appendix E: Report by SINTEF NBL on fire effect (In Norwegian)

Appendix F: Report by SP Technical Research Institute of Sweden on smoke gas production (In Swedish)

Appendix A: Safety recommendations

The investigation of this accident has identified several areas in which the AIBN deems it necessary to submit safety recommendations for the purpose of improving road safety.[7]

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The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration and relevant fire services improve information for road users in the event of a fire in Gudvanga tunnel. Signs, radio alerts and text message notification should be considered, among other things.

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[7] The investigation report is submitted to the Ministry of Transport and Communications, which will take necessary measures to ensure that due consideration is given to the safety recommendations, cf. the Regulations of 30 June 2005 on Public Investigation and Notification of Traffic Accidents etc. Section 14.

Safety recommendation ROAD no 2015/05T

In connection with the fire in Gudvanga tunnel on 5 August 2013, the smoke was ventilated from the fire scene towards the tunnel opening in Gudvangen before the road users had a chance to evacuate from the tunnel. This resulted in 67 people becoming trapped in the smoke and 28 people suffering serious smoke injuries. The AIBN believes that the requisite conditions for the self-rescue principle were not met through the pre-defined strategy for fire extinguishing and rescue work as defined in the tunnel's emergency response plan. Corresponding findings were also made in connection with the fire in the Oslofjord tunnel on 23 June 2011.

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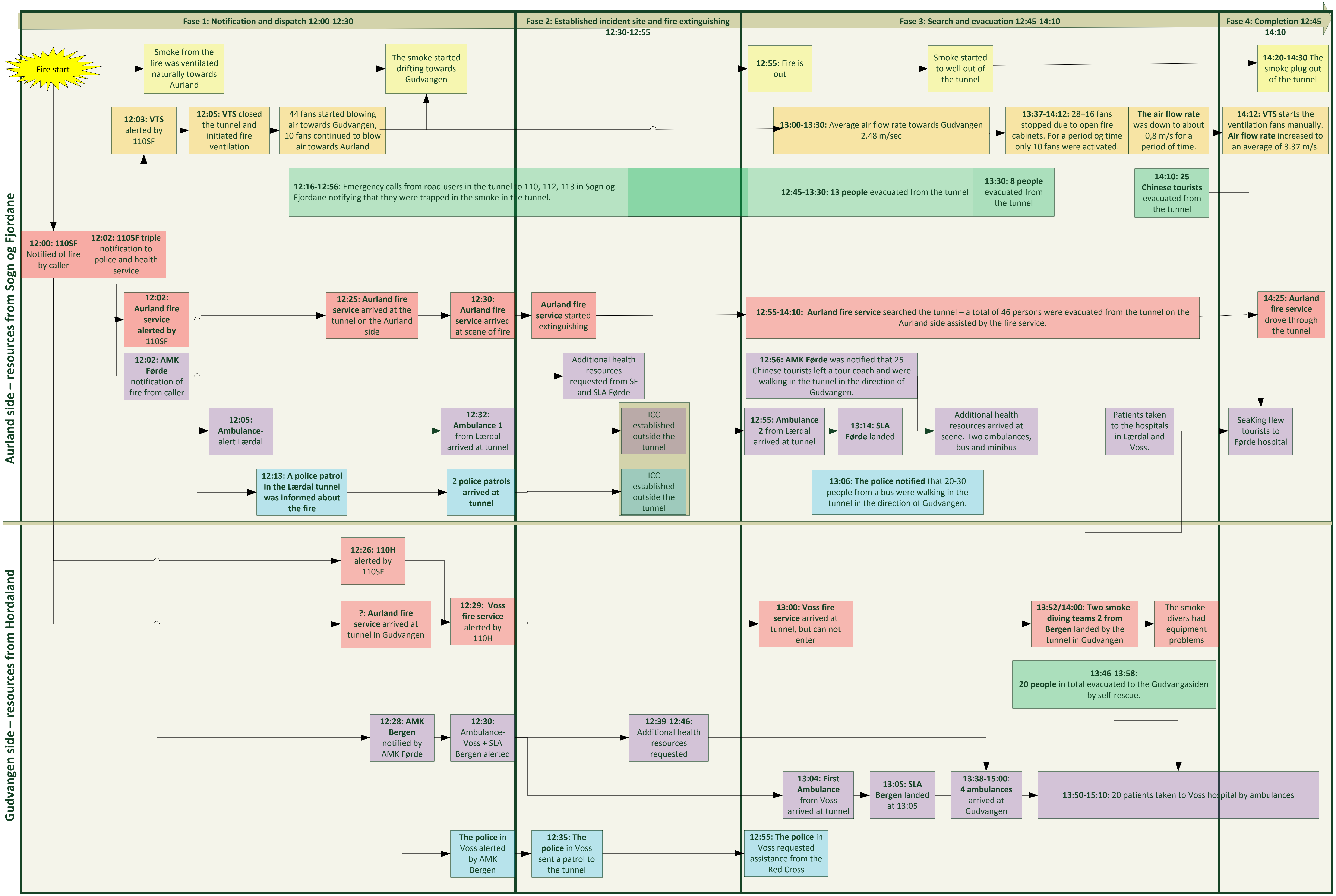
The Accident Investigation Board Norway recommends that the emergency services involved (the fire service, health service, police) in the Gudvanga tunnel coordinate the plans for notification, incident site command, information sharing and for ensuring sufficient resources.

Safety recommendation ROAD no 2015/07T

The investigation of the fire in Gudvanga tunnel on 5 August 2013 has shown that the requisite conditions for self-rescue were not present. The weaknesses are related to inadequate safety follow-up of the tunnel. The tunnel's emergency response plan and the Road Traffic Centre's and fire service's incident response plans/procedures for call-out to the tunnel said little about what was necessary to enable self-rescue and evacuation. Aurland fire service had not prepared an incident response plan for the Gudvanga tunnel. Drills described in HB R511 were not held and the fire service's inspection of the tunnel as a special fire object was inadequate.

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration Region West and Aurland fire service cooperate on updating and coordinating the emergency response and incident response plans for Gudvanga tunnel in order to improve the possibility of self-rescue, and carry out inspections and scenario-based drills in Gudvanga tunnel.

Timeline of the fire in the Gudvanga tunnel 5 August 2013



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The Gudvanga tunnel fire in 2013

A description of the road users' experiences and self-rescue efforts to escape the smoke-filled tunnel

VERSION
1.0

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SUMMARY
SINTEF Transport Research conducted interviews with individuals and families who were present in the Gudvanga tunnel during the fire on 5 August 2013. Prior to the interviews with the road users, we (SINTEF) carried out an inspection of the tunnel ai collected experiences of rescue crew members from both sides of the tunnel. The objective was to analyse the road users' experiences and self-rescue efforts. To achieve this goal, we have considered the following aspects in particular:

- What mental and physical stressors were the road users exposed to as they sought their way out of the tunnel that was suddenly filled up with smoke?
- What information did they receive and what rescue equipment were available to support them in their self-rescue efforts?
- How did foreign tourists experience the situation and what level of safety did they expect in Norwegian tunnels?
- What assistance do road users need to facilitate self-rescue?
- What can we learn from this incident about how people perceive, plan and carry

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SINTEF

Contents

1 Description of the events during the Gudvanga tunnel fire

1.1 The Gudvanga tunnel fire

At approximately 12:00 on Monday 5 August 2013, a fire breaks out in a heavy goods vehicle in the Gudvanga tunnel on E16 between Gudvangen and Aurland in the county of Sogn. The notification of the fire is received by the emergency communication centre (110) without delay at 12:00. The fire and rescue service in Aurland is called out at 12:10 and arrives at the scene of the fire at 12:30. In accordance with the emergency response plan, the road traffic control centre has by that time, reversed the direction of the tunnel ventilation. Consequently, the smoke is forced down towards the tunnel's western exit at Gudvangen. This, to enable the fire and rescue service from Aurland to enter the tunnel and reach the burning vehicle.

When the smoke is forced westwards in the direction of Gudvangen, a part of the tunnel suddenly fills up with smoke. Consequently, the road users present in this section of the tunnel are now unable to see anything at all. Some of the road users trapped in the smoke on the western side of the fire are in contact with the emergency communication centre and are advised to stay in their cars, or lie down inside the car. Others choose to slowly walk or to drive their car inside the smoke-filled tunnel, westwards towards Gudvangen. After about two hours, they reach this exit, and some of them are completely exhausted. They are treated with oxygen and brought to the Voss Hospital, and subsequently transferred to the Haukeland University Hospital in Bergen.

The fire is extinguished after approximately one hour. The rescue crew can now pass the burnt-out vehicle and move westwards in the tunnel. The road is partially blocked by cars that have been locked by their driver and left behind. The team has to move the cars with the strength of their hands . A bus driver and two Norwegian couples receive assistance from the rescue team and are brought out of the tunnel on the eastern side (the Aurland side). As they proceed through the tunnel, more people are brought out, including all the Chinese coach passengers. They are brought to the hospital in Lærdal, and most of them are subsequently transferred to the hospital in Førde.

The rescue crew come out of the tunnel on the Gudvangen side at 2:30 p.m., after ascertaining that nobody is still inside the tunnel.

1.2 The Gudvanga tunnel and the emergency preparedness

The information provided in this following section is based on an inspection of the tunnel and interviews with the rescue personnel in Aurland and Voss in autumn 2013, among other sources.

The Gudvanga tunnel on the E16 road is an 11.4 km long single bore tunnel rising at a gradient of 3.5% from Gudvangen in the west towards Aurland in the east. The tunnel has ceiling lights, untreated walls and partially gravelled shoulders between the edge markings and the tunnel walls. There are emergency lay-bys with emergency telephones, alternately on the right and left side of the road. There are no evacuation room in the tunnel. The tunnel has radio and mobile telephone coverage.

The tunnel has natural ventilation towards Aurland in the east. To make it possible for the fire and rescue service in Aurland to reach and extinguish a fire in the tunnel, it has been decided that in the event of a fire in the tunnel, the direction of the ventilation is to be reversed so that it blows towards Gudvangen in the west. This is activated by the road traffic control centre in consultation with the fire and rescue service.

The conditions after a fire in the tunnel, including the position of the vehicles that had been left behind, are registered before the tunnel is cleared.

After the fire in August 2013, there was extensive damage to the tunnel and many of its installations. The tunnel was closed for renovation and upgrading. On 5 September, the tunnel was reopened. The speed limit was reduced for a month, the walls have been painted white, and adjustments have been made to the hard shoulders along the tunnel wall.

2 General considerations relating to road tunnels and emergency preparedness

2.1 Emergency preparedness in Norwegian road tunnels

Generally, the road administration and rescue services have very little information about the conditions in the tunnel when a critical incident occurs such as a fire . Information about the burning vehicle and its load is often lacking, as well as the information about other road users in the tunnel. Such information could be very useful to the emergency communication centres and to the rescue personnel in their choice of the strategy to decide for the rescue work. We have gathered the following decisive factors:

- The incidents that can potentially occur, and the emergency response plans
- The conditions that vary greatly from one tunnel to another, from one fire to another and from one person to another.

- How should rescue work strategies be chosen under different circumstances?
- How should road users act without information in the self-rescue phase in different situations?
- How would assisted self-rescue function, when road users are required to respond to information and rescue equipment?

Road users in a road tunnel where a fire breaks out are left to their own devices; the self-rescue principle applies until they are assisted by rescue personnel after the fire has been brought under control, if at all. Successful self-rescue is therefore essential for these road users to find out a safe place.

There are several factors that call for a re-assessment of this actual crisis management strategy. For example, the consequences of reversing the direction of ventilation after the outbreak of the fire can have a major impact on the road users' self-rescue possibilities. In tunnels with an intact communication system, the road users can obtain or procure valuable information that can be used as the basis for choosing a good self-rescue strategy. Then it is not just a matter of self-rescue, but a form of **assisted self-rescue**. However it is importantthat the information provided is relevant and correct and that it does not invite road users to make unfortunate choices. Emergency communication centres and rescue personnel must agree on what information should be provided and make sure that it is communicated as briefly and concisely as possible. Information from rescue crews to the emergency communication centre about the conditions in the tunnel can also be crucial, for example the information that the fire has been extinguished, that the amount of smoke will decrease and that rescue crews are on their way.

2.2 The road users' preconditions for self-rescue

The single most important prerequisite for successful self-rescue is to recognise the danger early enough to be able to leave the dangerous area before it is too late. Both general knowledge and specific information about the situation in question will increase the possibility of taking action before the emergency develops.

SINTEF

Research on how the brain's decision-making processes work under severe stress shows that intense emotional states associated with fear affect the attention process, the quality of decisions, and the planning and performance of self-rescue behaviour. The people inside the tunnel experienced strong negative stress, which led to high levels of the stress hormone cortisol and increased the adrenaline level. Elevated cortisol levels reduce people's working memory and their ability to split their attention, and thus the risk increases with the situation's complexity, level of difficulty and level of danger. The following are primary factors that people experience in any situation:

1. **Context:** Define the context. Where am I? What is happening? What am I doing here? What happens next?
2. **Goals:** Set goals for one's actions in the specific context, expected outcome and how to proceed.
3. **Outcome:** What was the outcome and what were the consequences?

All the people were physically present in the same tunnel, but the individualcontexts were different. For example:

- Distance to the fire meant that some people did not know what was going on
- Some people were close enough to see the fire and chose to drive past it
- Many were waiting inside their car in the queue. Why?
- Some started to make a U-turn. What does that mean?
- Had a caravan, which restricted freedom
- Families, single persons, children, dogs, age differences
- Thick smoke, can't see a thing, distressing
- Much noise, people calling, loud booms, collisions etc.
- Some had water and towels
- Tourists, unfamiliar with the area and Norwegian tunnels, language problems

The list of factors is very long; some of them are partly common factors and others very different such as the type of vehicle driven by the persons present in the tunnel. It is a matter of what each individual can do and has the possibility of doing, and about what type of help they can get. Each person together with others close by, must planwhat is the best to do.

Natural survival mechanisms are activated in those who are unable to get away and therefore end up in such a dramatic and critical situation. They are well-known reactions linked to the 'fight or flight' motivation. Some will flee or get away without considering whether what they are fleeing to may be worse than what they are fleeing from. For others, situations of extreme stress lead to an inability to react or an apathy. The emergency communication centre's communication with people in situations of extreme stress is demanding and can be very difficult. It is important that the operators in the emergency communication centres have the knowledge and experience required to communicate with people in such situations and that they are informed about the incident so that they can provide correct and important information and guidance.

SINTEF has focused on what the road users experienced in the successive phases, the choices they made and their self-rescue performance. How did they assess the situation, and what were the premises for the choices they made?

3 Description of the road users in the Gudvanga tunnel

No complete overview is available of all the road users who found themselves in the Gudvanga tunnel from the time when the fire broke out until the tunnel was closed for traffic. Some road users who got out of the tunnel at an early stage, were interviewed by various media about their experiences. Some of those who followed closely behind the burning vehicle were able to make a U-turn and to exit at the west side in the direction of Gudvangen, avoiding thus to being trapped by the smoke. Some of the road users coming from the east side, used their hazard warning lights to warn road users trapped in the car queue behing the burned vehicle.

The objective of this SINTEF's study is to analyse the behaviour of the 67 people who were trapped in the smoke in the western section of the tunnel, after that the ventilation had been reversed . All the ten families interviewed, experienced extreme stress and acute fear of dying. Such an experience can have as consequences, severe after-effects and traumas.

People are different even under normal conditions, but we gradually learn to know ourselves and each other. Highly traumatic situations are seldom experienced – by some people never experienced and by others only once or a few times in their lives. None of us knows how we will react to such situations, and much less how others will react.

Fifty (50) of those who were in the tunnel were non-Norwegian citizenswho could not speak and understand Norwegian, and some of them knew very little English as well. Twenty-five (25) of these people were Chinese (Taiwan) citizens travelling in a tour coach driven by a Slovak driver. Sixteen (16) of the people in the tunnel were Norwegian citizens: two retired couples, one family with three daughters, a father with two daughters, a father and his daughter, one person accompanied by a non-Norwegian cohabitant, and one driver alone in the car.

We have no information about the gender or age of the Chinese tourists. Age and prior state of health: none had any serious mobility impairments. One Norwegian national and one non-Norwegian national were alone in their cars, the rest were accompanied by family members, friends or by co-passengers in the tour coach.

Some of the vehicles in the tunnel were difficult to turn around: one tourist coach, one heavy goods vehicle, four passenger cars with trailers, one camping van. Two trailers were disconnected from their vehicles, but before the tunnel was filled with smoke. With the exception of the drivers of the heavy goods vehicle and the tour coach, all the road users were on holiday.

Most of the Norwegian road users, though not all, were used to driving in long single bore tunnels and had driven through the Gudvanga tunnel many times before. None of the Norwegian road users expected to find evacuation rooms in the tunnel. Some of the non-Norwegian road users did expect to find such rooms, and several of them even tried to locate them. The French road users referred to the accident in the Mont Blanc tunnel in 1999 in connection with their experience in the Gudvanga tunnel.

3.1 Method and how the interviews were conducted

SINTEF used a semi-structured interview design for the interviews/conversations with a sample of those who were present in the tunnel, and focused on the issues specified by the Accident Investigation Board Norway (AIBN). Some of the foreign tourists were contacted by email and answered questions about their experiences in this way.

The AIBN and SINTEF carried out an inspection of the Gudvanga tunnel and discussed with/interviewed rescue personnel from Aurland and Voss prior to interviewing the road users. The fire and rescue and the ambulance crews present at both the tunnel entrances described in detail their experience of how the fire developed, how the fire was put out and how they evacuated people from the tunnel, administered first aid and transported people to hospital.

It was important to have this information prior to starting the interviews, as it provided us an insight into what happened and enabled us to organise the questions in topics and conduct interviews/discussions with the road users in an informative and sympathetic manner.

Based on information provided by the AIBN, SINTEF collected the overview of the following:

- The number of cars, the types of car, their position in the tunnel and the state they were in
- The number of road users who were present in the tunnel and were taken care of outside the tunnel
- Their age, gender, nationality and role (driver, passenger etc.)

It is important to keep in mind that there were specific challenges involved in interviewing road users. Here is the summary:

- The time that has lapsed since the incident occurred is both a positive and a negative factor. On the positive side, people have had time to reflect on the incident, achieve a certain distance in reflexion, and possibly been able to talk to others about it and to gain some perspective on what happened. What is unfortunate is that important elements of what happened in the tunnel are more difficult to recall and people's concrete memory of what happened has changed. This is completely normal, as people's neural networks are continuously changing and dependent on repetition. At the same time, people themselves contribute actively to such changes through reading about the accident, talking with others about it etc.

- Some may have had unpleasant emotional reactions to the incident, which may have caused stress reactions that affect both their short-term memory and their ability to store and recall what happened.

- Language and cultural differences are important to keep in mind, as we had to deal with many nationalities. The choice of interpreter is important, because an interpreter does not just translate, but needs to have an understanding of the actual incident in order to convey the subtleties that people express in their mother tongue.

- The interviews were conducted by telephone and followed up by emails to verify what the interviewees had told us.

- To some, we sent the questions by email. They answered our questions and had no objection to telling us about their experiences in the tunnel.

Ten interviews were conducted (nine by telephone and one face to face) and three people answered questions by email. In some of the interviews, two people participated together. In all, we have covered the experiences of 32 people and obtained a description for the group of 25 tourists in the coach and their driver. Directly and indirectly, we have thus covered the experiences of 57 of the 67 people who were trapped in the tunnel and had to take self-rescue actions when the tunnel was filled with smoke.

4 Phases of the time spent by road users in the Gudvanga tunnel and their self-rescue

4.1 Self-rescue behaviour and the experiences of Norwegian road users

All the road users covered by SINTEF's study entered the tunnel from Gudvangen in the west after the heavy goods vehicle that caught fire and before the tunnel was closed for traffic, i.e. in the course of approximately 10–15 minutes around 12:00. The reactions of the Norwegians who were in the tunnel are described below. The non-Norwegian road users and their experiences are described in section 4.2. The schematic diagram below illustrates the sequence of events divided into time phases numbered 1 to 5 (Figure 1).

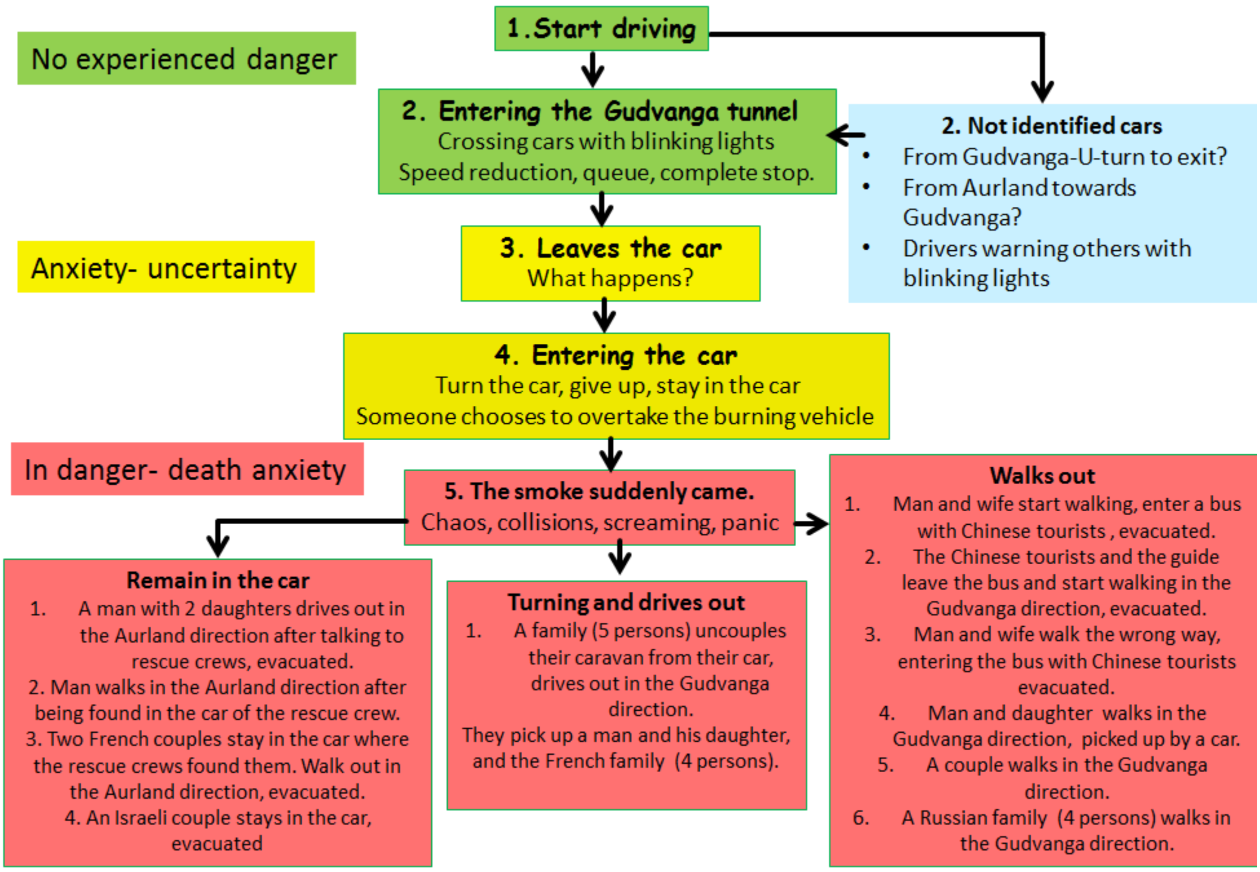

Figure 1: *Presentation of the most important phases and the road users' self-rescue behaviour during the Gudvanga tunnel fire.*

Figure 1 is the presentation of the most important phases of the event and what happened, based on the information obtained through our interviews with the car occupants present in the tunnel during the fire. The development can be described as follows:

<u>Phase 1 and 2: No perceived danger</u>

They had all started off at different times and covered different distances before reaching the Gudvanga tunnel. One person had noticed a lorry at the petrol station just before the entrance to the tunnel. The lorry did not seem to be working as it should. It drove into the tunnel shortly before they themselves entered the tunnel. When asked, everybody said that they perceived the situation as normal when approaching the tunnel and nobody felt that they were in any form of danger. This did not change as they entered the tunnel, despite the fact that oncoming cars were flashing their lights as they drove towards the exit.

- Some mention that they believe that part of the tunnel was unlit as they drove into it, but that they did not reflect on this at that time.
- Some noticed that oncoming cars were flashing their lights, but they did not reflect on what this could mean.
- Everybody continued driving until the traffic gradually slowed down and finally came to a complete stop.
- Nobody expressed that they had any concern at this time about an eventual danger that might lie ahead.
- One couple said that they thought the flashing of lights was perhaps to warn them that there were sheep in the tunnel. That was quite common where they came from.
- An unknown number of road users who entered the tunnel from the west side got out before they were caught in the smoke, either by overtaking the burning vehicle or by turning around and drove back out towards Gudvangen. These road users are an important source of information about what was happening to the cars and people inside the tunnel who were unable to turn around and exit, but they have not been interviewed by SINTEF.
- Others chose to take a chance and drive past the burning heavy goods vehicle, which was up in flames by that time. Fortunately, they did not meet anyone driving in the opposite direction. They drove into the smoke on the eastern side of the burning vehicle and managed to reach the eastern tunnel exit (on the Aurland side).
- They must clearly have done so before the direction of the tunnel's ventilation was reversed. Some road users who drove into the tunnel from the east side probably passed the burning vehicle and drove on, exiting the tunnel at Gudvangen on the western side.
- The most probable scenario is that it was these drivers, along with some of those who turned around in the early phase, who flashed their lights and used the hazard warning lights to warn drivers who were on their way into the tunnel from the Gudvangen side.

Phase 3: Anxiety and uncertainty

At one point all the cars have stopped, and they are standing in a queue, waiting to drive on. It does not take long, however, before they all begin to feel uncertain about what is happening.

- One of the cars that had come furthest into the tunnel was so close to the fire (approximately 100 metres) that the occupants considered to overtake it. The cars in front, did so, but they (a married couple) chose not to because of the fire risk. This car was left standing closest to the fire. Then the driver of the burning heavy goods vehicle came and asked them to borrow their mobile phone, as his own was broken. According to the couple, he had 'a long conversation' with his employer. When asked by the occupants of the car, the driver of the heavy goods vehicle said that he did not know what kind of load the vehicle was carrying. After that, the driver disappeared.

- The couple tried to uncouple the caravan, but did not succeed. They tried to reverse, but after having hit the tunnel wall a few times, they gave up and chose to leave the car and two dogs behind. They heard some loud booms and thought that they would not get out alive.

- Those whose cars were further back and further away from the fire (approximately 400–500 metres) left their cars to look ahead and see if they could see anything that explained why there was a queue and why they had come to a standstill. But, at that time, nobody saw anything that could explain the traffic situation and the queue.

- Nobody has told us that they contacted other drivers or occupants of cars that were waiting in the queue in front or behind them in this situation.

Phase 4: Distress

This is when the situation changes as some people start to turn their cars around to drive back towards Gudvangen. Their anxiety spreads to the other road users, and it does not take long before most people make attempts to turn their cars around.

- Several people hear loud booms (most probably from the exploding tyres of the burning vehicle) and become uncertain as to what this can be.

- Some drivers are turning their cars around, and the level of distress rises.

- The thought catches on and more people start to turn their cars around. As yet, there is no smoke or smell to indicate that there is a fire.

- Some successfully turn their cars around before the smoke reaches them and drive back towards Gudvangen and out of the tunnel.

- It was most probably some of these drivers who flashed their lights in an attempt to warn people who were entering the tunnel.

Phase 5: In danger and fear of death

The smoke arrives suddenly, reducing visibility and making people disoriented. Some of those who are in the process of turning their cars around, collide with the tunnel wall or other cars and finally give up.

- The road users find themselves enveloped in smoke in the course of 5–10 seconds and cannot see a thing.

- One observer stated 'it was as if the smoke had been let out of a bag, almost like an avalanche'.

- At this point, chaos broke out, with cars crashing into each other and into the tunnel walls, and people shouting and screaming. Many describe the situation as one of fear, panic and complete chaos.

- As the dense smoke builds up in the tunnel, some choose to remain in their cars, while others choose to leave their cars and starts to walk back towards Gudvangen.

- They all perceive the situation as very dramatic and used the following terms to describe it: 'we did not think we would get out of this alive', 'I feared for my life, but did not panic, and held onto my daughter's hand the whole time', 'there was not enough air and we feared that we would not survive', 'became calmer after a while, but doubted that we would survive', 'we thought our days were numbered', 'we were worn out, supressed our fear and focused on getting out', ' we thought we were doomed, but we got back up on our feet and continued', 'became harder and harder to breathe and we worried that we would not get out alive'.

- Those who left their cars used one hand to fumble along the wall while holding a piece of cloth in front of their nose and mouth with the other. They zig-sagged along due to being disoriented or having lost their bearings. They sustained cuts and bruises from the irregular tunnel wall and tripped on the uneven verge.

- Those who were closest to the fire felt that it got very hot, and a caravan approximately 100 metres from the fire partially melted. It became so hot in a tour coach that the driver was afraid it would catch fire.

- Two Norwegian couples found the coach full of tourists by literally colliding with or walking into the coach. While one couple had moved away from the fire towards Gudvangen, the other couple had walked in the wrong direction when they chose to leave their car. This couple were exhausted when they entered the coach.

- The two couples stayed in the coach and helped to make sure that the tourists did not leave the coach while the smoke was at its densest. According to one of the couples, 'the coach was full of more or less hysterical Chinese'.

- The tourists (Chinese) left the coach together with their guide approximately 30–45 minutes after the Norwegian couples arrived. They walked in the direction of Gudvangen and, according to other observers, they were running and looked very frightened. They thought there were escape routes/evacuation rooms, and chose to go and look for these as they had seen the telephones.

- Calls were made to all three emergency telephone numbers – 110 (fire), 112 (police) and 113 (ambulance) – by those who were present in the tunnel, and some were in contact with the emergency communication centres most of the time they were there. The communication centres advised them to stay in their cars. Some called home or spoke to friends.

- One family drove all the way out of the tunnel, and picked up another six people on the way. The drive was a slow one as they kept running into the tunnel wall.

- Those who chose to stay in their cars set the ventilation to recirculation to prevent the smoke from getting in. Many had water and soft pieces of cloth, and one person described how he lay down low in the car.

- The smoke thinned and the rescue crew eventually arrived, and those who were in their cars were instructed to move towards the exit on the Aurland side (the nearest exit). After having walked a while and passed the burnt-out heavy goods vehicle, they were transported out by rescue vehicles and ambulances.

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- Many expressed that they had expected to encounter rescue personnel at an earlier stage rather than when they were almost at the tunnel exit. One of the Norwegian couples spoke with a German family who were shocked by the safety conditions in the tunnel. They believed that, in Germany, traffic was not permitted in tunnels that had no escape routes or evacuation rooms.

- As soon as they came out of the tunnel, they were received by rescue and ambulance personnel. Those that needed it the most were given oxygen, and everybody was examined and sent for treatment.

- There were dogs in several of the cars. They were rescued and appeared to be in good shape.

4.2 Self-rescue behaviour and the experiences of road users from other countries

We have been in contact with road users from other countries to learn about their situation inside the tunnel, their performance in terms of self-rescue behaviour and their personal experiences. We have chosen to consider their accounts in a separate section, as some of the factors they describe are important to look at separately from how the situation was experienced by Norwegian road users.

Three interviews have been conducted with people from France, while people from Israel, Russia, China and Germany were sent questions by email. We have not received replies from the Germans. Everybody was on holiday in Norway and, except for the occupants of the coach, they all drove hired cars.

We describe the experiences of the foreign tourists with reference to Figure 1 above.

<u>Phases 1 and 2:</u>

Nobody has stated that they observed anything out of the ordinary when they approached and entered the tunnel from the Gudvangen side. Nobody remembered having seen oncoming cars flashing their lights in warning as they drove further into the tunnel.

- The coach with the Chinese tourists stopped when the driver saw the burning heavy goods vehicle, while there were several cars in front of them that chose to overtake the truck. There was no possibility of turning the coach around inside the tunnel.

- The tourists in the other cars behind them stopped as the cars in front of them stopped, and were left standing in the queue without knowing that there was a fire up ahead.

- The situation soon reminded the French tourists of the accident in the Mont Blanc tunnel, although they had no information about what was happening.

- As they entered the tunnel, one of the French families was actually discussing the dangers of long tunnels. But they expected the safety level in the Gudvanga tunnel to be in accordance with European standards based on what had been learnt from the fire in the Mont Blanc tunnel, and believed that there were no grounds for concern.

- While standing in the queue, this family started to feel concerned and considered turning back, but thought that would be too risky. They chose to get their lunch out and eat while waiting for the queue to subside.

Phases 3 and 4

Everyone has now stopped in the queue and are waiting to see what is happening. People start to feel anxious, increasingly so as oncoming cars flash their lights to try to warn them. One tourist leaves the car, while the others remain inside, waiting.

- When oncoming cars flash their lights, they start to feel anxious about what might be happening.

- The French people in one car say that approximately 8–10 cars passed in the opposite direction (in the direction of Gudvangen), and they had noted that the faces of those in the last two or three cars were deathly pale as if they were thinking 'you will not survive'. It was as if they had 'seen the devil'.

- Then drivers in front and behind start to turn their cars around and the situation becomes chaotic.

- From the driver's seat, the driver of one of the cars looks further into the tunnel and sees the smoke coming. He tries to manoeuvre the car around, but it is suddenly enveloped in smoke. They collide with the tunnel wall and cannot see a thing, so they give up.

- The French family who had previously discussed the fire in the Mont Blanc tunnel as they drove in, became very anxious at this stage and felt that they were about to panic.

- There is also some distress among the Chinese tourists in the coach, but their guide remains calm at this point. In her own words: 'I was not scared during this phase and was focusing entirely on the survival of my guests (the passengers)'.

- According to the guide, there was no possibility of turning the coach around inside the tunnel.

Phase 5:

The smoke has arrived, they cannot see a thing and feel very distressed, and they are at loss for what to do. Some stay in their cars and later come out on the Aurland side, while others choose to walk towards Gudvangen.

- Everybody is in the process of turning their cars around as the smoke arrives. They collide with the tunnel wall and with other cars.

- Some did not dare to leave their cars for fear of being hit by other cars. There was a lot of shouting and they heard some loud booms.

- The situation was felt to be very dramatic, and some thought they would die. In the words of one woman: 'I called my parents because I thought we were going to die.' They chose to remain in the car and called 113 (the medical emergency number) after approximately 15 minutes. They maintained contact with 113 until the smoke started to thin and the rescue crews arrived (after approximately 45 minutes).

- One Russian family of four with two children tried to turn around, but collided and gave up. They had to look after their children, who became distressed and anxious. One of the children panicked. They decided to walk towards Gudvangen, and they covered the whole distance on foot.

- While the Russian family was still in their car, two Chinese women arrived who called out for help and wanted to get into the car.

- Some leave the car to look for an evacuation room, but give up attempt and return to the car. They call 112 (the police emergency number) and receive the following message: 'Stay in the car and you will save your life.' This group chose to follow this advice; they remained in contact with 112 throughout and set the car's ventilation system to recirculation to avoid the smoke.

- One person left the car and contacted people in the cars in front and behind to help to turn the cars around, but the smoke made it impossible.

- One group describes that while they were waiting in the car, ten Chinese people suddenly came running past in the direction of Gudvangen. They became anxious. What was happening? Should they also leave their car and head for the exit on foot? They knew that they would have to walk 7 km, so they chose to remain in the car even though they were afraid.

- Those who chose to stay in their cars gradually found that the smoke thinned out, and then rescue personnel arrived and told them that they could make their way towards the tunnel exit on the Aurland side where they would be met by ambulances.

- Those who had remained in their cars were instructed by the rescue crew to walk towards Aurland. They first had to pass the heavy goods vehicle, in which the fire was virtually extinguished. But they encountered a new danger.

- One person described it as follows: 'One of the scariest moments was when we were rescued. The rescue service men told us to walk toward the ambulance. Just as we were sure we were safe, parts of the tunnel started falling around us when we were walking. Luckily, we made it to the ambulance with no injuries.'

- It was only now, when they saw the burnt-out heavy goods vehicle that they understood why the queue had developed and traffic had come to a standstill in the tunnel and where the smoke came from.

- One French family of four left their car and made their way towards Gudvangen, a distance of approximately 8–9 km. They expected to find an evacuation room and to encounter fire service personnel soon. They found some emergency telephones and searched for evacuation rooms. They chose not to call because of possible language problems and because they did not want to lose time.

- It was frightening to leave the car. People were panicking, there was shouting and screaming, a lot of commotion and cars that crashed into each other. They were unable to see the cars or the car lights.

- The father leads the way and the rest of the family follow hand in hand. The father uses one hand to feel his way along the tunnel wall and holds a rucksack in the other, and has several harsh encounters with the tunnel wall. Once, the impact was so hard that he almost becomes concussed, throws up, becomes confused and starts to walk in the wrong direction.

- They give up finding an evacuation room and leave the irregular ditch for the road. They have stumbled along and sprained some ankles. Up on the road, they are eventually able to discern the white edge markings.

- At one point, they hear a loud noise sounding like motors. Looking back, they think that this was when the tunnel ventilation was reversed, sending the smoke in their direction. They had hoped that the smoke situation would improve.

- They called out loudly and knocked on windscreens and bonnets to avoid being hit by cars. They did not want a lift, they simply wanted to give warning: 'We were lucky that nobody ran over us, it was scary.'

- The family met a man with his daughter on the way out. They spoke to him, but he did not answer.

- Then they heard a car crash into the tunnel wall. They were afraid of being hit by a car. They used the lights on their mobile phones to make themselves visible. They thought it would not stop for them, but it did.

- There was little room in the car, the air was stale, and the father of the French family was very exhausted, and they thought he was having a heart attack. The car drove slowly, and they thought that they were going to die in the car.

- When they came out of the tunnel, one of the firemen said that they must remain in the car for a few minutes. They did not like that, as they were now in the open air and wanted to get out.

- The coach with the Chinese tourists takes on board two Norwegian couples. They help to keep the Chinese calm so that they do not leave the bus while the smoke is at its densest. But the heat in the coach gradually becomes so intense that the driver is afraid it will catch fire. The Chinese tourists leave the coach and head towards Gudvangen.

- In the words of the guide: 'I let the Norwegians call to the police station.' The driver of the coach did not know what he should do.

- The Russian family of four left their car and walked in the direction of Gudvangen. The father stated the following: 'Yes I was afraid. When I saw the panic among my family, then I stopped to panic and started to think about how to leave the car and what things a can use and take. I decide to use our wet T-shirts and outcothers as filter to breathe.'

- According to the father of the Russian family: 'The first 4-5 km it was difficult to walk fast. I bent down, quite at knees, and used my lighter to see the white line.'

<u>How did the rescue operation function and what experiences are the non-Norwegian road users left with?</u>

They have different experiences when it comes to how they were taken care of and how it has affected them afterwards.

- There was a limited supply of oxygen which had to be shared, and some of them found this frustrating when they came out of the tunnel.

- Some had expected to find professional rescue crew rather than civilians at the tunnel exit, but they received excellent help at the hospital.

- They received different treatment according to their state of health, which meant that they were split up and lost contact with each other. Some were flown to Bergen while others remained in the local hospital and were transported by bus.

- Many of the tourists had hired cars, which involved some organising to pick up their luggage etc. and there was inadequate cooperation.

- Many have seen a psychologist. Some are still struggling with the experience and do not want to talk about it, and many are frequently reminded of it in their daily lives, triggered for example by the smell of smoke and confined spaces.

- Others have suffered no psychological aftereffects. In the words of one person: 'we are positive people so we tried to learn from this experience just to appreciate life and live to the fullest because you never know what is going to happen.'

- The Russian family is very grateful for the help they received and for the medical follow-up when they came out of the tunnel.

The tourists gave the following advice:

- Evacuation rooms are necessary, international standards must be respected, there must be enough oxygen available, assistance from rescue crew during evacuation and professionals outside the tunnel exits.

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5 How can self-rescue behaviour be ensured and made safer?

On the basis of the accounts to which we have referred, which are based on the experiences of those who were present in the tunnel and survived, each in their own way, we recommend the following improvements to strategies for self-rescue and assisted self-rescue in the event of a fire in a single bore tunnel:

Self-rescue and assisted self-rescue

Self-rescue is a main principle in connection with most types of tunnel incidents. Self-rescue actions must therefore be of a quality that saves lives and causes as little harm as possible. In the Gudvanga tunnel, there were few aids available, and everybody had to plan what to do to save their lives as best they could based on their own perception of the situation.

- The best form of self-rescue is to get out of the tunnel before the smoke and heat catches up with you. It is important to turn the car around and get out one time too often rather than one time too few. It can be difficult to make a U-turn in a narrow tunnel in a stressful situation, however. Big vehicles will find it impossible. Those who are able to turn around should pick up other road users on their way out of the tunnel.

- Road users should make sure that they keep a good distance to the car in front when they stop. They should wait and not try to overtake the queue, and look out for traffic in the opposite direction, which will also be stressed when trying to turn around. There is a need to make it possible for drivers to do safeU-turns in narrow road tunnels.
- Closed vehicles at some distance from the fire can function as good 'evacuation rooms' during fires of short duration, such as the one in the Gudvanga tunnel. If the air conditioning is set to recirculation, one can stay in the car for a relatively long period. For how long will the supply of breathing air inside the car last?

- Consideration should be given to when the road users should be advised to remain in their cars and when they should be encouraged to make their way out of the tunnel, however. Good advice depends on reliable information about the scene of the fire, its expected duration and what toxic fumes to expect. Establishing evacuation rooms in more tunnels should be considered.

- Most people chose to use their mobiles rather than the emergency telephones in the tunnel. Mobile phones are commonly used today and everybody carries one. It is therefore important to ensure mobile phone coverage in tunnels.

Physical measures that contribute to assisted self-rescue

When people are to engage in self-rescue behaviour, it is critical that aids are in place to reduce the number of strategy and action options, for example the choice between driving or walking out of the tunnel.

- Consideration should be given to replacing emergency lay-bys with U-turn facilities at more frequent intervals than today's lay-bys. Further studies should also be made to determine how such U-turns can best be made in narrow single bore tunnels where the drivers of oncoming vehicles may already have been stressed by the fire further inside the tunnel.

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- Almost continuous safety lighting is required when the smoke is as dense as in the Gudvanga tunnel. Visibility was so poor that the road users had to feel their way along the tunnel wall, and they were unable to see the road markings when standing upright.

- Visual solutions in the form of continuous lights along the edge of the road and a steel rail along the wall that cars can get close to and follow.

- A walkway on the inside of the steel rail or railings would make it possible to walk out of the tunnel.

- The walkway would need to be tarmacked and at a higher level. There are examples in other countries of 90 cm wide and 1 m high walkways.

Information and training

The following aspects are important to consider in this context:

- Information to Norwegian and non-Norwegian road users about what they should be aware of if something happens in a tunnel. It is difficult to prepare a fixed procedure for self-rescue behaviour, as the situation will vary depending on the tunnel, type of incidence and the people inside the tunnel. It is possible, however, to prepare some standard procedures to provide helpful information

- Those who arrive first on the scene are the first to discover an incident. It is important to give road users clear instructions about how to notify the emergency communication centre and, not least, other road users.

- Clear information must be available to the road users concerning the conditions in each individual tunnel or group of tunnels as regards ventilation, communication etc.

- Relevant equipment to carry in the car for people who often drive through long tunnels. Gas mask, oxygen, water and towels, a charged mobile phone. The car should have ventilation air filters and the recirculation option should be used.

- For how long is it advisable to stay in an area of dense smoke from a vehicle fire?

- People who leave their cars inside the tunnel must leave their car keys in the ignition, so that the rescue crew can move them if necessary in order to pass.

- The period for which people can breathe freely in recirculated air inside a closed vehicle depends on the number of passengers and the volume of the vehicle. One person uses approximately half a cubic metre of air per hour. How does this work out in lorries and coaches/buses carrying passengers?

Fire warning, communication and guidance to road users

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The following aspects are important to consider in this context:

- How can people inside the tunnel be warned of the fire? Many of the road users in the tunnel were not aware that there was a fire. That is why early detection is important so that the tunnel can be closed as soon as possible.

- Obtaining information about which vehicles and mobile phones are inside the tunnel at any time. Use of this information by the emergency communication centres in an emergency. What advice should be given to the road users? Correct information about the type of vehicle, the load and type of load must be available.

- What self-rescue action are the people inside the tunnel taking? How many are making their way towards the exits on foot?

- Information from people inside the tunnel to the emergency communication centres about what is happening. Information to the rescue crew about conditions in the tunnel from those come out of the tunnel.

- What equipment do rescue crew need to assist people who are trapped in a smoke-filled tunnel?

- What do people expect from rescue crew in terms of being evacuated or receiving assistance?

- Any strategy that involves reversing the direction of ventilation in the tunnel in the event of fire should be reconsidered in light of the experience gained from the Gudvanga tunnel. Since the road users have not been forewarned by the smell of smoke, the smoke comes as a great surprise to them, and it will quickly become very dense as a result of the mechanical ventilation reversing of the smoke that was naturally ventilated initially in the opposite direction. (It is possible that some road users on the eastern side of the fire were saved by the fact that the direction of ventilation was reversed).

The following would be the most effective contributions to assisted self-rescue:

1. Earliest possible detection of fire (close the tunnel, raise the alert, warn people inside the tunnel)

2. Correct information about the source of the fire (position, load, type of load, amount of load)

3. The number of people inside the tunnel, where they are and what they are doing (cars, people, animals)

4. Good guidance to contribute to safe and efficient assisted self-rescue

It is important to point out that those who handle direct communication with people inside the tunnel must have the competence required to provide guidance to people who find themselves in what they perceive as a life-threatening situation. The staff may not have all the necessary information, and they must be able to keep up a dialogue that does not add to people's fears, but strengthen their will and capacity for self-rescue.

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6 Conclusion

The road users included in the SINTEF's study were all caught in the smoke on the western side (Gudvangen side) of the burning heavy goods vehicle. Some of those who were closest to the heavy goods vehicle drove out of the tunnel before it filled with smoke, some towards Aurland in the east and some towards Gudvangen in the west. Those who were at longer distance from the fire did not know how critical the situation was until the tunnel suddenly filled up with smoke.

There was a high number of non-Norwegian road users among those who were caught in the smoke. We have focused on understanding the road users' experiences during their self-rescue efforts in the tunnel. As shown in Figure 1, we have divided the incident into phases that cover the whole period from the time when the road users entered the tunnel under normal conditions, through the gradual onset of uncertainty and anxiety until the smoke suddenly enveloped them and their struggle to survive began.

Norway has a zero vision as regards the number of traffic fatalities and serious injuries. This vision also applies inside tunnels. People's tolerance limits and ability to cope with situations are important factors in relation to the zero vision. What psychological and physical capabilities of each individual are decisive for the performance of self-rescue? How significant are age, gender, knowledge and state of health? Evacuation measures should be considered on the basis of how people actually act in such a situation (formative), and not on how they should act (normative). The situation that arose in the Gudvanga tunnel must be viewed in this perspective. We wish to draw attention to the following key factors:

- Everybody perceived the fire as an extremely stressful and life-threatening incident, and there were times when they feared for their life. Many walked 7–8 km in the dense smoke, surviving only as a result of coincidence and strong motivation to survive.

- Some of the road users remained in their cars. That proved to be a good solution in this case. As the burning vehicle was empty, the fire was put out after approximately 60 minutes. This may not necessarily have been the best solution had the circumstances been different. We do not know what information the emergency communication centres had when they instructed people who called them to remain in their cars.

- Most of the road users did not have a view of the fire, and there were no other indications that there was a fire. Everybody was taken by surprise, became scared and were unable to get an overview of the situation when the tunnel suddenly filled up with smoke. In the panic and chaos that arose few, if any, managed to turn their cars around and drive out.

- Communication with the road users at the earliest possible time is absolutely essential. The information must be correct, in which case it will assist self-rescue. It can reduce fear and thus increase each person's possibility of maintaining their focus and making the right choices in the relevant context. Some people received this type of assistance from the emergency communication centres.

- The tourists who were trapped in the smoke expected there to be escape routes and evacuation rooms. They were in Norway, a rich and highly developed country, and they are unable to comprehend that there should be such a low level of safety in such a long tunnel. They left their cars to look for escape routes and evacuation rooms.

- The French tourists remembered the fire in the Mont Blanc tunnel and expected the lessons learnt from that incident to have had an impact on tunnel safety in Norway.

- Everybody reports that they received very good care in hospital during the first few days. Some of them point out that there was a shortage of oxygen when they came out of the tunnel.

- Some of the road users have stated that, after the incident, smells, noises and other factors have been distressing reminders of their experiences in the tunnel.

Based on what the road users have told us, we are left with the following main impression:

Many lives could have been lost as a result of the fire in the Gudvanga tunnel. The fact that no lives were lost was due to a strong motivation for survival, successful self-rescue behaviour among the road users and the rescue crews' efforts to put out the fire and rescue people.

The burning heavy goods vehicle was empty, or the fire would have been of a different scope and severity in terms of heat and smoke development. The fire would most likely have spread from one vehicle to the next and the smoke could have had a higher content of toxic substances. In the event of such an incident, the possibility of self-rescue would have been much reduced and peoples' coping and tolerance limits would have been exceeded.

The following material has been used in preparing this memo:

- Inspection reports and reports from conversations with ambulance personnel and fire and rescue personnel
- Reports from interviews with and questions asked by email of road users who were present in the smoke-filled tunnel
- Interviews with road users published in various media
- Material received from the Accident Investigation Board Norway
- General literature on road tunnels
- General literature on what people experience and how they act under extreme stress

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Rapport utarbeidet for Statens Havarikommisjon for Transport (SHT)

Helsemessige konsekvenser av brannen i Gudvangatunnelen den 5. august 2013

En retrospektiv analyse av 28 tilfeller av akutt røykskade [1, 2]

1. juli 2014

Innhold

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Helsemessige konsekvenser av brannen i Gudvangatunnelen 5. august 2013

1. Innledning

I denne rapporten beskrives helsemessige konsekvenser av brannen i Gudvangatunnelen den 5. august 2013. For en nærmere redegjørelse av hendelsesforløpet vises det til hovedrapporten om brann i vogntog på E16, Gudvangatunnelen 5. august 2013, fra Statens Havarikommisjon for Transport (SHT).

På ulykkesdagen befant det seg 67 trafikanter i det røykfylte tunnelløpet vest for brannstedet over et tidsrom på 45 - 135 minutter. De fleste av disse ble tatt hånd om av helsepersonell etter evakuering og mange ble transportert til sykehus for behandling og observasjon.

For 28 av trafikantene er det i ettertid gjort en nærmere medisinsk vurdering av de akutte helseskadene som ble påført under brannen. Utvalget består av trafikanter som fikk opprettet medisinsk journal i forbindelse med innleggelse i sykehus. Disse tilhørte kjøretøy nr. 1 - 16 (indeksert i hovedrapporten) og kommer fra Estland, Russland, Tyskland, Israel, Frankrike, Slovakia, Polen, Kina og Norge. For alle 28 er det gjort en individuell vurdering av røykeksponering, skademekanismer og skadeomfang. Helseeffekter ut over det akutte behandlingsforløpet er ikke kartlagt. Trafikanter som ikke ble innlagt eller som ikke fikk opprettet journal i forbindelse med prehospital behandling, har ikke blitt vurdert nærmere.

2. Medisinsk vurderingsgrunnlag

Den medisinske vurderingen er gjort av to spesialister i h.h.v. lungemedisin og anestesiologi med bred erfaring fra røykskadebehandling og klinisk toksikologi. Arbeidet er basert på en systematisk gjennomgang av ambulansejournaler, sykehusjournaler, epikriser (utskrivings-rapporter), journalførte notater fra sykepleiere og fysioterapeuter, samt utskrift av aktuelle blodgassanalyser, EKG-registreringer (hjerteregistreringer), klinisk-kjemiske laboratorieprøvesvar og lungerøntgenbilder. Et eget spørreskjema er benyttet i ettertid for å kvalitetssikre opplysninger og tidsforløp under og etter brannen. Innsamlingen av helseopplysninger er gjort av SHT. Dokumentene gir ikke et komplett bilde av den enkeltes helsetilstand forut for ulykken, men utgjør et tilstrekkelig vurderingsgrunnlag for helsetilstanden umiddelbart etter brannen.

Skadeomfanget for de involverte trafikantene (heretter også kalt ”pasientene”) er vurdert etter de kliniske kriteriene i tabell 1. Graderingen samsvarer med den som brukes av Statistisk sentralbyrå (SSB) for veitrafikkulykker med personskade[i] (kirurgiske skader). Det vil si at alle skader som en tid truer pasientens liv klassifiseres som *meget alvorlig skade* mens øvrige tilstander som krever sykehusinnleggelse klassifiseres *alvorlig skade*. Skader som kan behandles utenfor sykehus betegnes *lett skade*. SSB benytter også begrepet *hardt skadde* som en samlebetegnelse for alvorlig og meget alvorlig skadede.

***Tabell 1** - gradering og kliniske kriterier for skadeomfang, brann i Gudvangatunnelen 5. aug 2013*

Lett skade	Luftveisirritasjon eller hoste uten pustebesvær.
Alvorlig skade	Pustebesvær og funn av sot i luftveiene.
Meget alvorlig skade	Alvorlig oksygeneringssvikt, høye kullosverdier (HbCO), nedsatt bevissthet, større sotmengder i nedre luftveier, sirkulasjonssvikt, tegn til alvorlig cyanidforgiftning (høye laktat/cyanidverdier) eller behov for aktiv pustehjelp (respirator eller overtrykksmaske).

3. Beskrivelse av pasientgruppen

Blant de 28 trafikantene var det på skadetidspunktet 22 voksne (26 - 58 års alder; 14 menn og 8 kvinner) og seks barn under 16 års alder (3.5, 7, 10, 12, 13 og 14 år gamle; 2 gutter og 4 jenter). Gruppen består av hovedsakelig friske personer der kun to voksne har kjent lungesykdom fra tidligere (astma) og bare èn er oppgitt å røyke sigaretter daglig. 11 av 28 er bekreftede ikke-røykere. Ingen personer er angitt å ha kjent alvorlig kronisk hjerte- eller lungesykdom.

4. Akuttbehandling og behandlingssted

Samtlige 28 trafikanter fikk tidlig oksygenbehandling (≥ 10 liter O_2/minutt på maske) etter evakuering fra tunnelen og under transport til sykehus. I tillegg fikk mange inhalasjonsmedisiner (astmamedikamenter) og betennelsesdempende medisiner (kortikosteroider) ordinert av sykehuslege. Ti av pasientene ble primærinnlagt ved Voss sykehus; ni av disse ble transportert videre til Haukeland universitetssykehus etter kort tid. De resterende 18 pasientene ble primærinnlagt ved Lærdal sykehus; 11 av disse ble transportert videre til Haukeland og 6 til Førde sentralsykehus. I følge journalopplysninger hadde ingen av pasientene brannskadet hud. Røykforgiftning var hoveddiagnose hos alle; ICD-10 kode T59.8 - ”Toxic effect of smoke and fire.”

5. Brannrøyk - vanlige skademekanismer

Dødsfall ved brann skyldes oftest akutt røykforgiftning og i mer sjeldne tilfeller alvorlige forbrenningsskader[ii]. Selv når det foreligger kombinerte røyk- og sårbrannskader regner man med at lungekomplikasjoner bidrar til død i mer enn 75% av tilfellene[iii] [iv]mens kombinasjonen av varm og giftig røyk er forbundet med de mest alvorlige skadene og gir høyest dødelighet[v] [vi].

Inhalasjon av brannrøyk vil - avhengig av type brennbart materiale, temperatur, oksygentilførsel, forbrenningsgrad og eksponeringstid/grad - kunne gi skader som varierer fra kun moderate forbigående luftveisplager til livstruende lungesvikt[vii]. Sammenliknet med andre typer branner karakteriseres ofte tunnelbranner av langvarig røykeksponering og relativt høy røykintensitet. De vanligste skademekanismene er:

1) Opptak av giftige gasser i blodet - f.eks kullos og cyanid (hemmer O_2 -transport og omsetning).
2) Inhalasjon av sotpartikler - uforbent karbon (kan hemme gassutvekslingen i lungene).
3) Inhalasjon av bronkopulmonale toksiner/ irritanter (kan gi slimhinnehevelse/ trange luftveier).
4) Termal skade (varmluftskade i luftveiene, sjeldent forekommende).

Kullos (karbonmonoksid - CO) er en svært giftig branngass som binder seg ca. 250 ganger sterkere til hemoglobin (Hb) i blodet enn oksygen og derfor effektivt hindrer oksygentransport i organismen.[viii] Den andelen hemoglobin i blodet som er bundet til kullos kan måles på sykehus med et blodgassapparat og angis da som ”HbCO” (i % av hemoglobin). Normalt er HbCO < 3 % hos ikke-røykere. Verdier mellom 10 - 20 % gir vanligvis få symptomer hos hjerte- og lungefriske, mens mer alvorlige symptomer kan oppstå ved ytterligere stigning over 20%. HbCO-verdier over 50 % er forbundet med koma, kramper og akutt fare for død.[ix]

Fordi økt tilførsel av oksygen bidrar til reduksjon av HbCO, vil pasienter som har fått oksygen under transport til sykehus ha lavere HbCO-verdier på sykehuset enn da de ble evakuert fra brannstedet. I et forsøk på å beregne utgangsverdiene for de tidspunktene da pasientene faktisk ble evakuert fra tunnelen (d.v.s. umiddelbart før påbegynt oksygenbehandling i ambulanse) har vi valgt å sette halveringstiden ($t_{½}$) for HbCO til 90 minutter, vel vitende om at det opereres med forskjellige halveringsverdier i litteraturen under ulike forutsetninger. Eksempelvis vil HbCO $t_{½}$

i vanlig romluft (21% oksygeninnhold) være rundt 5 timer, mens den faller til under 90 minutter hvis fraksjonen av oksygen i inhalert luft (FiO_2) økes til 100%. Ved medisinsk behandling i trykktank (3 bar, FiO_2 100%) vil HbCO $t_{½}$ være bare 15-30 minutter. [x xi xii]

Under normale forhold bidrar også økt ventilasjon (raskere og dypere pusting) til kortere halveringstid. Det motsatte skjer hvis sot i nedre luftveier hemmer gassutvekslingen eller pustevolumet reduseres pga hevelse i bronkiene (obstruktiv ventilasjonsinnskrenkning).
For pasienter som har pustet mye sotholdig røyk vil imidlertid $t_{½}$ = 90 minutter være et rimelig anslag, gitt rutinebehandling i ambulanse med 100% oksygentilførsel (maske med reservoar og O_2-flow ≥ 10 liter/min) ved 1 atmosfæres trykk.

Cyanid (blåsyre) kan frigjøres bl.a. ved brann i plaststoffer og vil etter opptak i blodet hemme omsetningen av oksygen i kroppscellene og forårsake raskt stigende nivåer av melkesyre (laktat) i blodet, typisk til serumnivåer > 10mmol/L[xiii]. Alvorlig cyanidforgiftning forekommer sjeldnere enn alvorlig kullosforgiftning. Fordi det var grunn til å mistenke at cyanidavgivende stoffer kunne frigjøres under brannen i Gudvangatunnelen, ble flere av pasientene undersøkt med tanke på dette. Cyanid er imidlertid et ustabilt stoff og blodprøver må derfor fryses ned tidlig, og analyseres hurtig, hvis resultatet skal være pålitelig. De aktuelle prøvesvarene for cyanid kan derfor være beheftet med usikkerhet.

6. Hovedfunn

Samtlige 28 pasienter hadde ved innleggelse i sykehus den 5. august 2013 respirasjonsbesvær (tung pust) og synlig sot i øvre luftveier (nese/munn) og i ekspektorat (opphostet slim). Hos alle pasienter som fikk journalført auskultasjonsfunn (9 stk) er det beskrevet pipelyder over lungene forenelig med luftveisobstruksjon (forsnevring av luftveiene). Ingen av pasientene hadde ved innleggelsen tegn til sirkulasjonssvikt eller laktatverdier forenelig med alvorlig cyanidforgiftning. Analyse av cyanid i blodprøver var negativ hos alle pasienter som fikk tatt slik prøve (10 stk).

Hos 25 av de 28 pasientene ble det tatt arteriell blodgassanalyse etter innleggelse med tanke på kullosforgiftning. Hos samtlige målte man HbCO over referanseverdien for ikke-røykere. Pga stor individuell variasjon i tidspunktene for prøvetaking (fra 55 til 483 minutter etter påstartet oksygenbehandling) er det gjort tilbakeregning til estimert utgangsverdi bare for de åtte pasientene som raskest fikk tatt slike prøver (55 - 285 minutter etter påstartet O_2-behandling; median tid 74 minutter). Gitt HbCO $t_{½}$ = 90 minutter under pågående oksygenbehandling hadde disse pasientene estimerte kullosverdier (HbCO) på hhv 16%, 21%, 24%, 24%, 27%, 31% og 33%. Det betyr at blodets transportkapasitet for oksygen (HbO_2) var tilsvarende redusert. Fordi halveringstiden er beheftet med usikkerhet kan de reelle kullosverdiene avvike fra dette.

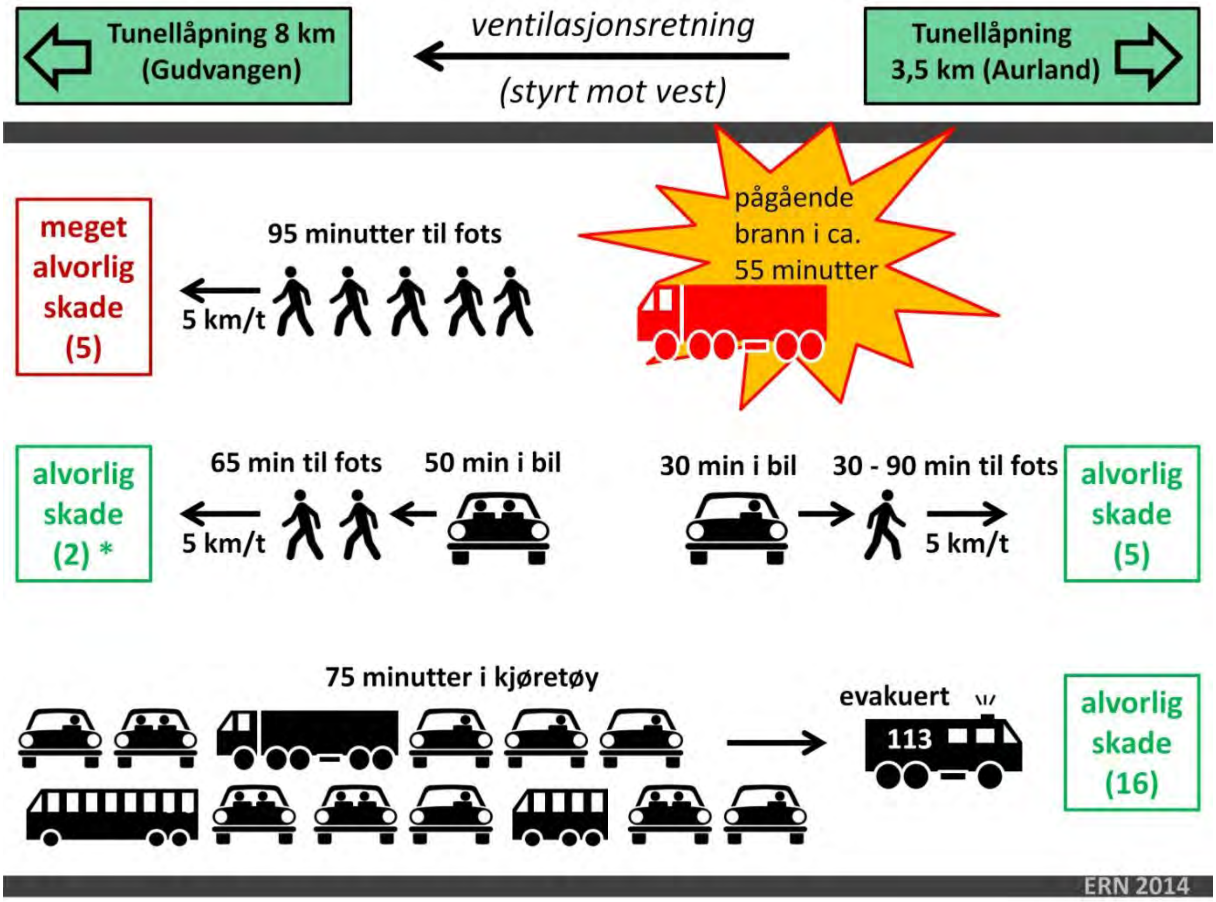
7. Skadeomfang

Fem pasienter skiller seg tydelig ut fra de øvrige. Disse selvevakuerte i retning Gudvangen umiddelbart etter at brannen startet og gikk til fots ca. 8 kilometer i samme retning som røyk/ventilasjonsretningen i tunnelen. Under evakueringen utførte de et oksygenkrevende fysisk arbeid (gjennomsnittlig ganghastighet 5 km/t) over 95 minutter i svært røykfylte omgivelser, mens de øvrige 23 trafikantene ble sittende i sine kjøretøy i inntil 75 minutter og hovedsakelig evakuert ut med redningsbiler. (Se Figur 1.)

De fem nevnte pasientene hadde alle alvorlig oksygeneringssvikt ved innleggelse og høye estimerte HbCO-verdier (24-33%). To hadde akutt behov for ventilasjonsstøtte; en ble lagt på respirator og en fikk overtrykksventilasjon på maske før helikoptertransport til Haukeland universitetssykehus. Det ble sett rikelig med sot i nedre luftveier hos to av pasientene under terapeutisk bronkoskopi (oppsuging av sot fra lungene). De samme to pasientene hadde nedsatt bevissthet etter evakuering. Fire av fem hadde også patologiske lungerøntgenfunn (lungevev med redusert luftholdighet og infiltrater). Alle fem ble primærinnlagt ved intensiv/ overvåkningsavdeling og behandlet på sykehus i mer enn en uke. En hadde fortsatt patologisk lave oksygenverdier i blodet ved utskrivelse.

Blant de øvrige 23 pasientene er det journalført to med nevrologiske symptomer i form av hodepine, svimmelhet og sløvhet (markert med * i figur 1 nedenfor); estimert HbCO for disse to var hhv 16% og 22%. De var også de eneste som valgte å gå til fots i retning Gudvangen (i ca. 65 minutter) etter først å ha sittet i eget kjøretøy i rundt 50 minutter. De øvrige ble sittende i egne kjøretøy helt frem til evakuering, bortsett fra fem personer som gikk til fots i retning Aurland (altså mot røyk/ventilasjonsretningen) etter først å ha sittet i eget kjøretøy i ca. 30 minutter.

Figur 1 *- Medisinsk status (n=28) etter evakuering til fots og etter opphold i bil før evakuering, Gudvangatunnelen 5. august 2013. Brannrøyk fortsatte å bevege seg i ventilasjonsretningen etter at brannen var ferdig slukket. Syv trafikanter selvevakuerte til fots i samme retning.*



For 39 av de 67 trafikantene som befant seg vest for brannstedet foreligger ikke tilgjengelig journal fra prehospital behandling. Blant disse må man anta at det forelå et større antall med lettere skader.

For de 28 sykehusinnlagte pasientene som er gjenstand for vurdering i denne rapporten fordeler skadeomfanget seg som angitt i tabell 2.

Tabell 2 *- skadeomfang blant 28 innlagte trafikanter etter brann i Gudvangatunnelen 5.aug 2013*

Lett skade	**Ingen**
Alvorlig skade	**23 personer**
Meget alvorlig skade	**5 personer**

Blant de 23 med alvorlig skade hadde èn forbigående stigning av hjerteenzymer i blodet som tegn på oksygenmangel i hjertemuskelen. Flere har dessuten beskrevet plagsom hoste og psykisk engstelse for tunneler som de viktigste helseplagene i etterkant av hendelsen.

8. Konsekvens av forlenget evakueringstid

På bakgrunn av høye estimerte kullosverdier og alvorlige kliniske sykdomstegn er det grunn til å tro at ytterligere røykeksponering i tunnelen ville satt de fem pasientene som hadde meget alvorlig skade i akutt livsfare. Det samme må antas innenfor gjeldende eksponeringstid dersom en eller flere av disse hadde hatt vesentlig høyere alder, kronisk hjerte- eller lungesykdom eller vært fysisk svekket av annen årsak. Også to av pasientene i gruppen med alvorlige skader må antas å kunne ha utviklet livstruende symptomer ved forlenget eksponeringstid, da de på evakueringstidspunktet allerede hadde symptomer på alvorlig kullosforgiftning.

9. Konklusjoner

1. Blant trafikantene som ble behandlet for røykskader på sykehus etter brannen i Gudvanga-tunnelen den 5. august 2013 var 28 hardt skadde. 23 av disse hadde alvorlige skader og 5 meget alvorlige skader.

2. Sot og kullos (karbonmonoksid) bidro vesentlig til sykdom hos trafikantene. Cyanid (blåsyre) ble ikke påvist i blodprøver og klinisk var det heller ikke holdepunkter for alvorlige tilfeller av cyanidforgiftning.

3. Ung alder og god helse var trolig medvirkende årsaker til at liv ikke gikk tapt under brannen.

4. Trafikantene med de mest alvorlige symptomene hadde lengst opphold utenfor bil og høyest grad av fysisk anstrengelse i tunnelen.

5. Et forlenget opphold i tunnelen ville trolig satt minst fem av trafikantene i akutt livsfare.

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NBL F13131 - Fortrolig

Rapport

Beregning av branneffekten ved brann i vogntog i Gudvangatunnelen

Branntekniske vurderinger

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Branneffekt

Rapport

Beregning av branneffekten ved brann i vogntog i Gudvangatunnelen

Branntekniske vurderinger

VERSJON
2

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SAMMENDRAG

5. august 2013 oppsto det brann i et vogntog i Gudvangatunnelen, Europavei 16. Veiavdelingen ved Statens havarikommisjon for transport (SHT) undersøker hendelsen, og har i den forbindelse henvendt seg til SINTEF NBL med ønske om å få beregnet brannens effekt i MW.

En forenklet beregningsmodell gir estimert maksimal branneffekt til å være 25 MW.

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Innholdsfortegnelse

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Sammendrag og konklusjoner

- 5. august 2013 oppsto det brann i et vogntog i Gudvangatunnelen, Europavei 16. Brannen startet i trekkbilen på venstre side av motoren. Det estimeres at brannspreding fra trekkvogn til semitrailer tok ca. 2 minutter, og brannen i semitrailer og trekkvogn utvikles til overtenning i løpet av 15 minutter. Semitraileren og dekkene var utbrent etter 30 minutter. Brannen i trekkvognen ble slokket 55 minutter etter antennelse.

- En forenklet beregningsmodell gir estimert maksimal branneffekt til å være 25 MW.

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1 Innledning

1.1 Bakgrunn

5. august 2013 oppsto det brann i et vogntog i Gudvangatunnelen, europavei 16. Veiavdelingen ved Statens havarikommisjon for transport (SHT) undersøker hendelsen, og har i den forbindelse henvendt seg til SINTEF NBL med ønske om å få beregnet brannens effekt i MW.

1.2 Målsetting

Målsettingen er å estimere effekten av brannen i vogntoget (i MW) basert på tilgjengelig informasjon om skader på vogntoget og lasten, og på opplysninger om hendelsesforløpet.

Usikkerheten til estimatene er avhengig av kvaliteten på tilgjengelig informasjon, og detaljeringsgrad av informasjonen.

1.3 Metode

Branneffekt, eller hastighet for varmeavgivelse, er den mest brukte parameter for å estimere størrelsen på kjøretøybranner i tunneler, og for å vurdere andre viktige brannparametere, som varmefluks og gasstemperatur [2]. Hvordan branneffekten varierer under brannforløp i veitunneler har vært undersøkt tidligere, både i fullskala og laboratorieskala brannforsøk i tunneler [3-7], og viser et karakteristisk mønster som kan deles opp i 3 faser i brannforløpet:

- Brannutvikling fra antennelse til alt brennbart materiale er involvert i brannen.
- Periode med fullt utviklet brann med maksimal branneffekt.
- Branneffekten reduseres, og brannen slokkes eller slokner av seg selv.

Arealet under branneffektkurven representerer den totale brannenergien fra antennelse til slokking. Derfor er følgende metode brukt i arbeidet for å karakterisere brannen i vogntoget i Gudvangatunnelen:

1. Representasjon av brannforløpet ved bruk av en forenklet branneffektkurve.

2. Analyse av brannforløpet for å estimere overtennings-, reduksjons- og slokkingstider i branneffektkurven.

3. Estimering av total brannenergi ved å analysere skader i vogntoget.

4. Estimering av maksimal branneffekt basert på integralet av branneffektkurven.

Figur 1.1 viser den forenklete branneffektkurven som er brukt for å representere brannen i vogntoget. Denne kurven viser 3 påfølgende brannstadier:

- Brannspredning, med lineær økning av branneffekt til overtenning på tidspunktet t_1.
- Fullt utviklet brann med konstant maksimal branneffekt til tidspunktet t_2.
- Reduksjon av brannen og slokking, med lineær reduksjon av branneffekten til slokking på tidspunktet t_s.

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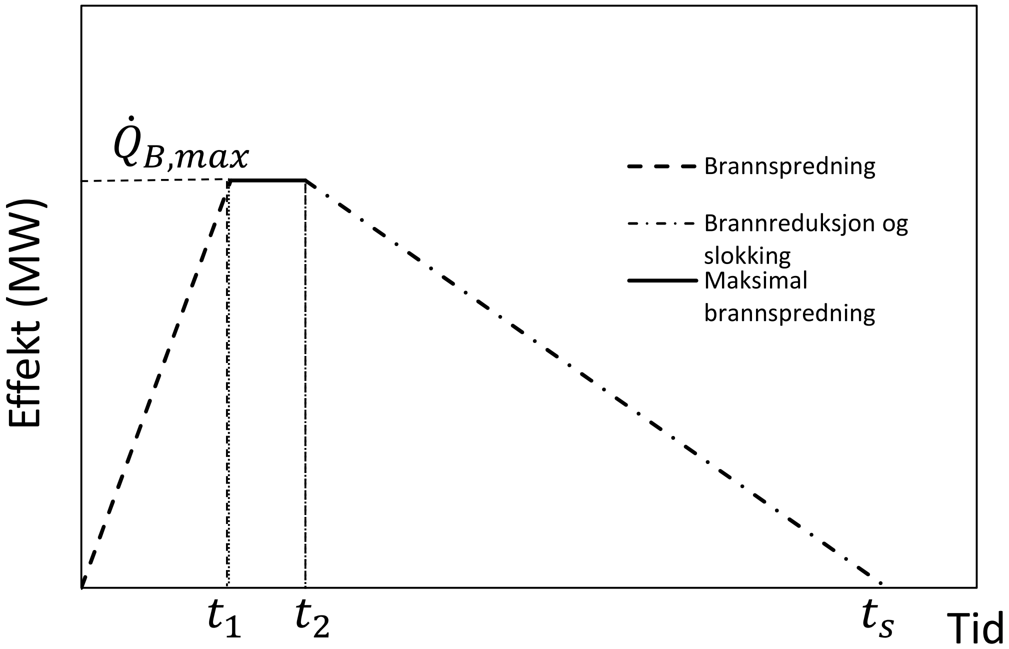

Figur 1-1: Forenklet branneffektkurve brukt for å representere brannen i vogntoget.

2 Opplysninger fra oppdragsgiver

2.1 Hendelsesforløpet

Tabell 2-1 viser hendelsesforløpet for brannen i Gudvangatunnelen fra antatt brannstart ca. kl. 12.00, til brannvesenet har kontroll over brannen kl. 12.55 samme dag.

Tabell 2-1 Hendelsesforløpet fra antatt brannstart kl. 12:00 til brannvesenet kontrollerer brannen kl. 12:55.

Tidspunkt [tt.mm]	Tid etter brannstart [min]	Hendelse	Referanse
12:00	0	Brann startet i trekkbilens motor på venstre side	[1]
12:15	15	Antagelse gjort av SHT ut fra opplysningene de har om brannen.	[1]
12:30	30	Brannvesenet ankommer stedet, semitrailer og dekk allerede utbrent	[1]
12:55	55	Brannvesenet melder at de har kontroll over brannen.	[1]

Ut fra opplysningene i tabellen kan man gjøre følgende antakelser:

- Brannen starter i trekkbilen på venstre side av motoren, brannårsaken er ukjent.
- Brannen i vogntoget har fått utvikle seg fritt, og vogntoget ble overtent med maksimal branneffekt i løpet av de første 15 minuttene. Basert på opplysningene gitt fra SHT, antas det at brannspredning fra trekkbil til semitrailer tok kort tid og at semitraileren ble overtent i løpet av 15 minutter ($t_1 =$ 15 min. i branneffektkurven i Figur 1-1).
- Brannslokkingstidspunkt er 55 minutter fra antennelse ($t_S = 55$ min i branneffektkurven i Figur 1-1).

Hvor lenge man hadde fullt utviklet brann, det vil si før brannen ble redusert (t_2 i branneffektkurven i Figur 1-1), er avhengig av blant annet brannvesenets slokkemetode og ventilasjonsforholdene i tunnelen, noe som gjør det vanskelig å anslå t_2. Derfor er t_2 i disse beregningene en variabel parameter. I tillegg opplyser brannvesenet at semitraileren og dekkene allerede var utbrent ved dere ankomst 30 minutter etter antennelse.

2.2 Vogntoget og lasten

Figur 2-1 viser bilde av et vogntog av type Renault Magnum 440.19 T 4x2. Følgende informasjon om vogntoget og lasten er oppgitt av oppdragsgiver:

- Dimensjonene på semitrailerens lasterom følger europeisk standard: lengde 13,62 m, bredde 2,55 m og høyde 2,60 m [1].
- Semitraileren hadde ingen last [1]. Lastevolumet angir semitrailerens volum over tilhengerens lasteplan [1]. Høyden fra bakken til toppen av lasteplanet er 1,3 – 1,4 m [1].
- Semitraileren hadde et overbygg dekket av presenning, som antas å være PVC-belagt polyester og gulvet i semitraileren bestod av 30 mm vannfast finer.
- Trekkvognen hadde 6 dekk med dimensjon 315/70 R 22,5 og semitraileren hadde 6 dekk med dimensjoner 385/65 R 22,5.
- Total vekt for et dekk antas å være gjennomsnittlig 55-80 kg, hvorav 45 % er gummi og resten er metall (felg) [8].

Figur 2-1 Eksempel på et vogntog av type Renault Magnum. Det aktuelle vogntoget kan fravike noe fra bildet utseendemessig.

2.3 Brannskadene på vogntoget og lasten

Figur 2-2 o**g** Figur 2-3 viser restene av vogntoget etter at brannen var slokket. Av figuren kan vi se at alt brennbart materiale, både på trekkbil og semitrailer, synes å være helt oppbrent.

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Figur 2-2 Bilde av den utbrente trekkvognen. Foto: SHT.

Figur 2-3 Bildet viser den utbrente semitraileren. Foto: SHT.

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3 Estimering av branneffekten

Estimering av branneffekten i MW er basert på metoden beskrevet i seksjon 1.3.

3.1 Total brannenergi

Brannenergien Q_B [GJ] estimeres fra følgende likning:

$$Q_B = \sum_i M_i H_i f_i \quad (1)$$

hvor

M_i = vekt av materiale *i* (kg)
H_i = netto forbrenningsvarme for materiale *i* (GJ/kg)
f_i = vektfraksjon som er brent av materiale *i* (%)

3.1.1 Semitrailer og dekk

Tabell 3-1 oppsummerer estimater for brannenergi for semitraileren og dekkene basert på følgende forutsetninger:

- Estimat av presenningens vekt er 0,9 kg/m^2. For det aktuelle vogntoget har vi ingen opplysninger om dette, men dette er den maksimale verdien funnet når flere leverandører av slike presenninger sammenliknes.
- Presenningens netto forbrenningsvarme antas å være 28,0 MJ/kg, som tilsvarer forbrenningsvarme for polyester [9].
- Gummiens netto forbrenningsvarme antas å være 32,0 MJ/kg [9,10].
- Presenning og gummidekk er fullstendig oppbrent.

Tabell 3-1 Estimering av total brannenergi for semitraileren og dekk.

Komponent	Materiale	Vekt	Netto forbrenningsvarme	Masse brent	Brannenergi
		kg	MJ/kg	%	GJ
Tregulv	Vannfast finer	500	16,5	100	8,3
Presenning og tak	Polyester + PVC	90	28,0	100	2,5
Dekk	Gummi	280	32,0	100	9,0
Estimert total brannenergi					**19,8**

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3.1.2 Trekkvogn

Tabell 3-2 oppsummerer estimater for brannenergi for trekkvognen og drivstoffet basert på følgende forutsetninger:

- 200 liter av drivstoffet har brent. Dette er annslått ut fra at drivstofftankene var hele etter brannen og at brannen bestod av en jetflamme fra åpningene på maksimalt 1 MW fra hver tank.
- Materialet i førerhuset er anslått til å bestå av forskjellige plaststoffer og skumgummi med en middels forbrenningsvarme på 30 MJ/kg som er en middelverdi for forskjellige plastmaterialer.
- Vekten av materiale i førerhuset er grovt anslått.

Tabell 3-2 Estimering av total brannenergi for trekkvogn inkludert drivstoff.

Komponent	Materiale	Vekt	Netto forbrenningsvarme	Masse brent	Brannenergi
		kg	MJ/kg	%	GJ
Drivstoff	Diesel	166	46,0	100	7,6
Diverse plastikk, stoff og seter i førerhus	Polyester/skumgummi	100	30	100	3,0
Estimert total brannenergi					**10,6**

3.2 Estimering av maksimal branneffekt (i MW)

Integralet av branneffektkurven i Figur 1-1 fra antennelse til slokking representerer den totale brannenergien Q_B. Derfor kan den maksimale branneffekten $\dot{Q}_{B,max}$ beregnes som funksjon av total brannenergi og de karakteristiske tidspunktene i branneffektkurven:

$$\dot{Q}_{B,max} = 2Q_B/(t_s + t_2 - t_1) \qquad (2)$$

Utfra at brannvesenet melder at semitraileren var fullstendig utbrent mens førerhuset og drivstofftanken fortsatt brant har vi valgt å dele opp beregningen av disse to med forskjellige tider for start av brannreduksjon og slokking.

3.2.1 Semitrailer og dekk

Figur 3-1 viser variasjonen av maksimal effekt av brannen i semitraileren og dekkene som funksjon av t_2 (tidspunkt for starten av brannreduksjon) basert på total brannenergi vist i Tabell 3-2. Overtenningstidspunkt $t_1 = 900\ s$ (15 min) og slokkingtidspunkt $t_s = 1800\ s$ (30 min).

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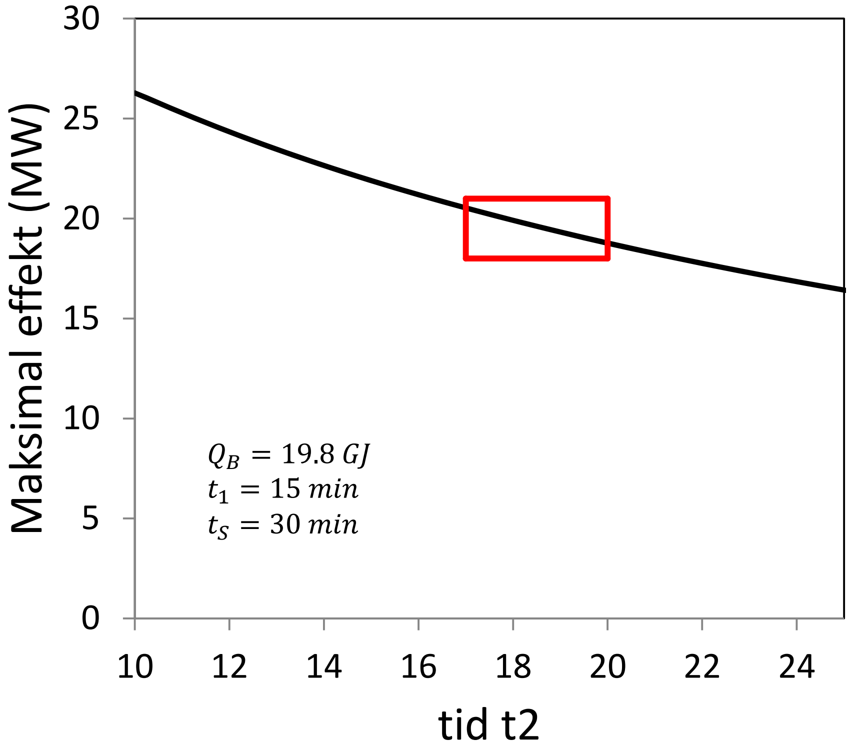
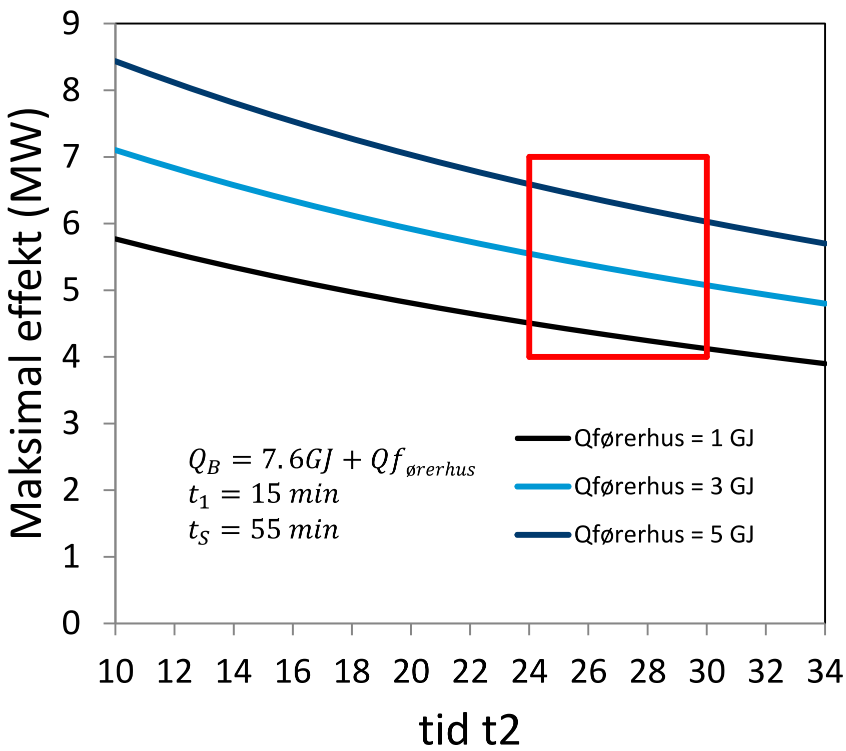


Figur 3-1 Variasjon av maksimal effekt av brannen i semitraileren og dekkene som funksjon av t_2 (tidspunkt for brannreduksjon). Det røde området markerer maksimal effekt ved t_2 mellom 17 og 20 minutter.

3.2.2 Trekkvogn

Figur 3-2 viser variasjonen av maksimal effekt av brannen i trekkvognen som funksjon av t_2 (tidspunkt for starten av brannreduksjon) basert på total brannenergi vist i Tabell 3-2. Overtenningstidspunkt $t_1 = 900\ s$ (15 min) og slokkingtidspunkt $t_s = 3300\ s$ (55 min).



Figur 3-2 **Variasjon av maksimal effekt av brannen i trekkvognen som funksjon av t_2 (tidspunkt for brannreduksjon). Det røde området markerer maksimal effekt ved t_2 mellom 24 og 30 minutter.**

3.2.3 Maksimal branneffekt totalt

For å finne den totalt maksimale branneffekten legges estimatene for trekkvognen sammen med estimatet for semitraileren og dekkene. Dette gir en estimert verdi for den maksimale effekten til 22-27 MW. Vi kan derved anta at maksimal effekt er 25 MW.

3.2.4 Usikkerhet rundt mengde drivstoff

Det har vært noen usikkerheter rundt mengden Diesel som har bidratt i brannen. En første antagelse gjort av SHT var 600 liter. Det er urealistisk at så stor mengde har fordampet og mengden ble redusert utfra opplysninger om at tankene var hele og at all flamme var avdamping fra tankene gjennom åpningen. Enkle konservative beregninger har gitt en maksimal brannlast fra hver tank på 1 MW og et totalt forbruk på 200 liter. Om det er mer Diesel som har deltatt i brannen vil dette ha stor innvirkning på brannlasten og de første beregningene med 600 liter Diesel gav en total maksimal brannlast fra vogntoget mellom 35 og 45 MW.

3.2.5 Nødvendig ventilasjon for å unngå ventilasjonskontrollert brann

En brann i en tunnel med en viss effektutvikling vil kreve en viss mengde luft for å brenne fritt. Ved mindre lufttilførsel enn dette vil det oppstå ventilasjonkontrollert brann. For å unngå dette, trengs det luft nok til fullstendig forbrenning av det brennbare materialet. Ved ventilasjonskontrollert brann oppstår ufullstendig forbrenning, noe som igjen fører til økt produksjon av CO,(karbonmonoksid). En brann med den estimerte effekten, og med antatt tunneltverrsnitt på 50 m^2 trenger bare en lav ventilasjonslufttilførsel (0,2 m/s) for å

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unngå underventilert branntilstand. Lokalt kan det allikevel ha oppstått underventilert brann inne i trekkvognen, avhengig av om dører eller vinduer har vært åpne.

4 Diskusjon

SINTEF NBL har ikke hatt mulighet til å inspisere tunnelen eller den utbrente traileren etter brannen. All informasjon som ligger til grunn for denne analysen er basert på bilder og rapporter som er tilsendt av oppdragsgiver. Denne informasjonen har mangler, siden ingen observasjoner av forløpet er tilgjengelig utover det brannvesenet og vitner har gitt. Dette medfører at vi har vært nødt til å gjøre noen forenklinger i modellen samt trekke noen antagelser om brannforløpet.

Man har blant annet ikke hatt noe informasjon om trekkbilen om hvor mye plastmaterialer denne inneholdt så dette er det kun gjort et grovt estimat av.

Av andre antagelser har man måttet estimere hvordan materialene brenner fra litteraturen. Brennverdier er avhengig av blant annet geometri og komprimeringsgrad av materialet. Derfor er det klart at disse verdiene kan avvike fra de reelle materialenes egenskaper og dermed gi et avvik i estimatet av den maksimale effekten. Man har også måttet anta hvor lenge de ulike fasene av brannen varte. Dette ble gjort med bakgrunn i opplysninger fra oppdragsgiver. Andre varigheter ville kunne gitt andre estimat.

Det kan også være at andre brennbare materialer i tunnelen har bidratt til brannen, men dette har vi ikke hatt noen informasjon om.

Med bakgrunn i det lave detaljnivået i dataunderlaget for denne analysen, kan man si at den forenklede modellen som ble benyttet, sammen med de antagelser som ble gjort, er adekvat for å estimere brannens maksimale effekt.

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Lastbilsbrand i tunnel: Rökgasproduktion

Beskrivning av uppdrag

På grund av lastbilsbranden i Gudvagnatunnelns 5 augusti 2013 har Statens Haverikommisjon for Transporter (SHT) gett SP Fire Research i uppdrag att söka svar på följande frågor:

1. Hvilke gasser inneholder røyk fra brann i et tomt vogntog. Det tas utgangspunkt i et standard vogntog som brukes i de fleste europeiske land (toakslet trekkbil og treakslet semitrailer – se eksempelbilde under). Antatt dieselmengde i drivstofftanker settes til 600 liter.

Figur 1 Fjärrlastbil med släp

2. Hvordan sprer erfaringsmessig røyken seg fra brannen starter i et vogntoget til det er overtent. Det forutsettes at det ikke er mekanisk ventilasjon i tunnelen.
3. Hvordan er røykintensiteten fra et tomt vogntog i forhold til et fullastet vogntog (40 tonn totalvekt). Vi ønsker at det gis eksempler på flere forskjellige typer last.
4. På bakgrunn av informasjon fra de som var inne i tunnelen beveget røyken seg i "propper". Dette medførte at det i deler av tunnelen var tettere røyk i enkelte områder av tunnelen enn i andre områder. Er dette et kjent fenomen når det blir benyttet mekanisk ventilasjon?
5. Ved brannen i Gudvangatunnelen ble røyken ventilert slikt at innsatspersonellet kunne komme til fra den "røykfrie" siden. Dette medførte at trafikantene som var på den

andre siden ble fanget i røyken, slik at de ikke fikk evakuert. Redningspersonell kom heller ikke inn på denne siden på grunn av minimal sikt.

- Hvordan ser SP på denne problemstillingen?
- Har dere vurdert dette, og hvordan kan det evt. løses?

Analys

I detta avsnitt försöker vi utifrån befintlig kunskap svara på frågorna i föregående avsnitt. Avsikten är inte att uppskatta brandens storlek i MW, eller varaktighet, utan att uppskatta rökproduktion och bildning av olika toxiska ämnen, för att kunna ge svar på de frågor som SHT ställer.

Fråga 1: Brandgaser från tom lastbil

Lastbilen som brann var tom och har då en tjänstevikt på ungefär 17 ton (semitrailer 7 ton, dragbil 10 ton). Bilderna i figur 2 är från en motsvarande lastbil som den som brann i tunneln, de har använts för att uppskatta material och ytor som kan brinna.

Figur 2 Bilder över lastbil och förarhytt.

Utifrån dessa bilder och annan teknisk information som vi erhållit från SHT har golvytan inne i förarhytten uppskattas till 6 m^2, bakre väggen till 6 m^2, stolar till 2 m^2 och instrumentbräda till 3 m^2. Motorn antas börja brinna framtill där den överhettade kylaren sitter, med en uppskattad area av 1 m^2. Därtill tillkommer de 12 däcken (varje däck har en area av 4,5 m^2) samt 600 l diesel, som antas brinna på 1 m^2. Semitrailern har en lastyta på 33 m^2 med 30 mm tjock vattentät plywood. Denna areauppskattning hjälper oss att uppskatta olika rökmängder och mängder toxiska ämnen i röken.

En brand kan ge upphov till produktionen av mängd olika gaser. I huvudsak förbrukas syre medan vatten och koldioxid produceras. En begränsande faktor vid utrymning är narkotiska gaser som leder till medvetslöshet, vanligen kolmonoxid (CO), koldioxid (CO_2),cyanid (HCN) samt låg syrehalt (O_2,. CO bildas vid alla bränder och härleds ofta som dödsorsak. Mängden

CO som bildas är starkt beroende på lokala temperatur- och ventilationsförhållanden som är svåra att förutse. För att HCN ska bildas krävs material som innehåller kväve (N). Irriterande gaser som vid höga koncentrationer försvårar utrymning är t.ex. väteklorid (HCl), väteflorid (HF) och isocyanater. Cancerogena ämnen som ger symptom på längre sikt och som bildas vid brand är t.ex. bensen och dioxiner. I den här utredningen så fokuserar vi på de i första hand kritiska gaserna för utrymning, dvs. O_2, CO, CO_2 och HCN. En översiktlig summering över en lastbils material ges i nedanstående tabell.

Tabell 1 Data för att uppskatta brandens yta för olika material i fordonet samt rök- och gasproduktionen från materialen. [(Tewarson, 2004, Persson and Simonson, 1998)].

Material	$\dot{m}''$ (kg/m^{2}s)	A (m^2)	Yield (g/g)			D_{mass} (m^2/kg)	H_{ec} (MJ/kg)
			CO	CO_2	HCN		
PUR	0,024	8	0,16	1,99	0,01	304	17
Polystyren	0,034	3	0,22	2,20	-	335	27
Diesel/olja	0,030	2	0,041	2,86	-	250	32
Textilier	0,016	6	0,055	1,43	-	230	27
12 st Däck	0,0084	54	0,24	3,04	-	87	25

Den longitudinella lufthastigheten, u antas vara ungefär 2,5 m/s. Tunnelns tvärsnitt uppskattas till 50 m^2 och rökgaserna antas vara jämt fördelade över tvärsnittet.

Tabell 2 Beräknad gas- och rökproduktion.

Material	Gaskoncentration (%)				Sikt (m)
	Förbrukat O_2	CO	CO_2	HCN	
PUR	0,11	0,015	0,12	0,0010	-
Polystyrene	0,089	0,011	0,069	-	-
Diesel/olja	0,062	0,0012	0,053	-	-
Textilier	0,084	0,0025	0,042	-	-
12 st Däck	0,50	0,062	0,50	-	-
Totalt	0,85 (20,01)	0,0917	0,784	0,0010	0,93

Beräknade värden i Tabell 2 är de värden som erhålls när branden är fullt utvecklad. Sikten i röken är beräknad utifrån ekvation (13.24) i referens (Ingason, 2012). Gaskoncentrationerna i Tabell 2 kan sättas i relation till gränser för exponering som leder till medvetslöshet ifrån Tabell 3. Inga utav de utvärderade gaserna i Tabell 2 kommer upp i kritiska nivåer. Lägre ventilationshastigheter än 2,5 m/s leder till ökade koncentrationer. En halvering till 1,25 m/s leder exempelvis till en dubbelt så hög gaskoncentration. I verkligheten skulle CO, CO_2 och HCN samverka och göra att tiden till medvetslöshet minskar. Utifrån tidigare uppskattningar som SP har gjort är gaskoncentrationerna i Tabell 2 rimliga för en lastbil utan last.

Tabell 3 Gränser för giftiga (asphyxiant) gaser och medvetslöshet vid 5 respektive 30 minuters exponering (Blomqvist, 2005).

Ämne	Medvetslöshet vid 30 min exponering	Medvetslöshet vid 5 min exponering
CO	1 550 ppm (0,15 %)	7 000 ppm (0,7 %)
HCN	105 ppm (0,0105 %)	175 ppm (0,0175 %)
CO_2	6,5 %	7,5 %
O_2	12 %	11,5 %

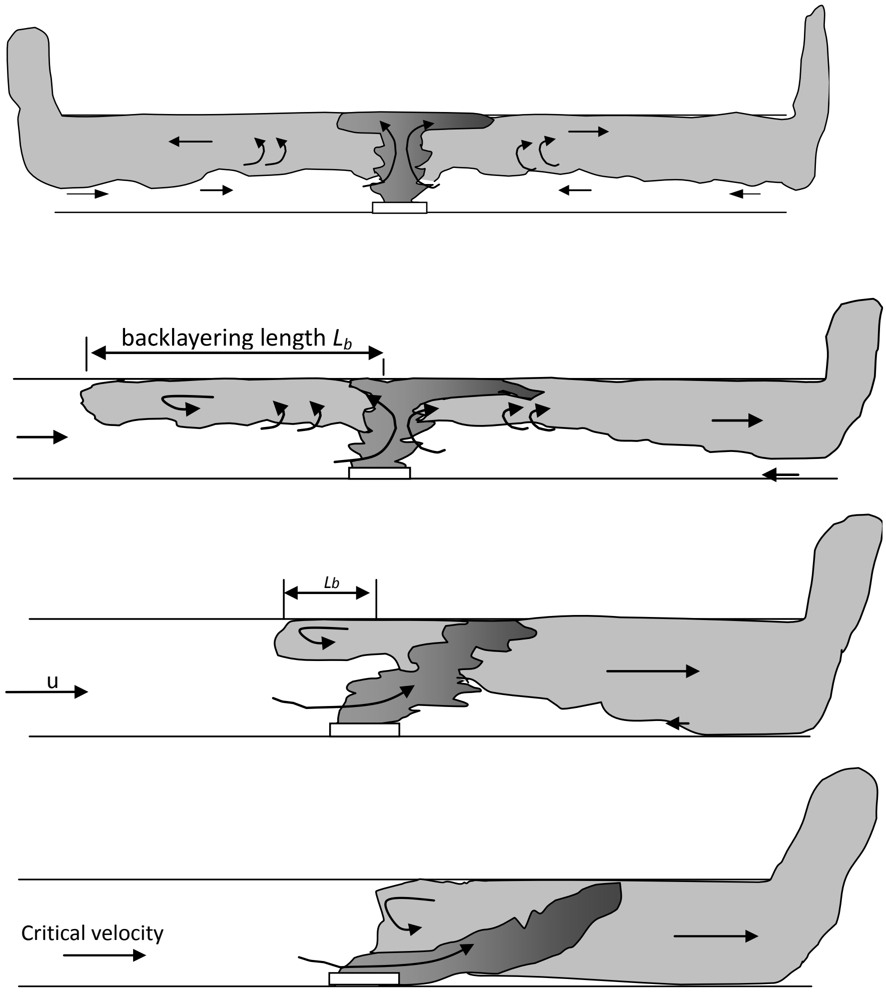
Notera att HCN och CO är mycket svåruppskattade brandgaser, koncentrationen beror på typen av bränsle, geometri, ventilation och temperatur förhållanden. CO_2 däremot är relativt väl kopplad till brandens storlek och därmed ganska lättuppskattad.

Fråga 2: Brandutveckling för tom lastbil i tunnel beroende på ventilation

I en brand i ett till större delen slutet utrymme kan man få övertändning när allt bränsle pyrolyserar och bidrar till branden som då blir ventialtionskontrollerad, dvs. beroende av syretillförsel in i utrymmet. I en tunnel får man inte övertändning i samma bemärkelse eftersom det generellt finns gott om syre i förhållande till brandens storlek. Dock kan man få övertändning i förarhytten eller eventuellt släpet, men eftersom släpet har presenning på sidorna kommer det att brinna sönder varför ingen övertändning sker där. Det här betyder dock inte att tunnelbränder är mindre än slutna bränder i byggnader (rumsbrand). Man kan få lokalt högre brandtemperaturer i tunnlar än i rumsbränder, uppemot 1350 grader C jämfört med ungefär 1000 grader C i rumsbränder eftersom det finns så gott om syre och därmed sker en mer effektiv förbränning. I det aktuella fallet kan högsta tak temperaturen uppskattats till ungefär 1000 ^{o}C.

Naturlig ventilation behöver inte innebära att luftens hastighet i tunneln är låg. Beroende på vind och lufttrycksskillnad mellan portalerna kan höga lufthastigheter uppnås utan mekanisk ventilation. Eftersom Gudvangatunneln lutar med 3,5 % kan en hög naturlig ventilationshastighet väntas, allt i från några decimeter per sekund till några meter per sekund. På vintern stiger den naturligt uppemot Flåm, då lufttemperaturen kan vara högre inne i tunneln. På sommaren kan det bli naturligt flöde ned mot Gudvangen, då temperaturen är lägre inne i tunneln. Även yttre vind och atmosfärtryck kan påverka flödet. Om vi dock förutsätter en låg lufthastighet (0.1-0.3 m/s) i tunneln som antingen uppnås genom naturlig eller mekanisk ventilation så kommer den varma röken till att börja med att sprida sig längs taket i båda körriktningarna. Initialt kommer röken att vara skitad, men för stora bränder (som den här) och när röken kylts ned kommer rökgaslagret att sjunka mot vägbanan. Inom en sträcka på 300 m bör röken ha kylts av så pass mycket att röken kommer att sjunka ner mot vägbanan. Dock kommer alltid frisk luft att passera längs vägbanan, då den luft som transporteras bort från branden måste ersättas av ny luft. För lufthastigheter i storleksordningen 1 m/s eller lägre kommer röken att stanna på uppströmssidan, och en såkallad backlayering kan bildas, se figur 3.

För ventilationshastigheter över 2 m/s kan röken förutsättas röra sig med luftriktningen och ha en låg eller ingen skiktning på nedströmssidan. Uppströms bildas en relativt kort backleyering. Vid lufthastigheter på mellan 2.5 och 3 m/s kommer ingen backleyring att bildas, all rök går åt ett och samma håll. I figur 3 visas en principiell bild över hur rökens skiktning påverkas av olika lufthastigheter i tunneln.



Figur 3 Skiktning av rök i tunnel vid olika lufthastigheter u (från överst och nedåt u=0.3 m/s, u= 1m/s, u=2 m/s och slutligen u=3 m/s) (Ingason, 2012).

Fråga 3: Rökintensitet för fullastad relativt tom lastbil

Rökintensiteten och brandgaskoncentrationen kan förenklat sett anses vara proportionell mot brandeffekten. En fullastad lastbil kan ge 80-200 MW vilket betyder att rökintensiteten också ökar med motsvarande faktor. Sikten förväntas minska 4-10 gånger.

Branden från en tom lastbil kan dock mycket väl vara tillräckligt stor för att tidigt ge en obefintlig sikt. Experiment från Runehamar 2003 (Ingason et al., 2011) ger exempel på dieselbrand (200 l) och fullt utvecklade lastbilsbränder med last. Efter fem minuter är rökintensiteten 458 meter nedströms en dieselbrand på 6 MW redan så hög att sikten i det närmaste är noll meter. För de större lastbilsbränderna är sikten också noll. Dock är skillnaden stor för produktionen av giftiga gaser, t.ex. CO, där dieselbålet ger mycket låga koncentrationer medan de större lastbilsbränderna ger mycket höga värden (620 – 2900 ppm). Olika typer och kombinationer av last-, temperatur- och ventilationsförhållanden kan ge olika mängd giftiga gaser. I Runehamar gjordes fyra försök med varierande last för vilka produktionen av CO, CO_2 och O_2 summeras i tabellen nedan.

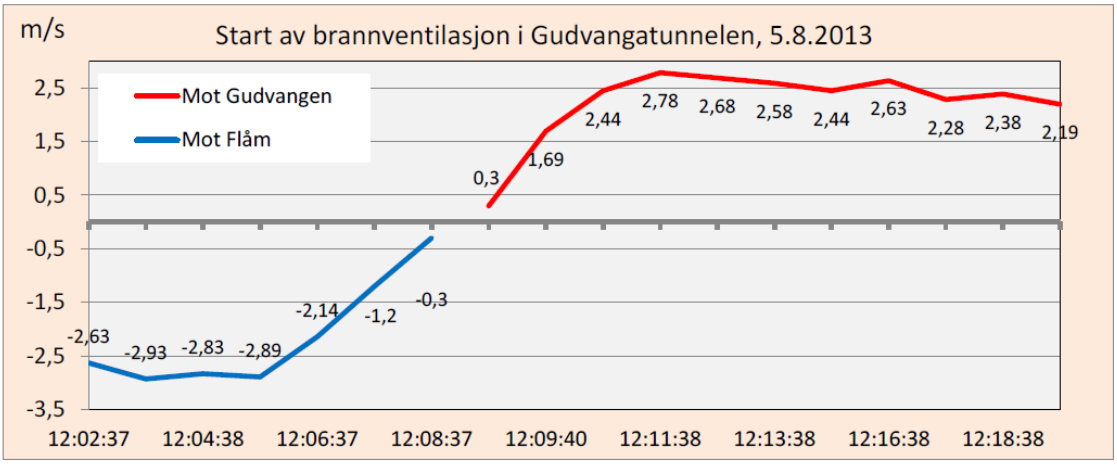
Tabell 4 Summering av CO produktion för olika typer av gods (Ingason et al., 2011).

Försök	Last	Brandstorlek (MW)	Max CO (%)	Max CO_2 (%)	Min O_2 (%)
1	Trä+plast	202	0,23 (2300 ppm)	12	7
2	Trä+PUR	157	0,29	10	10
3	Möbler+PUR+lastbilsdäck	119	0,062	7	13
4	Papp+plast	66	0,087	4	16

Förutsatt att branden i dragfordonet inte är ovanligt stor, visar Tabell 5 att lasten är dominerande för produktionen av höga toxiska nivåer i tunneln. Resulterande koncentrationer av CO och CO_2 för förarhytt inklusive last kan uppskattas genom att addera värden för tom lastbil och relevant last från något av försöken ovan. Medvetslöshet enligt kritiska doser i Tabell 3 kan då väntas inom 5 minuter för försök 1, 2 och 3 i Tabell 5. Notera att i Runehamarförsöken hade man ungefär samma tunneltvärsnitt och lufthastighet (2-2.5 m/s). Sammanfattningsvis så hade de personer som befunnit sig i röken i upp till 5 minuter blivit medvetslösa om motsvarande last hade funnits i trailern.

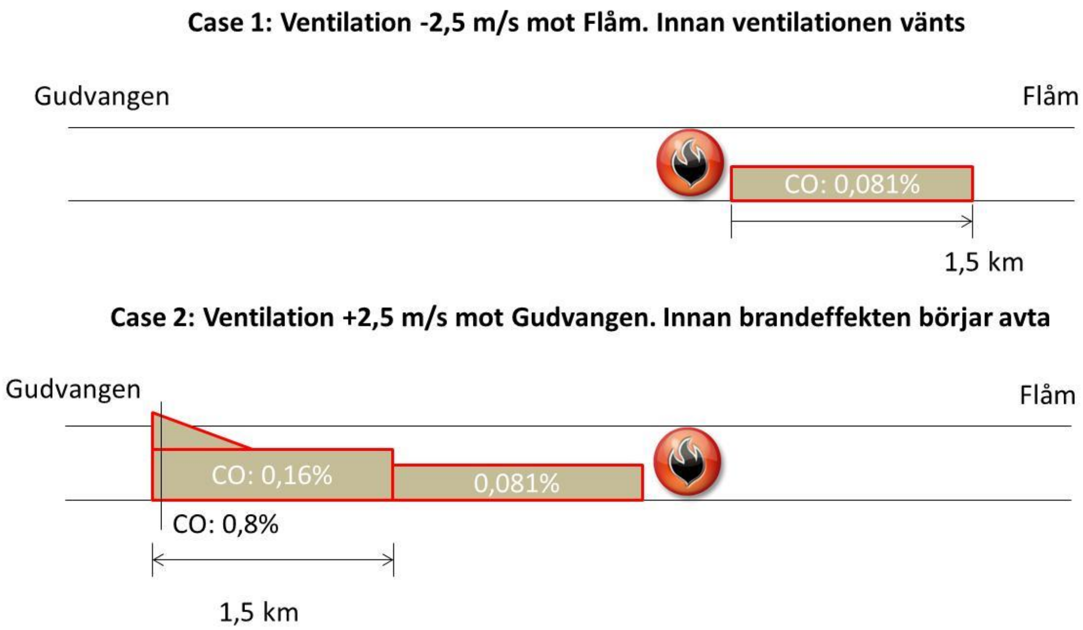
Fråga 4: Påverkan av mekanisk ventilation

I Figur 4 ses att ventilationen ändras från ungefär -2,5 m/s till +2,5 m/s under en tid av ungefär 5 minuter. Som sagt tidigare så kan naturlig ventilation ge luftflöden i paritet med mekanisk ventilation. Dock får man en tydligare så kallad ”rökpropp” om ventilationsflödet vänds eftersom branden då redan kan ha vuxit sig stor och därmed producerar mycket brandgaser som hamnar främst i rökproppen. Därtill kommer redan producerad rök som tidigare befann sig nedströms branden (mot Flåm) att spädas på med mer rök när den passerar branden igen.



Figur 4 Ventilationsflöden i tunneln (källa: Gunnar Lotsberg, Statens vegvesen)

Resulterande rökgaskoncentrationer kommer som lägsta uppskattning dubbleras och sikten halveras för vändande och nyproducerad rök. Högst koncentration blir det mycket riktigt längst fram i den vändande röken, varför benämningen rökpropp är passande. Som exempel blir koncentrationen CO vid 0,5 m/s ungefär 0,4% (4000 ppm), vilket är betydligt högre än i Tabell 2 med 5 gånger högre flöde på 2,5 m/s. När den sedan vänds och kommer upp i -0,5 m/s och passerar branden igen blir koncentrationen det dubbla, alltså 0,8%, eller 8000 ppm, vilket leder till medvetslöshet inom 5 minuters exponering. Då luftflödet vänder och ligger inom intervallet 0,5 till -0,5 m/s blir koncentrationen ytterligare högre i den resulterande rökproppen, dock varar detta tillstånd under en relativt kort period, ungefär 1 minut, se Figur 4. Detta betyder att dessa höga koncentrationer som kan ge medvetslöshet inom 5 minuters exponering uppnås under ett tidsintervall av ungefär 1 minut. Detta förklarar varför inga personer förlorade medvetandet. I Figur 5 ges en schematisk beskrivning av rökgaskoncentrationen för CO under antagandet att branden är konstant enligt Tabell 1 och 2. Koncentrationen för övriga gaser ökas på samma sätt.



Figur 5. Schematisk beskrivning av rökgaskoncentration innan och efter ventilationen vänt. Över 0,8% CO väntas längst fram i rökproppen mot Gudvangen.

Fråga 5: Strategi för mekanisk ventilation, utrymning och räddningsinsats

En grundprincip för bi-direktionella (trafik i båda riktningar) tunnlar bör vara att ha en minimal ventilation under utrymning så att röken sprids långsamt inne i tunneln och människor nedströms och uppströms branden hinner utrymma. Detta kan uppnås genom mekanisk eller naturlig ventilation beroende på väderförhållanden vid tunnelns portaler. Sedan, efter utrymningen är avslutad, för att hjälpa räddningstjänst att nå branden kan ventilation slås på från ett håll så att räddningstjänst kan gå in i rökfri miljö, normalt räcker 3 m/s för att uppnå gynnsamma förhållanden uppströms branden, se figur 3. Den utrustning som finns i många tunnlar där man kan få information om antal fordon och placering inne i tunnlarna kan användas som beslutsunderlag för räddningstjänsten. Detta bör göras i samråd med vägtrafikcentralen.

Man bör vara varsam med ändringar av ventilationsflöden inne i tunnlarna efter att branden har startat. Den främsta anledningen är att om det finns människor i tunneln uppströms branden bör man inte vända ventilationsriktningen eftersom mer rök då finns i tunneln under längre tid, och högre koncentrationer uppnås i rökproppen. Med andra ord leder detta till högre rökgaskoncentrationer för de personer som tidigare befann sig uppströms branden när gammal plus nyskapad rök når upp dem.

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