Accident Investigation Board Norway

Issued July 2016

REPORT ROAD 2016/03

REPORT ON COACH FIRE IN THE GUDVANGA TUNNEL ON THE E16 ROAD IN AURLAND ON 11 AUGUST 2015

The Accident Investigation Board has compiled this report for the sole purpose of improving road transport safety. The object of any investigation is to identify faults or discrepancies which may endanger road transport safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for road transport safety shall be avoided.

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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

TABLE OF CONTENTS

NOTIFICATION OF THE ACCIDENT 3

SUMMARY 3

1. FACTUAL INFORMATION 5

1.1 Sequence of events 5
1.2 Rescue operations 7
1.3 Personal injuries 8
1.4 Damage to vehicles 9
1.5 Damage to the tunnel structure 9
1.6 The coach driver 9
1.7 Vehicle and load 10
1.8 Road conditions 15
1.9 Communication systems 20
1.10 Laws and regulations 22
1.11 Authorities, organisations and leadership 22
1.12 The AIBN's other investigations of fires in tunnels 24
1.13 Implemented measures 26

2. ANALYSIS 29

2.1 Introduction 29
2.2 Assessment of the sequence of events 29
2.3 Fire progression 31
2.4 Ventilation and accident development 32
2.5 Information and communication needs in emergency situations 35
2.6 Follow-up of safety and learning points 37

3. CONCLUSION 40

3.1 Important results of the investigation with a bearing on safety 40
3.2 Investigation results 40

4. SAFETY RECOMMENDATIONS 42

REPORT ON ROAD TRAFFIC ACCIDENT

Date and time:	11 August 2015 at 13:15
Scene of the accident:	The E16 road – the Gudvanga tunnel, Aurland Municipality in Sogn og Fjordane County
Road no, main section (hp), km:	E16 Hp 8 km 7.000
Type of accident:	Coach fire
Vehicle type and combination:	Swedish-registered Neoplan P15 tour coach, 2010 model
Type of transport:	Passenger transport

NOTIFICATION OF THE ACCIDENT

The Accident Investigation Board Norway (AIBN) first became aware of the coach fire in the Gudvanga tunnel via the media at approximately 13:45, and was notified of the incident by the Traffic Control Centre (VTS) somewhat later.

SUMMARY

On 11 August 2015, a tourist coach caught fire in the 11.4-km-long Gudvanga tunnel. Witness observations and technical findings indicate that the cooling system started leaking towards the end of the drive, probably as the coach was heading up the Flenja tunnel. The AIBN has not identified a clear cause of the fire. It was not until 300 m after entering the Gudvanga tunnel that the driver observed smoke and stopped the coach immediately. The driver notified the police and quickly evacuated the coach.

The triple alert notice to the other emergency services worked as intended. The 110 emergency communication centre in Sogn og Fjordane County notified the Traffic Control Centre (VTS), which immediately closed the tunnel with road barriers and a flashing red stop signal. Aurland fire service was in place at the scene of the fire inside the tunnel after approximately 15 minutes. During the first telephone conversation between the 110 centre and the VTS, the VTS was asked to wait to initiate fire ventilation. When the driver removed the fire extinguisher from the wall of the tunnel to try to extinguish the fire, the fire ventilation started automatically and the pre-set direction of ventilation was towards Gudvangen.

The automatic fire ventilation meant that the smoke was ventilated to the most distant exit (11.1 km) through the part of the tunnel that held the greatest number of road users. The automatic system, which is used in several of the longest tunnels in Norway, exposed the road users closest to the scene of the fire to greater danger and reduced their possibility of self-rescue. It also affected the VTS and the fire service's ability to gain control of the situation at an early stage. In the AIBN's opinion, the Norwegian Public Roads Administration (NPRA) should change the automatic system so that the ventilation is controlled in a way that facilitates self-rescue.

A scenario with many people on foot in the tunnel, like in the Gudvanga tunnel fire in 2013, was avoided because all 32 passengers from the coach could fit in an empty van that happened to arrive at the scene. 19 vehicles managed to turn around in the tunnel. Three vehicles containing a total of

five people were trapped in the smoke in the tunnel, but mobile phone communication with the emergency services helped to ensure that everybody stayed in their cars in the tunnel.

That the fire service decided to reverse the direction of ventilation on being notified that road users were trapped in the smoke further into the tunnel had a decisive impact on the development of the situation. The decision shows that Aurland fire service had learnt from the fire in the tunnel in 2013. In the AIBN's opinion, this tactic can be further developed and used in other tunnels. The five people who were left in the tunnel were found by smoke divers from Voss fire service after approximately 1.5 hours and taken to hospital to be treated for smoke injuries.

The investigation shows that the NPRA's equipment and procedures are inadequate, considering that they can be decisive for the outcome of a tunnel fire. The AIBN calls for technology that can provide a real-time overview of the number of vehicles, their location and the number of people inside the tunnel, and an immediate notification from the VTS to motorists in the event of a fire. Furthermore, the AIBN believes that direct, uninterrupted communication is very important in an emergency, and that the VTS should therefore be able to communicate directly with the emergency services by being connected to the Norwegian Public Safety Network (Nødnett).

It is the AIBN's view that the fire could probably have been prevented had the driver performed a safety inspection of the coach before entering the Gudvanga tunnel. A safety inspection should consist of a brief stop in a suitable place where the vehicle can be inspected for leakages, overheating and smoke development. In the AIBN's opinion, facilities should be established to enable drivers to perform the recommended safety check before entering certain tunnels.

The AIBN proposes a total of five safety recommendations in connection with this investigation.

1. FACTUAL INFORMATION

1.1 Sequence of events

A tourist coach carrying 32 Chinese passengers left Oslo in the early morning of 11 August 2015, heading for Gudvangen. Gudvangen was one of the day’s destinations, from which the passengers would be transferred by ferry to Flåm.

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

Around 13:00 the coach passed through Flåm on its way to Gudvangen. After entering the 5-km-long Flenja tunnel on the E16 road, the coach driver experienced a loss of engine power, but he saw no warnings on the dashboard. When the coach's engine power returned after a short while, he drove on as planned.

According to the witness statement of a motorist following the coach through the Flenja tunnel, the coach left a trail of steam and a smell of cooling agent. The witness drove behind the coach and observed a notable loss of speed on entering the Flenja tunnel, followed by an increase in speed about halfway through the tunnel. At the exit from the Flenja tunnel, the witness observed blue smoke coming from under the coach. Approximately midway between the two tunnels, the witness drove slightly across the centre line while flashing the car headlights in an attempt to alert the coach driver.

The coach continued westwards along the approximately 800-metre-long open stretch of the E16 between the Flenja tunnel and the 11.4-km-long Gudvanga tunnel. After entering the Gudvanga tunnel, the coach driver looked in the side mirror and noticed flames coming from the rear left-hand side of the coach. The coach's fire extinguishing system was activated, and warning signals were given in the form of lights on the dashboard and an alarm horn.

The coach driver brought the coach to a halt in the nearest lay-by inside the tunnel, 360 m from the entrance, and evacuated all the passengers from the coach. The coach driver then took the fire extinguisher from the coach and emptied it into the engine compartment without opening the hatch to the engine compartment. Then, at 13:15, he called the police emergency phone number (112) on his mobile phone.

At first the fire seemed to die out, but when it quickly flared up again, the driver removed a fire extinguisher from the tunnel wall to try once more to put it out. When the driver removed the fire extinguisher (at 13:18), he triggered an automatic function that changed the direction of ventilation in the tunnel. Consequently, the smoke, which initially had flowed towards Flåm that day, changed direction and started to flow towards Gudvangen.

At that point, a motorist driving an empty van (Mercedes Sprinter) happened to pass through the tunnel. The driver managed to find room in his van for all of the 32 Chinese coach passengers standing beside the coach in the tunnel, and drove them out of the tunnel to Gudvangen.

The fire extinguisher that the coach driver had removed from the wall had no effect on the fire in the engine compartment. When his efforts to extinguish the fire seemed to be to no avail, the coach driver walked further into the tunnel to warn other motorists.

The coach driver managed to proceed 300 m into the tunnel from the scene of the fire before the smoke reached him. The coach driver sought refuge in a heavy goods vehicle that was parked in the direction of Flåm and remained there together with the driver. Figure 2 and Figure 3 show visibility inside the tunnel at a distance of 3.5 km from the Flåm exit at 13:38 and 13:39, respectively.

Figure 2: At 13:38, the heavy goods vehicle turned around after travelling 3.5 km into the tunnel towards Gudvanga. Photo by NPRA

Figure 3: Visibility in this location became very poor at 13:39. Photo by NPRA

The driver of the heavy goods vehicle and the driver of the burning coach, another driver in an empty coach, and two people in a passenger car towing a caravan were trapped in the smoke approximately 700 m from the exit on the Flåm side of the 11.4-km-long tunnel. See Figure 4.

The road users were in contact with the emergency services by mobile phone throughout the incident, and were told to remain inside their vehicles and breathe through moist towels until the fire service arrived. While waiting, one vehicle reported a recorded temperature of 55 °C outside the vehicle, zero visibility, loud bangs, and smoke seeping into the vehicle.

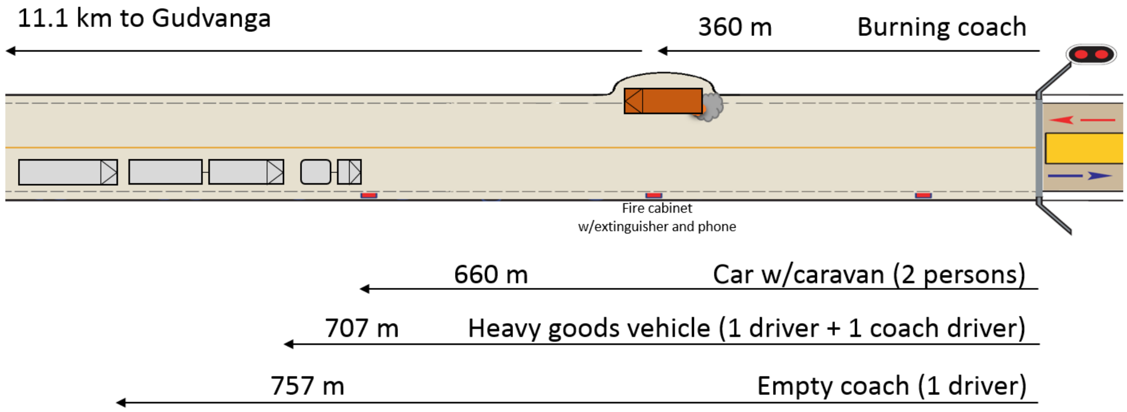

Figure 4: Overview showing the position of vehicles and road users trapped in the smoke. Source: The police/AIBN

The five people still in the tunnel were found by smoke divers from Voss fire service and taken to hospital to be treated for smoke injuries, approximately 1.5 hours after they were caught in the smoke.

The NPRA's traffic counter inside the tunnel, located 3.5 km from Langhuso, registered that 19 vehicles turned and headed back towards Gudvangen between 13:23:03 and 13:38:40. The final three of these vehicles were two heavy goods vehicles and the van carrying the tourists from the coach. The figures show that all passenger cars that arrived from Gudvangen without trailers in tow were able to turn and exit from the tunnel. Approximately 30 passenger cars stopped and turned less than 3.2 km from the fire. All the passenger cars that came from Flåm reversed out of the tunnel.

1.2 Rescue operations

At 13:15, the coach driver called the police emergency number by mobile phone after emptying the coach's fire extinguisher to no avail. A telephone conference link was immediately set up between the police and Emergency Medical Communication Centre (AMK), and a triple alert was issued within two minutes. At 13:17, the emergency communication centre in Sogn og Fjordane (110) called the VTS immediately and requested that the tunnel be closed.

The VTS closed the Gudvanga tunnel by lowering road barriers and activating red flashing stop signals at both ends. The VTS operator asked the emergency communication centre whether the ventilation should be activated (fire ventilation towards Gudvangen), but was told to wait. Just after 13:18, fire ventilation was activated automatically when the coach driver removed the fire extinguisher from the tunnel wall (see Section 1.8.3).

At 13:26, the VTS operator realised that automatic fire ventilation had started and notified the 110 emergency communication centre. At 13:26, the VTS activated stop lights (flashing red lights) and signs bearing the text 'snu og kjør ut/stop and exit' at the turning bays inside the tunnel from Gudvangen.

The VTS observed on the video screen that two heavy goods vehicles were awaiting instructions and would be trapped in the smoke. The VTS operator was told by the VTS team leader to issue the following emergency radio message: *'There is a fire in the Gudvanga tunnel on the E16 road, the smoke is moving towards Gudvangen. Evacuate.'* At the first attempt, the communication was interrupted. The operator was told to try again, and the message was retransmitted at approximately 13:33. The VTS observed that the message was received and that both the heavy goods vehicles managed to turn and leave the tunnel. The VTS operator also issued the following message via NRK Trafikk (the Norwegian Broadcasting Corporations' traffic news channel): *'There is a fire in the Gudvanga tunnel. Road users must evacuate. The smoke is moving towards Gudvangen.'*

Aurland fire service was dispatched to the Gudvanga tunnel and arrived at the scene of the fire at 13:30, approximately 15 minutes after receiving the call that notified of the fire. Aurland fire service experienced some major challenges in extinguishing the fire. At the same time, they were notified of road users trapped in the smoke further inside the tunnel, towards the Gudvangen exit. Aurland fire service had conducted a search along the 360-metre section between the tunnel entrance on the Flåm side and the scene of the fire and confirmed that there were no road users in that area. Aurland fire service therefore decided to interrupt the extinguishing operation and change the direction of ventilation. By doing so, the 11.1-kilometre section of tunnel in which the road users were trapped between the scene of the fire and the Gudvangen exit would be cleared of smoke.

The message to change the ventilation direction was passed on to the VTS via the 110 emergency communications centre at 13:53, 23 minutes after Aurland fire service had arrived at the scene of the fire. Aurland fire service then returned to the Flåm exit.

The VTS changed the ventilation direction as soon as it was instructed to do so. The smoke, which by that time had moved approximately 6.9 km into the tunnel towards Gudvangen, was forced back towards the fire and the tunnel opening on the Flåm side.

Voss fire service was notified in connection with the triple alert and arrived at the tunnel entrance in Gudvangen at approximately 14:00. They followed the smoke as it retreated into the tunnel for approx. 40 minutes before reaching the road users who were trapped in the smoke. The road users were transported out of the tunnel by ambulance personnel. Voss fire service started extinguishing the fire in the coach under highly demanding conditions, with loose rock falling down from the tunnel ceiling. After approximately 20 minutes, it was only the final extinguishing that remained to be done.

The Bergen fire service also responded to the triple alert. The fire crew arrived at the Flåm entrance of the Gudvanga tunnel by helicopter and proceeded by car to Gudvangen when the fire had been put out.

1.3 Personal injuries

Four of the five people inside the tunnel were transferred to hospital for observation and treated for smoke injuries.

1.4 Damage to vehicles

The coach was completely burnt out; see Figure 5.

Figure 5: The burnt-out coach inside the tunnel. Photo: AIBN

1.5 Damage to the tunnel structure

The tunnel ceiling was seriously damaged, with fractured rock in the area above the coach. Debris and rocks had fallen from the ceiling above the coach and along an almost 50-metre long section of tunnel in the direction of Flåm. When Aurland fire service arrived at the scene at 13:30, the response personnel were unable to get close to the burning coach because of the falling debris.

Figure 6: Fallen debris, viewed from the Flåm side. Photo: Aurland fire service

Figure 7: Close-up of fallen debris. Photo: Aurland fire service

1.6 The coach driver

The coach driver was 31 years old at the time of the accident, born in 1984. He had been licensed to drive category CE and D vehicles (bus and heavy goods vehicles) since 2011, and was a qualified bus mechanic. He had driven this coach approximately 45,000 km since March 2015, when he had joined Stenstorps Buss. The assignment in question was a week-long package tour, and it was the sixth time he had driven this particular route, which started in Stockholm and stopped at Oslo, Gudvangen and Copenhagen.

The driver was expected to perform basic maintenance tasks such as tightening and replacing dynamo belts and topping up coolant and engine oil.

The driver stated that the coach was very easy to drive; it had a lot of extra equipment, including a line assist system. He also stated that the coolant level indicator was sensitive. When he received a dashboard warning, the level in the coolant tank was often satisfactory, but if he nonetheless added just 1 dl, the warning light went off. He did this every 10,000 km.

1.7 Vehicle and load

1.7.1 The coach

The coach was a Neoplan P15 Cityliner 2010 special edition model, manufactured by MAN and owned by Stenstorp Buss. There was documentation showing that the coach had been regularly serviced at an authorised dealer's garage as well as a local garage. The AIBN found no record of any defects or work done on the cooling system over the past two years.

The coach had undergone a periodic inspection (‘*kontrollbesiktning*') in Sweden on 6 July 2015, during which five defects were noted (side marker lights, coolant analysis report, engine oil spill, leaking brake hose, defective daytime running lights (half-lights)).

When the defects had been repaired, the coach underwent a new inspection on 3 August 2015, but failed again on account of engine oil spill. Oil spills are rated in the lowest category of defects, while oil leakages are rated in the next category. No oil leakage was found during any of the inspections. The coach was then taken to the garage on 5 August 2015, where the engine was chemically cleaned and a turbocharger oil return hose replaced. All the defects noted by the inspection authority during the most recent inspection had been repaired, but not checked, prior to departure for Gudvangen on 10 August 2015.

The AIBN has examined an undamaged coach of the same type to look at the design, the fire extinguishing system in the engine compartment, the cable feedthroughs, and the engine compartment.

Inside the coach, a fire-extinguishing system had been installed, with nozzles mounted directly above the engine. The method of detection was a heat detection cable that melts and issues a warning at approximately 180 °C. The extinguishing system was released in connection with the incident, but had insufficient capacity to extinguish the fire that broke out.

1.7.2 Fire-technical examination of the coach

Representatives of the AIBN and the National Criminal Investigation Service (Kripos) cooperated on the technical examination of the coach.

The coach’s electrical system, brakes, turbocharger, cylinders, valves, camshaft and gearbox were examined without finding any signs of abnormal wear or any indication of these being the cause of the fire. The hydraulic drive of the engine cooling fan was disassembled and removed for further examination because the fire damage suggested that the fire had started in the rear part of the engine, above the gearbox.

Figure 8: The damage to the coach's gearbox as a result of the fire. Photo: AIBN

Figure 9: Radiator and fan pump (behind the round disc). Photo: AIBN

Figure 10: There were soil marks on the radiator. Photo: AIBN

The radiator was partially burnt out and soiled. The AIBN took samples of the deposited material, which consisted mainly of mineral and salt particles. This suggests that there may have been deposits in parts of the radiator before the fire occurred. This may have affected the cooling performance of the engine's radiator, which is an important component in the cooling system.

Figure 11: Dashboard display on release of the fire extinguishing system in a similar coach. Photo: Stenstorp Buss

Figure 12: Nozzles from the fire extinguishing system located at the back of the engine compartment. Photo: AIBN

Traces of arcing were found in the coach's electrical system from the engine compartment as far as the batteries, which were located in the middle of the coach's luggage compartment. The cables at feedthroughs and clamps showed signs of short-circuiting and seizure.

Figure 13: Hydraulic pump covered in melted aluminium after the fire. Photo: AIBN

Figure 14: The luggage compartment and battery box. Photo: AIBN

The passenger compartment had inspection hatches of aluminium in the floor above the engine compartment, and there were technical components of aluminium inside the engine compartment. These hatches and components had melted. Aluminium melts at a temperature of approximately 660 °C.

1.7.3 Calculation of heat release rate from the coach

Commissioned by the AIBN, SP Fire Research AS calculated the heat release rate from the coach that caught fire. Based on available data, it was estimated to be around 30 MW.

1.7.4 Examination of the coach engine's cooling system

The cooling system was designed with a hydraulic oil pump connected directly to the engine's drive shaft. The hydraulic oil pump was connected by a high-pressure hose to a hydraulic motor for operation of the cooling fans. The return oil from the fan motor was carried at low pressure via an expansion tank and back to the hydraulic pump. This was a closed hydraulic system with room for 10–12 litres of oil.

A hole was observed close to the hose end fitting on the discharge side of the pump before the engine was removed, and large amounts of melted aluminium were found on the pump.

1.7.4.1 *Fan motor and hydraulic hose*

The Norwegian Armed Forces’ chemistry and material technology laboratory service (FOLAT) was commissioned to examine the hydraulic hose and fan motor belonging to the coach's cooling system, in order determine whether they might have been defective.

Figure 15: Fan motor for the cooling system. Photo: FOLAT

Figure 16: A radiographic examination was carried out of the fan motor before it was taken apart. Photo: FOLAT

The examination of the fan motor showed no indication of the motor having been defective prior to the fire (see Figure 15 and Figure 16).

Figure 17: For reference purposes, the photo shows a new hydraulic hose on the left. The burnt-out and broken hydraulic hose is shown on the right. Photo: FOLAT

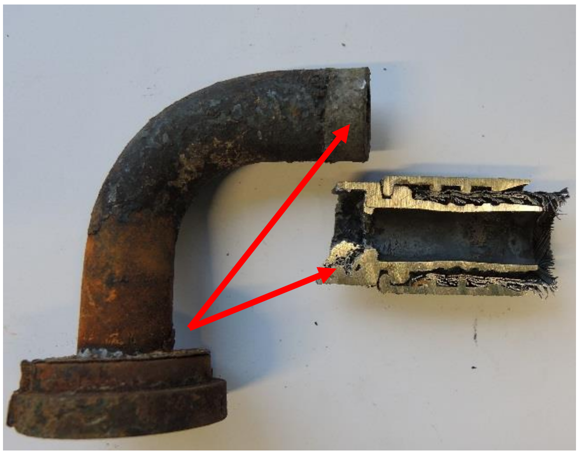

Figure 18: Broken hose end fitting. The red arrows mark the aluminium in the soldered hose end fitting. Photo: AIBN

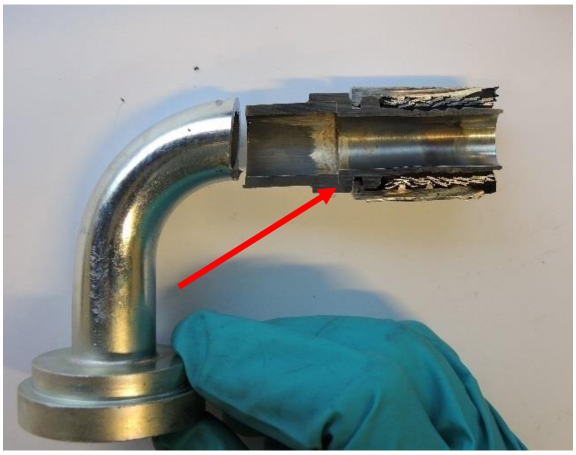

Figure 19: The red arrow marks the silver/copper soldering in a new hose end fitting. Photo: AIBN

The burnt-out hydraulic hose was compared with an identical, unused hose and hose end fitting for reference purposes (see Figure 17). Traces of aluminium were found in the soldering inside the burnt-out hose end fitting (see Figure 18 and Figure 19). Only silver/copper were found in the reference fitting. FOLAT provided the following description:

'The oil hose had sustained significant burns, and the temperature probably exceeded the melting point for the silver/copper solder used in the soldered connection, i.e. 800–900 °C. For reasons unknown, the solder was mixed with aluminium, deposits of which were also found on the inside of the hose. The traces of aluminium could be observed symmetrically around the soldered connection, and on the hose end fitting that had separated from the hose.'

In its report, FOLAT was unable to conclude as to whether the hydraulic hose and soldered connection had broken before, during or after the fire. At FOLAT's request, the AIBN investigated whether there had been any previous attempt to repair the hydraulic hose using aluminium solder, but no signs were found to indicate this. After a subsequent review by the AIBN of the photo material, it became clear that the hydraulic pump had been in contact with aluminium; see Figure 13.

1.7.4.2 *Hydraulic pump*

The hydraulic pump supplying the fluid and pressure to rotate the cooling fan so as to increase the air flow through the radiator was also examined. This was a standard hydraulic pump, BOSCH A10VO, coupled to the coach engine by means of an adaptor. The pump was designed for a working pressure of 20 bar, adjustable to a maximum pressure of 260 bar. The pump was connected in such a way that in the absence of an electrical signal it would supply maximum pressure to the fan and full cooling effect to the radiator. The control panel in this coach model would not give any fault indication in the event that no electrical signal was transmitted to the hydraulic pump.

Bosch Rexroth, the manufacturer of this type of hydraulic pump, was engaged to examine the pump for possible defects. The hydraulic pump was disconnected and all its parts examined.

Figure 20: Disconnected hydraulic pump. Photo: AIBN

Figure 21: Worn drive shaft splines. Photo: AIBN

No damage was found on the pump to suggest internal pump failure, but the drive shaft splines were completely worn down. This may have caused the pump to stop working at some point while the engine was running for the last time.

1.8 Road conditions

1.8.1 The E16 road between Flåm and Gudvangen

Together, the Gudvanga and Flenja tunnels cover most of the E16 road between Flåm and Gudvangen in Aurland Municipality in Sogn og Fjordane County.

The Flenja tunnel is a 5-km-long single-bore tunnel between Flåm and Langhuso. It rises at a steady gradient of 6.5 % through half the tunnel and then at a 5 % gradient as it approaches Langhuso. At Langhuso, the road continues to rise at a 5 % gradient along an 800-metre-open section before flattening out and entering the 11.4-km-long Gudvanga tunnel heading west towards Gudvangen. Approximately 50 m before entering the Gudvanga tunnel when heading west, there is a lay-by on the left-hand side of the road.

1.8.2 The Gudvanga tunnel – design, traffic and safety installations

The Gudvanga tunnel is a single-bore tunnel measuring 11,428 m in length and situated on the E16 between Langhuso and Gudvangen. It was opened for traffic on 17 December 1991. The tunnel rises at a gradient of 3.5 % from Gudvangen towards Langhuso. The speed limit in the tunnel is 70 km/h.

According to figures provided by the NPRA[1], the Gudvanga tunnel had an annual average daily traffic (AADT) of 1,967 vehicles in 2015. The traffic volume varies through the year and peaks in July with 3,888 vehicles per day. There is also a marked increase at weekends as a result of weekend travel. Heavy goods vehicles represented 26.5% of the traffic in 2015.

The Gudvanga tunnel was designed and constructed in accordance with the regulations and guidelines that applied at the time when it was built (the NPRA road design standard ('*Vegutforming*') of 1981 and to some extent the NPRA's Manual 021 – Road Tunnels (1992) [2].

At the time of the incident, the tunnel's safety installations consisted of boom barriers, lay-bys, turning bays, emergency cabinets and fire extinguishers at regular intervals inside the tunnel. Communication installations consisted of the Norwegian Public Safety Network (Nødnett), emergency telephones, and coverage for mobile phones subscribing to both Telenor and Netcom's mobile phone networks (for more information, see Section 1.9). There are also cameras installed in the tunnel.

The Gudvanga tunnel is equipped with traffic counters to record the traffic volume. Two of these traffic counters are connected to photo boxes (automatic traffic control – ATC) installed inside the tunnel.

The NPRA's emergency response plan for the Gudvanga tunnel of 5 January 2015 contains information about the tunnel design, the safety equipment and strategies for handling emergency situations. According to the risk analysis in the emergency response plan, a fire in a heavy goods vehicle inside the tunnel can be expected every 24 years.

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1 http://www.vegvesen.no/fag/Trafikk/Trafikkdata/Trafikkregistreringer

2 See the AIBN's Report ROAD 2015/02 for a more detailed description of the tunnel's safety installations and the tunnel design.

1.8.3 Ventilation

The Gudvanga tunnel has longitudinal ventilation with air inlet and discharge through the tunnel openings. There were 92 fans divided between five groups of fans inside the tunnel. Due to the level difference in the tunnel, the natural draught varies considerably according to the time of day and the season, but on the day of the incident the draught flowed from Gudvangen towards Langhuso/Flåm (until the coach driver removed the fire extinguisher from the tunnel wall).

The ventilations system worked as expected during the fire. At 13:13 the ventilation system was operating at level 3 (65 fans) towards Flåm. At 10:23, 44 fans were in operation towards Flåm.

The fire ventilation system is described in a separate chapter in the emergency response plan for the Gudvanga tunnel. It clearly states that the direction of fire ventilation must be from Aurland (Flåm) towards Voss (Gudvangen), and that this was decided in consultation with the chief fire officer in Aurland. If required, the fire service can request the VTS to deviate from the procedure. In the event of a fire, the fire ventilation must normally be set to level 3 with 64 fans operating at a minimum ventilation rate of 2.5 m/s. The previous emergency response plan indicated a rate of 1-2 m/s for fire ventilation. The ventilation system has also been configured so that if somebody lifts the emergency phone receiver all the fans in the nearest group of fans are deactivated and fans elsewhere in the tunnel are activated.

The emergency response plan describes the automatic control of the fire ventilation that occurs when a fire extinguisher is removed from the wall as follows:

> ***Removal of a fire extinguisher triggers automatic activation of the fire alarm system, i.e. the tunnel is closed*** *(the flashing red warning lights outside the tunnel entrances are turned on)* ***and the VTS and fire service are alerted.*** *The ventilation system starts automatically on removal of a fire extinguisher.*

The following is stated in the chapter on the emergency control panel and manual control of the ventilation:

> *Changing the direction of ventilation when a fire breaks out / smoke builds up can entail an additional risk for people inside the tunnel.*

1.8.4 The Traffic Control Centre's (VTS) equipment and procedures

The emergency response plan for the Gudvanga tunnel includes a detailed response plan describing the actions to be taken by the VTS if notified by phone of an accident/fire, if a fire extinguisher is removed or if an accident/fire occurs in an unknown location inside the tunnel.

Fourteen cameras placed at the tunnel entrances and by the five technical buildings inside the Gudvanga tunnel provide the VTS with a certain overview of the tunnel. Figure 22 and Figure 23 below show the graphical interface displayed in the VTS centre. In the VTS centre, images from up to 32 cameras can be observed simultaneously, and this was also done during the incident.

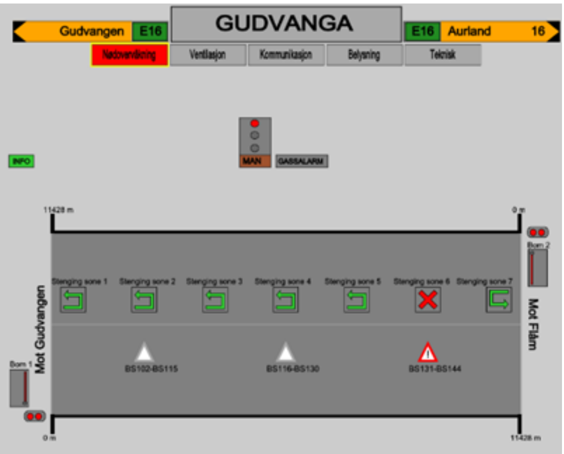

Figure 22: Screenshot from the VTS's monitor showing the entire Gudvanga tunnel on 11 August 2015. The U-turn symbol marks the position of the sign bearing the text 'Snu og kjør ut/Turn and exit'. Zone 6 should also have been closed to traffic from Gudvangen. Photo: NPRA

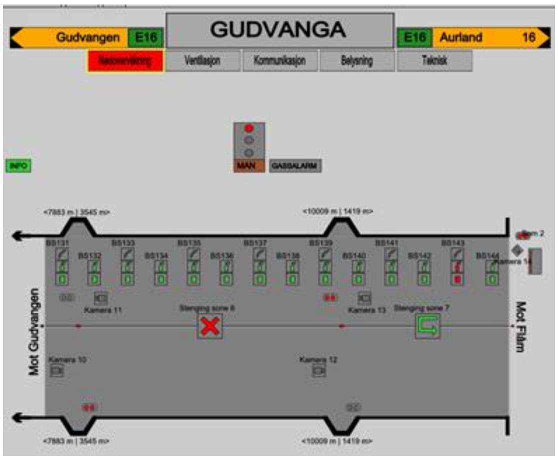

Figure 23: Screenshot from the VTS monitor showing a section of the Gudvanga tunnel, from 3.5 km inside the tunnel to the portal on the Flåm side, at approximately 15:50 on 11 August 2015. Photo: NPRA

The VTS's system logs all events, automated actions, operational messages, error messages and active commands on the part of the VTS.

Table 1: Extract from the VTS event log for the Gudvanga tunnel on 11 August 2015. Source: The NPRA/AIBN

Site	Object	Objectype	Text	Time	Priority	Type
Gudvangatunnel	F3 V01	VENTILATOR	direction 2 operating	11.08.2015 13:13	0	Info
Gudvangatunnel	ventilation	ventilation-steering3	step step 3	11.08.2015 13:13	0	Info
Gudvangatunnel	Closing	Closing	set state emergencyClosing (vts)	11.08.2015 13:17	0	Action/command
Gudvangatunnel	Closing	Closing	set steering manual (vts)	11.08.2015 13:17	0	Action/command
Gudvangatunnel	barrier 2	barrier-right	barrier closed	11.08.2015 13:17	0	Info
Gudvangatunnel	barrier 1	barrier-right	barrier closed	11.08.2015 13:17	0	Info
Gudvangatunnel	Closing	Closing	state closed	11.08.2015 13:17	15	Traffic
Gudvangatunnel	BS143	firecabinet-phone	door open	11.08.2015 13:18	35	Traffic
Gudvangatunnel	BS143	firecabinet-phone	fire-extinguisher removed	11.08.2015 13:18	45	Traffic
Gudvangatunnel	ventilation	ventilation-steering3	fire-ventilation on	11.08.2015 13:18	0	Info
Gudvangatunnel	Vinddirection	VINDdirection	Vind direction 1	11.08.2015 13:21	0	Info
Gudvangatunnel	ventilation	ventilation-steering3	step step 3	11.08.2015 13:21	0	Info
Gudvangatunnel	Closing	Closing	set state emergencyClosing (vts)	11.08.2015 13:26	0	Action/command
Gudvangatunnel	Closing	Closing	set steering manual (vts)	11.08.2015 13:26	0	Action/command
Gudvangatunnel	Closing	Closing	Closingpoint : 0.0=>6.0	11.08.2015 13:26	0	parameter
Gudvangatunnel	UF5 Nightlight 1	Lightcontactor-TIMER	fuse triggered	11.08.2015 13:29	25	operating
Gudvangatunnel	ventilation	ventilation-steering3	step step 4	11.08.2015 13:30	0	Info
Gudvangatunnel	F5 CO	CO-SENSOR-PARAM	Sensor critical high	11.08.2015 13:35	35	Traffic
Gudvangatunnel	BS143	firecabinet-phone	fire-extinguisher in cabinet	11.08.2015 13:41	0	Info
Gudvangatunnel	ventilation	ventilation-steering3	fire-ventilation off	11.08.2015 13:41	0	Info
Gudvangatunnel	BS143	firecabinet-phone	fire-extinguisher removed	11.08.2015 13:45	45	Traffic
Gudvangatunnel	ventilation	ventilation-steering3	fire-ventilation on	11.08.2015 13:45	0	Info
Gudvangatunnel	ventilation	ventilation-steering3	set steering manual (vts)	11.08.2015 13:53	0	Action/command
Gudvangatunnel	ventilation	ventilation-steering3	steering manual	11.08.2015 13:53	15	Traffic
Gudvangatunnel	ventilation	ventilation-steering3	fire-ventilation off	11.08.2015 13:53	0	Info
Gudvangatunnel	ventilation	ventilation-steering3	set steering manual (vts)	11.08.2015 13:53	0	Action/command
Gudvangatunnel	ventilation	ventilation-steering3	set direction direction 2 (vts)	11.08.2015 13:53	0	Action/command
Gudvangatunnel	ventilation	ventilation-steering3	set step step 4 (vts)	11.08.2015 13:53	0	Action/command
Gudvangatunnel	Vinddirection	VINDdirection	Vind direction 2	11.08.2015 13:56	0	Info

Table 1 shows the VTS event log for the Gudvanga tunnel on 11 August 2015. Actions/commands on the part of the VTS are highlighted in green, and pre-configured automatic responses are highlighted in blue. Notification of the automatic change of direction of ventilation towards Gudvangen came in the form of an info message at 13:18, immediately after fire extinguisher BS143 had been removed.

It was not until 13:26 that the VTS operator noticed that automatic fire ventilation had started, after which the operator proceeded to activate the stop lights (Turn and exit) at the turning bays inside the tunnel for motorists approaching from Gudvangen. In the Vegvokteren system, info messages are configured with priority 0 and therefore do not trigger any alarm.

Automatic increases in the ventilation rate level were observed at 13:21 and 13:30. At 13:53, the VTS operator manually changed the direction of ventilation at the request of the fire service. On both occasions when the direction of ventilation was changed, the system responded quickly. The set direction and rate of ventilation were achieved in the course of approximately three minutes (see Figure 24).

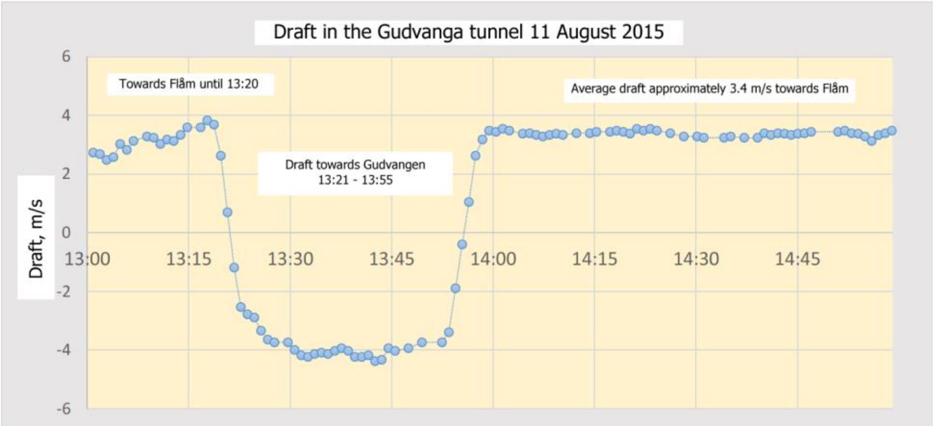

Figure 24: Direction and rate of ventilation in the Gudvanga tunnel on 11 August 2015. Source: NPRA

1.8.5 Technology for real-time information

According to the NPRA, there is currently no technology available for real-time information about the number and location of vehicles and their position or the number of people inside the tunnel. The counters in the Gudvanga tunnel are not connected to the VTS and do not provide a continuous overview of the number of vehicles inside the tunnel at any given time.

Up until the time of the coach fire in autumn 2015, the NPRA retrieved data from the registration point for vehicles inside the Gudvanga tunnel only once every 24 hours. In autumn 2015, the NPRA upgraded the registration equipment so that data are collected continuously, i.e. in real time. The new data collection system goes under the name of Datainn and is common for the whole country.

1.8.6 Choice of ventilation strategy for fires in single-bore tunnels

1.8.6.1 *Report from SP Technical Research Institute of Sweden on the production of smoke fumes in connection with fire in heavy goods vehicle*

Annex F to Report ROAD 2015/02 on the fire in the Gudvanga tunnel in 2013 describes the spread and density of smoke in connection with tunnel fires. The report was written by the SP Technical Research Institute of Sweden and commissioned by the AIBN.

The report includes the following description concerning the mechanical ventilation strategy:

> *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 ventilation or by natural ventilation, depending on the weather conditions at the tunnel portals. Then, once evacuation is completed, and in order to assist the rescue service, the ventilation can be activated 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 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 traffic control centre.*
>
> *Careful consideration should be given to changing the direction of ventilation flow in the 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 direction of ventilation should not be changed because this will cause smoke to remain in the tunnel for a longer period and produce higher concentrations in the smoke plug. In other words, it will increase smoke fume concentrations for those people who were previously upstream of the fire when the old smoke and the newly emitted smoke reaches them.*

1.8.6.2 *The risk analysis of April 2013 – 'E16 The Gudvanga tunnel. Risk analysis of road tunnel' (Matrisk)*

The risk analysis was conducted by the Swiss consultancy firm Matrisk, on assignment for the NPRA Region West in 2013.

Chapter 12 of the risk analysis discusses ventilation and smoke control. The following extract is taken from Section 12.4, which deals with conditions particular to the ventilation of tunnels carrying traffic in both directions:

> *Ventilation strategies*
>
> *In general, there are three strategies for ventilating 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 changed, as this can cause the tunnel cross-section to fill up with smoke during the period in which the direction of ventilation is being changed. If people flee in the direction that is free of smoke before the flow direction is changed, the smoke plume will catch up with them once the flow direction is changed, exposing them to critical concentrations of smoke. By changing the direction of ventilation, one is effectively depriving road users of any chance of escape.*

The following extract is taken from Section 12.6 *Assessment*:

> *It is only advisable to reverse the ventilation if 1) the operation can be carried out in an early phase of the fire before the fire has built up to significant degree and before evacuation has been initiated, or if 2) the operation is not carried out until everyone has been 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 pose a risk for those trying to escape.*

1.9 Communication systems

1.9.1 General information

The emergency services had an operative communication network, and Aurland fire service used this to initiate its response in the Gudvanga tunnel. The Norwegian Public Safety Network (Nødnett) had been installed in the area and was scheduled to be put into operation from 4 November 2015, but since it was already working, it did not take long to transfer communication between all the emergency services to this network. The VTS could receive calls from mobile phones and from the permanently installed emergency telephones (SOS telephones) inside the Gudvanga tunnel, but it was not connected to the emergency network. The emergency services are also given priority by the VTS, and they have specially assigned telephone numbers. The 110 emergency communication centre can establish immediate contact with the VTS if necessary.

Aurland fire service knew it could contact the VTS directly using the emergency telephones inside the tunnel. This was also one the learning points gained from previous exercises that Aurland fire service had held in the tunnel. The fire service chose not to use the emergency telephone system in connection with the present fire on the assumption that the many calls that the VTS would have to handle would make it inefficient.

1.9.2 The Norwegian Public Safety Network (Nødnett)

Nødnett is a separate mobile network owned by the Ministry of Justice and Public Security and operated by the Norwegian Directorate for Emergency Communication (DNK). It is primarily intended for use by the emergency services (the police, health and fire services). The network offers voice and simple data communication and talk functions that are adapted to the communication needs of emergency response personnel. Examples of such functions are talk groups, anti-eavesdropping protection, and 'walkie-talkie'- type communication.

DNK has described[3] how Nødnett coverage will be provided in road tunnels already covered by one or more emergency service networks. In addition, coverage will be provided in tunnels longer than 500 m with an annual average daily traffic (AADT) of more than 5,000.

Road tunnels without existing infrastructure and new tunnels built after 2006 will not come under the scope of the Nødnett development project. These will be financed by the NPRA in accordance with guidelines for administrative procedures concerning fire protection in road tunnels. The question of extending road tunnel coverage is a question

[3] See http://www.dinkom.no/Utbyggingen/Om-Nodnett1/Tunneler/ [accessed on 2 March 2016].

for consideration by the NPRA based on need, the NPRA's regulatory framework, and available funding.

1.9.3 Mobile phone networks

The Directorate of Public Roads has entered into an agreement with Telenor and others concerning the division of responsibility and the scope of technical mobile phone installations in Norwegian road tunnels.

During the incident, mobile phones were primarily used by road users, but also by the emergency services inside and outside the tunnel. This caused the mobile phone network to become unstable and incapable of handling more traffic. At one point, this blocked Aurland fire service's attempt to communicate with the VTS by mobile phone to request the direction of ventilation to be changed.

Since this line of communication was ineffective and the fire service needed more information from the 110 emergency communication centre, the fire crew chose to use Nødnett and the 110 number to get the VTS to change the direction of ventilation.

Three Telenor-operated base stations and one repeater are installed in the Gudvanga tunnel to provide mobile phone coverage. There is good 2G coverage throughout the tunnel, in addition to 3G coverage in the western section of the tunnel. Since only 2G coverage is available outside and inside the eastern section of the tunnel where the fire occurred on 11 August 2015, the capacity is limited to 25 concurrent calls. In the rest of the tunnel, where there is both 2G and 3G coverage, the capacity is greater.

1.9.4 Prioritised subscriptions in mobile phone networks

The Regulations of 21 October 2013 No 1241 on priority in mobile phone networks is intended to ensure that traffic critical to society is given priority in mobile phone networks in a crisis or emergency situation. The Norwegian Communications Authority (previously known as the Norwegian Post and Telecommunications Authority) administers access to these subscriptions. The advantage of priority subscriptions are:

1. *When the network is overloaded, other calls can be interrupted to gain access to the telephone network. This applies to voice calls only.*
2. *When your operator's network is down in a specific area, you will be hosted by another network that is up and running. This will enable you to place calls, send text messages and transfer data.*

All undertakings with a need for such access[4] may apply via the Altinn portal. The fire and rescue services are listed as undertakings that may have such a need.

Aurland fire service had no subscription for priority access to the mobile phone network during the coach fire in the Gudvanga tunnel. According to information received from the AIBN, Aurland fire service has subsequently obtained such a priority subscription.

[4] http://www.nkom.no/teknisk/sikkerhet-og-beredskap/prioritet-i-mobilnettet/for-virksomheter [accessed on 2 March 2016]

1.10 Laws and regulations

1.10.1 Acts of law:

The framework for the construction, use, operation, inspection, control of tunnels and fire preparedness in road tunnels is mainly regulated by the following Norwegian acts of law:

- Act of 21 June 1963 No 23 relating to roads (the Roads Act)
- Act of 18 June 1965 No 4 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)

1.10.2 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 726 relating to organisation and dimensioning of fire services
- Regulations of 17 December 2015 No 1710 on fire prevention
- Regulations of 06 December 1996 No 1127 relating to systematic health, Environmental And Safety Activities in Enterprises (Internal Control Regulations)
- Regulations of 19 June 2015 No 703 Instructions to the County Governor and Governor of Svalbard concerning civil protection, emergency preparedness and crisis management
- The NPRA's Manual N500 – Road Tunnels (2014). The manual has the status of a standard and was adopted in pursuance of the Road Act.
- The NPRA's Manual R511– Safety Management of Road Tunnels (2014). This manual has the status of a guideline.

1.11 Authorities, organisations and leadership

1.11.1 Norwegian Public Roads Administration (NPRA)

The NPRA is an administrative agency that reports to the Ministry of Transport and Communications. The agency is organised into two administrative levels: the Directorate of Public Roads and five regional offices. The NPRA is responsible for the 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 agency also prepares provisions and guidelines for road design, operation and maintenance, road traffic, road user training, and vehicles.

Norway has five Traffic Control Centres (VTS) that serve as points of contact with motorists. These are located in Oslo, Bergen, Porsgrunn, Trondheim and Mosjøen. Among other things, the VTS centres are charged with monitoring traffic and controlling tunnels and road sections in their respective areas.

The NPRA Region West is responsible for operating and maintaining the Gudvanga tunnel, and has overall responsibility for the Traffic Control Centre in Bergen.

1.11.2 Directorate for Civil Protection and Emergency Planning (DSB)

The Directorate for Civil Protection and Emergency Planning (DSB) is a government administrative agency that reports to the Ministry of Justice and Public Security. The DSB's responsibility in the public security area includes responsibility for national, regional and local civil protection and emergency planning, fire and electrical safety, protection of business and industry, hazardous substances and product, and consumer safety.

Together, the DSB and the NPRA have prepared guidelines for fire and electrical safety in road tunnels: 'Retningslinjer for saksbehandling og ivaretakelse av brann- og elsikkerhet i vegtunneler' (2011). The guidelines are primarily addressed to those who plan, build and operate road tunnels, those who supervise fire safety in road tunnels and those charged with responding to fires and accidents in road tunnels.

1.11.3 Aurland fire service

Aurland fire service is responsible for responding to accidents and fires in the Gudvanga tunnel. The fire service is organised with a chief fire officer and 20 part-time employees who respond to call-outs. Aurland has two fire stations: one in Aurland and an unmanned fire station in Gudvangen, in addition to a fire depot in Undredal. Aurland fire service will request assistance from other fire services as needed, including Voss, Bergen, Lærdal and Årdal.

Aurland fire service is responsible for inspecting tunnels (over 500 m) classified as 'special fire objects' in Aurland Municipality, including the Gudvanga tunnel. Aurland fire service is responsible for more kilometres (64.6 km in all) of road tunnels than any other fire service in Norway, including the two longest tunnels in Norway (Lærdal and Gudvanga).

Aurland fire service has informed the AIBN that, since the coach fire on 11 August 2015, it has been called out to the Gudvanga and Flenja tunnels several times because of smoke build-up from heavy goods vehicles. There was also a case of smoke build-up from a passenger car with a trailer.

1.11.4 Voss fire service

Voss fire service has no duty station, but it has seven full-time personnel and 41 part-time personnel. Voss has three fire stations, located at Voss, Vossestrand and Evanger.

1.11.5 County Governor of Sogn og Fjordane

The County Governor has a public duty to coordinate the county's work on civil protection and emergency preparedness and to promote and provide guidance on civil protection and preparedness issues.

1.11.6 Stenstorp Buss

Stenstorp Buss AB owned the coach that caught fire. The coach company's main business activities comprise school transport and tourist travel.

1.12 The AIBN's other investigations of fires in tunnels

1.12.1 Fire in heavy goods vehicle in the Oslofjord tunnel on 23 June 2011

On 23 June 2011, a Polish-registered heavy goods vehicle caught fire in the 7.3-km-long Oslofjord tunnel as a result of engine breakdown. Approximately 1.8 km before reaching the Drøbak exit, the heavy goods vehicle came to a halt. Søndre Follo fire service responded from the Drøbak side to extinguish the fire. The tunnel was ventilated towards Hurum in order to improve visibility while combating the fire. This caused the 5.5-km-long tunnel to fill with thick black smoke. The risk to road users was increased by the fact that the tunnel's safety equipment did not adequately facilitate self-rescue. Consequently, nine people were trapped in the smoke. It took the rescue crew approximately two hours to evacuate them.

For more information, see the AIBN Report ROAD 2013/05. The AIBN submitted four safety recommendations as a result of the investigation:

Safety recommendation ROAD No 2013/08T

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration, together with the Norwegian Directorate for Civil Protection and Emergency Planning and the fire services, review and update the emergency response plans for long single-bore tunnels, including the Road Traffic Centre's procedures in the event of fire, to safeguard the preconditions for the self-rescue principle.

Safety recommendation ROAD No 2013/09T

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration and the Norwegian Directorate for Civil Protection and Emergency Planning establish systems for registering fires and incipient fires in road tunnels, for use in systematic safety work.

Safety recommendation ROAD No 2013/10T

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration further develop its safety management system in terms of risk-based and proactive principles to ensure a satisfactory safety level for the Oslofjord tunnel and similar road tunnels.

Safety recommendation ROAD No 2013/11T

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration, together with the Norwegian Directorate for Civil Protection and Emergency Planning and the fire services, follow up and design *their rescue and fire extinguishing efforts based on realistic heat release rates and the specific design of each individual tunnel.*

1.12.2 Fire in a heavy goods vehicle in the Gudvanga tunnel on 5 August 2013

On 5 August 2013, an empty Polish-registered heavy goods vehicle caught fire in the 11.4-km-long Gudvanga tunnel. As soon as the fire was reported, the VTS routinely started the fire ventilation so that 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. Sixty-seven people were trapped in the smoke in the tunnel, and 28 people sustained acute smoke injuries.

For more information, see AIBN Report ROAD 2015/02. The AIBN submitted six safety recommendations as a result of the investigation:

Safety recommendation ROAD No 2015/02T

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

Safety recommendation ROAD No 2015/03T

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 the Gudvanga tunnel. Signs, emergency radio messages and text message notification should be considered, among other things.

Safety recommendation ROAD No 2015/04T

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 resulting from exposure to smoke in connection with tunnel fires in relevant accident statistics.

Safety recommendation ROAD No 2015/05T

The Accident Investigation Board Norway recommends that the Directorate for Civil Protection and Emergency Planning 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-bore tunnels, so that, as far as possible, fire ventilation does not come into conflict with road users' possibility of rescuing themselves.

Safety recommendation ROAD No 2015/06T

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

Safety recommendation ROAD No 2015/07T

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 the Gudvanga tunnel in order to improve the possibility of self-rescue, and carry out inspections and scenario-based drills in the Gudvanga tunnel.*

1.13 Implemented measures

1.13.1 Directorate for Civil Protection and Emergency Planning (DSB)

The Directorate for Civil Protection and Emergency Planning assessed the fire service's response and handling of the fire in 2015, and compared this with the fire service's response and handling of the fire in the same tunnel in 2013. The report offered 13 recommendations and measures, including that the VTS should be connected to Nødnett.

1.13.2 County Governor of Sogn og Fjordane

On 18 September 2015, the County Governor of Sogn og Fjordane arranged an evaluation meeting between Sogn og Fjordane Police District, Hordaland Police District, the emergency communication centre in Sogn og Fjordane (110), the emergency communication centre in Hordaland (110), Førde Hospital Trust, Bergen Hospital Trust, the NPRA, Aurland Municipality, Aurland fire service, Voss fire service, Lærdal fire service, the Red Cross, the Directorate for Civil Protection and Emergency Planning, and the County Governor.

The incident was reviewed, 27 items discussed, and 11 learning points were documented. The issues raised included the need to remove automatic control of fire ventilation, the need for time-outs for status updates during incidents, use of Nødnett, and the ambulance personnel's risk assessment and reduced response capabilities when surrounded by smoke.

1.13.3 Norwegian Public Roads Administration (NPRA)

1.13.3.1 *Measures to improve safety in certain tunnels*

Both in Report ROAD 2013/05 concerning the fire in the Oslofjord tunnel in 2011 and in Report ROAD 2015/02 concerning the fire in the Gudvanga tunnel in 2013, the AIBN questioned whether the tunnel owner had made arrangements to provide road users with a real chance of evacuating smoke-filled tunnels unassisted.

In response to the AIBN's Safety recommendation ROAD No 2015/05T, the NPRA sent a letter of information to the Ministry of Transport and Communications on 7 January 2016. The NPRA has prepared a draft report on measures to improve fire safety in certain tunnels (*Tiltak for å bedre brannsikkerhet i utsatte vegtunneler*), dated 17 November 2015. The draft report is the result of cooperation with the Directorate for Civil Protection and Emergency Planning, and seminars and meetings with both internal and external parties in the wake of the fire in the Gudvanga tunnel in 2013.

The NPRA identified some targeted measures that would be effective where most needed: heavy goods vehicles, long tunnels, and steep gradients. The NPRA describes the following measures and strategies to improve the possibilities for self-rescue:

- Increased use of automatic detection of incidents and related monitoring to ensure that tunnel fires are detected and verified at an early stage.

- Use of a personal address (PA) system[5] to ensure early messages to road users on desirable behaviour patterns and the type of danger they are in.

- Use of handrail with photo-luminescent material/lighting to provide adequate physical guidance.

- It is proposed that certain tunnels be upgraded with the safety equipment required in new tunnels of a similar type.

- Refuge chambers are being considered for long single-bore tunnels on national roads and tunnels with other distinctive features. The NPRA has begun work to examine this option.

- External rescue efforts must be prepared through updated emergency response plans, systematic training and regular drills. The proposed strategy highlights improvements in preparedness planning by the NPRA and the rescue services.

The report includes the following description of ventilation:

> *For single-bore road tunnels with two-way traffic and no detection equipment capable of identifying the location of the fire and the conditions on either side of the fire, a fixed and predefined ventilation direction should be chosen. If the ventilation system is in operating mode when the fire situation occurs, the same ventilation direction should be maintained (a fixed and predefined ventilation direction according to the operating mode).*

1.13.3.2 *Pre-project on safety management in road tunnels*

The NPRA management meeting has approved the setting up of a pre-project on safety management in road tunnels (*Sikkerhetsstyring i vegtunneler*). The content and technical grounds for the conclusions will be evaluated by the NPRA management in October 2016. It will then be decided whether the pre-project should be followed up by a four-year research programme. The following extracts are quoted from the mandate for the pre-project:

> *The tunnels fires that have occurred in recent years have revealed a strong need for more knowledge about preparedness, training, technology, management, and functional requirements related to tunnel fires and evacuation. This particularly applies to long single-bore tunnels.*
>
> *The need for such a pre-project has been further underlined by the Accident Investigation Board Norway's identification of several weaknesses in how we facilitate safe self-rescue for road users who are exposed to fire/smoke or other critical incidents.*

1.13.4 The AIBN's notification of critical safety issue to NPRA

Pursuant to Section 11 of the Regulations of 30 June 2006 No 793 on public investigation and notification of traffic accidents etc., the AIBN must notify the relevant public bodies

[5] Also known as Voice Alarm (VA) system.

of serious findings made in the course of an investigation and of its own preliminary assessment of them, insofar as this is deemed critical to road safety.

On 16 December 2015, the AIBN issued the following notification of critical safety issue to the NPRA Region West and Aurland fire service, with copies to the Directorate of Public Roads and the Directorate for Civil Protection and Emergency Planning:

> *The Accident Investigation Board Norway (AIBN) refers to Section 11 of the Regulations of 30 June 2006 No 793 on Public Investigation and Notification of Traffic Accidents etc. and hereby wishes to report an area which the AIBN deems critical to traffic safety.*
>
> *The AIBN's investigation of the coach fire in the Gudvanga tunnel on 11 August 2015 has shown that the ventilation control system in the tunnel is arranged in such a way that if a fire extinguisher is removed from the tunnel wall, ventilation will automatically be activated in a predefined direction, towards Gudvangen. This happens regardless of the location of the fire in the 11.4-km-long tunnel, of where a fire extinguisher is removed, and of the ventilation direction at the time. Similar conditions were also highlighted by the AIBN in Report ROAD 2015/02 in connection with the fire in a heavy goods vehicle in the Gudvanga tunnel on 5 August 2013.*
>
> *The automatic control of the fire ventilation means that the ventilation direction can change in an early phase of the fire without any basis in a situational assessment and without road users receiving any warning or an adequate time window for evacuating. The AIBN's assessment finds this incompatible with the principle of self-rescue.*
>
> *Based on previous investigations and on information that has come to light during the present investigation of the fire in the Gudvanga tunnel in 2015, the AIBN concludes that the automatic control function should be removed.*

On 8 January 2016 the NPRA replied to the notification of critical safety issue:

> *The Norwegian Public Roads Administration Region West takes note of AIBN's request to modify the ventilation control system. The control system for the Gudvanga tunnel needs to be reprogrammed, and it is estimated that this will take approximately 6 months. At the same time, the tunnel will be upgraded in compliance with the Tunnel Safety Regulations: Blasting work will be carried out to provide room for new technical buildings. Blasting/excavation work will also be carried out to create new emergency lay-bys, modify existing turning bays and to make room for ventilators. The tender invitation for the blasting work in the Gudvanga tunnel will be announced in January 2016 and the work is expected to start in April/May. This work is estimated to last for approximately one year, until March 2017. Work on upgrading safety equipment in the tunnel will begin in or around March 2017 and be completed by the end of 2018. In a meeting with Aurland fire service on 17 February 2015 it was therefore agreed to maintain the present system of ventilation in the Gudvanga tunnel until the upgrading work begins.*

2. ANALYSIS

2.1 Introduction

The AIBN initiated the investigation of the coach fire in the Gudvanga tunnel because of the big injury and damage potential of such an incident. It soon became clear that a scenario with many people on foot trapped in smoke in the tunnel – similar to the Gudvanga tunnel fire in 2013 in which 28 people were seriously injured – was avoided because all 32 coach passengers could fit into an empty van that happened to arrive at the scene. The AIBN believes that this incident serves as yet another reminder that fires in long single-bore tunnels are extremely challenging because of the size of the accident scene and the effects of smoke. The only chance for road users to evacuate is through the tunnel openings, and these may be sealed off due to smoke and heat.

The coach fire and the rescue work were investigated and analysed in line with the AIBN's framework and analysis process for systematic safety investigations (the AIBN method). The sequence of events, from the start of the fire until the time when everyone was evacuated from the tunnel, has been clarified through a sequential presentation in a STEP[6] diagram. The sequence of events was assessed both with respect to events and behaviour that may have had a negative impact on the sequence of events and safety (safety problems) and with respect to events that may have had a positive impact (safety enhancers). These factors from the sequence of events are discussed in Section 2.2. The AIBN believes that by also looking at what actually worked, we may learn more about what needs to be done to ensure good management of similar critical situations.

Furthermore, the AIBN has investigated and analysed the following issues in detail: the progression of the fire in the coach, the ventilation and the accident development, and information and communication needs. These issues are discussed in Sections 2.3, 2.4 and 2.5.

The investigation has also focused on what improvements and safety measures were made in the Gudvanga tunnel as a consequence of the fire in 2013 and the fire in the Oslofjord tunnel in 2011. The AIBN has compared the sequence of events and the firefighting and rescue efforts in all three fires. Comments on what future steps the NPRA, the Directorate for Civil Protection and Emergency Planning and the fire service should take to follow up safety in similar tunnels and to learn from previous incidents are presented in Section 2.6.

2.2 Assessment of the sequence of events

The following factors influenced the development and management of the sequence of events and rescue work in connection with the coach fire in the Gudvanga tunnel:

a) A critical fault in the coach probably occurred before it entered the Gudvanga tunnel. The coach driver received no immediate warning via the technical systems in the coach. It was only after entering the Gudvanga tunnel that he observed smoke and saw the warning sign displayed on the dashboard, and he immediately stopped the coach.

[6] Sequentially Timed Events Plotting.

b) The driver notified the police and quickly evacuated the coach. The triple alert notification to the other emergency services at both ends of the tunnel worked as intended. This is a notable improvement compared with the fire in 2013, when there was a 25-minute delay in the notification of the emergency services on the Hordaland side.

c) The 110 emergency communication centre in Sogn og Fjordane County notified the VTS, which immediately closed the tunnel with road barriers and flashing red stop signals. The fact that the tunnel is equipped with road barriers is an improvement made after the fire in 2013, and is important for preventing more vehicles from entering the tunnel in the event of a fire.

d) During the first telephone conversation between the 110 centre and the VTS, the VTS was asked to wait before initiating fire ventilation. When the coach driver removed the fire extinguisher from the tunnel wall in order to put out the fire, fire ventilation was activated automatically in the predefined direction towards Gudvangen. In the AIBN's opinion, the automatic fire ventilation does not support the principle of self-rescue. In December 2015, it therefore issued a notification of critical safety issue to the NPRA; see Section 1.13.4.

e) The automatic activation of the fire ventilation was transmitted to the VTS as information only, and not as an audible alarm. It therefore took eight minutes before the VTS operator realised that the fire ventilation had been activated and could initiate measures accordingly. The AIBN believes that such delays should be avoided given the role of the VTS as the point of contact with the road users.

f) The VTS activated the stop lights (Turn and exit) at the turning bays along the tunnel from Gudvangen and 19 vehicles managed to turn and leave the tunnel. In the 2013 fire, the stop lights were not activated because it took a long time before the VTS received information on the exact location of the fire. Consequently, only a few vehicles continued to the scene of the fire in 2015 compared with the fire in 2013.

g) An emergency radio message to road users inside the tunnel was issued seven minutes later, i.e. 18 minutes after the fire was reported and 15 minutes after fire ventilation was activated. In the AIBN's opinion, this is too late, considering that road users must be given an adequate time window to evacuate before the ventilation changes the situation.

h) Aurland fire service was dispatched to the Gudvanga tunnel (to the Flåm side of the tunnel) immediately, and arrived at the scene of the fire after approximately 15 minutes. In the AIBN's opinion, the fire service's decision to change the direction of the ventilation when it received reports that road users were trapped in the smoke further inside the tunnel was important for the subsequent rescue work.

i) Although the Gudvanga tunnel was equipped with 14 cameras – an improvement that was made following the previous fire – there was no technology that could provide the VTS with an overview of the number and location of vehicles and people inside the tunnel. Before the direction of the smoke was changed, Aurland fire service did not know exactly how many vehicles and road users were in the tunnel on the Gudvangen side of the fire.

j) A van found room for all 32 coach passengers and drove them out of the tunnel to Gudvangen. This coincidence and resolute action meant that a scenario with many people on foot trapped in the smoke in the tunnel was avoided. The AIBN's investigation of the fire in the Gudvanga tunnel in 2013 concluded that the most severe injuries were sustained by those who evacuated the tunnel on foot in the dense smoke.

k) Aurland fire service experienced difficulties in making contact with the VTS in order to ask for the direction of ventilation to be changed. The mobile phone network became unstable and incapable of handling more traffic. The fire service then decided to transfer to Nødnett in order to get the direction changed. The fire service decided not to use the SOS telephones on the assumption that the many calls that the VTS would have to handle would make it inefficient. Furthermore, the fire service needed more information from the 110 emergency communication centre. The VTS was not connected to Nødnett, and this led to a delay of approximately 13 minutes before the direction of ventilation was changed, because it meant that the information exchange between Aurland fire service and the VTS had to go via the 110 emergency communication centre.

l) Three vehicles carrying a total of five people were trapped in the smoke in the tunnel. The AIBN finds it important that the emergency services' communication with the trapped road users was conducted via mobile phone. It prevented people from leaving their vehicles in the tunnel and, consequently, limited the potential smoke injuries as a result of the fire.

m) The emergency services' communication network was up and running throughout the incident. In the 2013 fire, the communication network was interrupted because the communication cable, which only provided unidirectional feeding to the radiating cable segment, was destroyed by fire. This made it difficult for the emergency services to communicate internally and with each other. The bidirectional feeding of the radiating cable segment that is now installed in the tunnel roof was an improvement made after the previous fire.

The AIBN's review of the sequence of events has identified several improvements and changes to procedures after the previous fire in the Gudvanga tunnel in 2013. However, the AIBN has identified several areas where more work needs to be done to further improve safety. The AIBN will discuss these areas in detail in the following sections.

2.3 Fire progression

2.3.1 Fire development in the coach

Together with Kripos, the AIBN has tried to find out what caused the fire in the coach. The fire was found to have started in the area around the gear box, which is situated in the front section of the engine compartment. The investigation has not found any clear cause of the fire.

Witness observations and technical findings indicate that the cooling system began leaking towards the end of the journey, probably as the coach was driving uphill through the Flenja tunnel. Furthermore, the technical examination shows that some parts of the radiator cooling fins were heavily contaminated. This can reduce the radiator's capacity for cooling the cooling fluid for the engine. The hydraulic pump will in turn seek to increase the pressure to compensate for this. Worn splines in the hydraulic pump were the only clear fault found in the engine. The investigation was unable to determine whether this fault was a consequence or a cause of the fire. These factors combined could lead to an increase in temperature in the engine compartment, which may have contributed to starting the fire.

Signs of short-circuiting were found between the battery and the rear of the coach. This was probably consequential damage resulting from the fire that started in the engine compartment. The fact that the cable leading from the battery to the engine short-circuited may have caused the cable to overheat, which in turn may have contributed to the fire spreading towards the front of the coach.

Furthermore, the investigation shows that the fire extinguishing system in the coach's engine compartment was inadequate under the circumstances. It gives cause for concern that the installed extinguishing system was unable to put out the fire in the engine/gear box, so that the fire continued to spread and set the entire coach on fire.

2.3.2 Safety checks before entering tunnels

The AIBN is aware that fires in coaches often start in the proximity of the engine compartment while fires in heavy goods vehicles (trailers) often start in the brake system. The AIBN finds it probable that the coach fire in the Gudvanga tunnel in 2015 could have been prevented had a safety check been carried out before entering the tunnel. The reason for this is that the witness who drove behind the coach observed steam coming from the coach inside the Flenja tunnel and blue smoke when the coach drove out of the tunnel. The witness tried to alert the driver between the tunnels. In this instance, it was possible to stop on the left-hand side of the road in the coach's direction of travel, but since the coach driver did not notice that anything was wrong, he drove on into the tunnel. A safety recommendation is submitted on this issue.

Based on this and previous investigations, the AIBN believes that the NPRA, after assessing feasible and effective solutions, should make arrangements to facilitate safety checks to be carried out before vehicles enter certain tunnels. The safety check should consist of a brief stop in an appropriate place to check for leakages, overheated brakes and abnormal smoke/steam emissions from the vehicle. The NPRA should make sure that vehicles have the possibility of making a stop before entering a tunnel.

2.4 Ventilation and accident development

When a fire extinguisher is removed from the wall of the Gudvanga tunnel, automatic fire ventilation is programmed to start and operate in a specific direction. The automatic control function will change the direction of ventilation if the regular ventilation (towards Flåm) is in the opposite direction to the fire ventilation (set towards Gudvangen); (see Figure 25). The purpose of the automatic control of the fire ventilation, which is programmed into the NPRA's ventilation control system by agreement with the fire service, is that fire service personnel arriving from a particular side (in this case from Aurland fire service) should have fresh air behind them when approaching the fire.

The automatic control function ventilates the smoke to the furthermost exit (in this case, 11.1 km) through the section of tunnel where most of the road users are located, and leaves them with no chance to evacuate. In the AIBN's opinion, the automatic control function will worsen the situation for those in the proximity of the fire and reduce the time window for anyone attempting to extinguish the fire. The automatic control function could also put road users closest to the seat of the fire in great danger. In addition, the AIBN believes that the automatic fire ventilation affects the ability of the VTS and the fire service to gain control of the situation at an early stage.

In this instance, the coach driver and the four people in the three vehicles were deprived of the chance to evacuate when the fire ventilation was activated (see Figure 25). A scenario with many people on foot trapped in the smoke-filled tunnel, as in the Gudvanga tunnel fire in 2013, was avoided because all 32 coach passengers could fit into an empty van that happened to arrive at the scene. It was also important that the tunnel's stop lights (Turn and exit) were activated so that 19 vehicles managed to turn and exit before getting trapped in the smoke.

The AIBN refers to Section 1.8.6, which contains extracts from the report prepared for the AIBN by SP Technical Research Institute of Sweden and the risk analysis prepared by Matrisk for the NPRA Region West. Both reports recommend a basic principle for single-bore tunnels carrying traffic in both directions, namely that ventilation be kept to a minimum during the evacuation phase to slow down the spread of smoke through the tunnel and give people upstream and downstream of the fire an adequate time window to evacuate. In the AIBN's opinion, automatic fire ventilation on removal of a fire extinguisher and automatic control of fire ventilation do not ensure this.

The AIBN sees no natural connection between removal and use of a fire extinguisher, on the one hand, and automatic change of ventilation direction on the other, as this will necessarily entail the possibility of smoke being present on both sides of a burning vehicle. From a road-user perspective, it is both unexpected and illogical to find that the smoke has been turned towards you in the direction of the longest section of the tunnel after the shortest section has been blocked by smoke. It is also unexpected and illogical for a road user to unknowingly change the direction of ventilation while attempting to extinguish a burning vehicle.

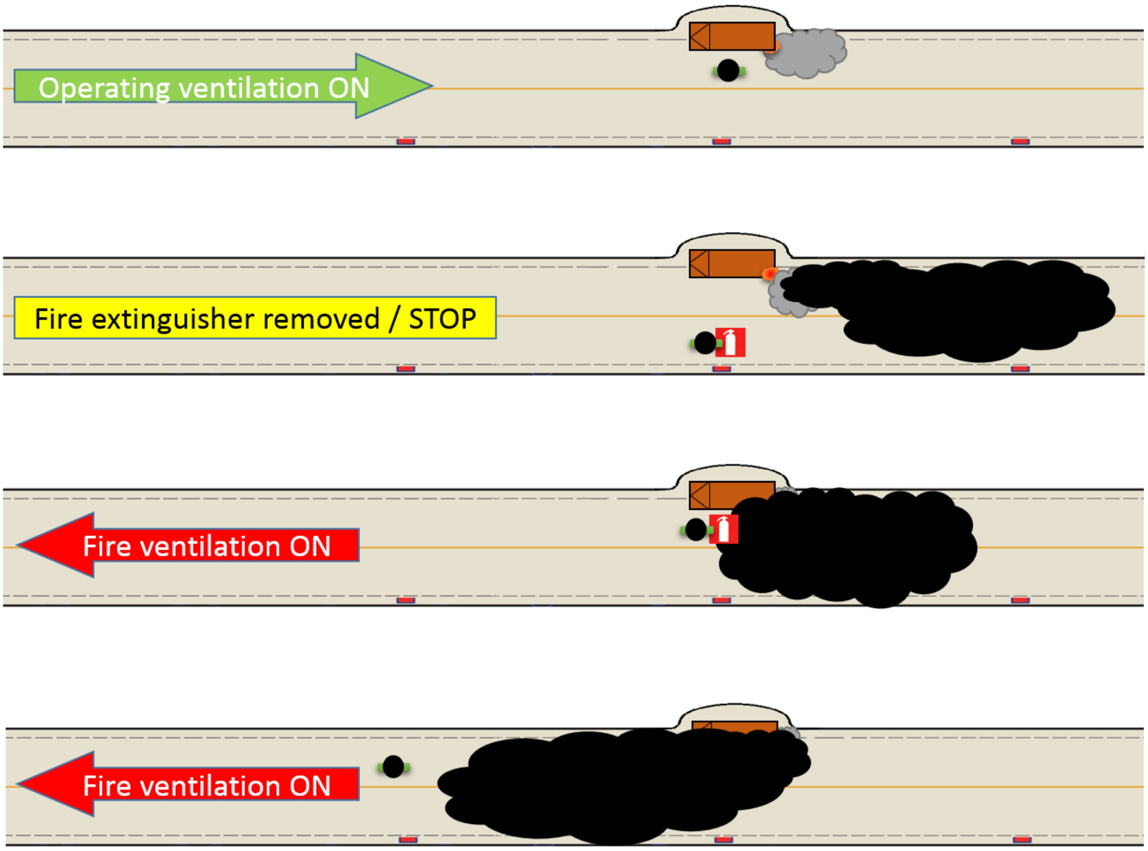

Figure 25: The effect of an automatic change of direction activated by removing a fire extinguisher, as in the Gudvanga tunnel. Illustration: AIBN

The AIBN has raised this specific issue in a notification of critical safety issue (see Section 1.13.4), and this function was and is known to the NPRA and the fire service. The NPRA Region West has decided not to modify the automatic control function until the entire tunnel is to be upgraded (see Section 1.13.4). Aurland fire service has approved this decision.

In the AIBN's opinion, if the automatic control system cannot be modified or disconnected for technical and/or resource reasons, then compensatory measures should be implemented to avoid that automatic control of fire ventilation comes into conflict with road users' chances of self-rescue. Compensatory measures could be a revision of the emergency preparedness plan for the tunnel and the emergency response plans for the VTS and the fire service. Furthermore, road users who are about to extinguish a fire using the fire extinguishers in the tunnel should be advised that this may cause the smoke to start moving in the opposite direction.

The AIBN would point out that automatic control of fire ventilation is not unique to the Gudvanga tunnel; it is used in many of Norway's longest tunnels, including in the Flenja and Lærdal tunnels. In the AIBN's opinion, the initial ventilation control actions must be based on as much information as possible and on a situational assessment of what is the best way to safeguard road users' chances of self-rescue. The AIBN submits a safety recommendation on this issue.

2.5 Information and communication needs in emergency situations

In the AIBN's understanding, the VTS is in possession of vital information and can change a situation to the advantage or disadvantage of those inside the tunnel. This was clearly shown in the AIBN's investigation of the fire in the Oslofjord tunnel in 2011.

2.5.1 Traffic monitoring and overview

Based on the current and previous investigations, the AIBN has identified a need for tunnel monitoring systems that can improve the decision-making basis to facilitate evacuation of as many road users as possible. According to the NPRA, no technology currently available can provide real-time information about the number and location of vehicles and people in a tunnel.

As described in Section 1.8.5, Datainn, the new nationwide data collection system, collects data continuously. In the AIBN's opinion, the NPRA must look into the possibility of further developing this system or other systems so that the VTS can at least obtain necessary real-time information about the number of vehicles in a tunnel. The AIBN submits a safety recommendation on this issue.

The tunnel has 14 cameras, at intervals of 2 km, but these do not provide enough information on the overall situation in the tunnel. If cameras are installed to provide total CCTV coverage of the tunnel, they should be arranged so that it is easy to get a complete overview.

2.5.2 Notifying road users

In previous reports, the AIBN has highlighted the need to immediately instruct road users inside the tunnel to evacuate in the event of fire. This issue was addressed in Safety recommendation ROAD No 2013/08T after the Oslofjord tunnel fire in 2011 and in Safety recommendation ROAD No 2015/03T after the Gudvanga tunnel fire in 2013 (see Section 1.12 for more details). In the AIBN's opinion, fast and good notification is a key element to safeguarding road users' chances of self-rescue before a tunnel is filled with smoke.

It took eight minutes before the VTS operator realised that fire ventilation had been activated, after which he activated the stop lights (Turn and exit). It took approximately seven minutes before the emergency radio message was transmitted to the road users in the tunnel. The 110 emergency communication centre had not instructed the VTS to issue an emergency radio message, but the VTS did so when it was observed on the video screen that two heavy goods vehicles were awaiting instructions and would be trapped in the smoke.

In the AIBN's opinion, the NPRA should ensure that an emergency radio message is issued as soon as the VTS is notified of a tunnel fire. The AIBN’s view is that road users should be notified as soon as possible to enable them to prepare for and start evacuation, even if the VTS does not yet know the exact location of the fire or the direction of the fire ventilation. The stop lights (Turn and exit) must be activated as soon as the scene of the fire is identified. A delay of eight minutes, as in this case, should be avoided, and the technical systems in the VTS must ensure this. The AIBN submits a safety recommendation on this issue.

The AIBN also welcomes the measure mentioned by the NPRA in its draft report on measures to ensure fire safety in certain tunnels concerning the use of a personal address system to ensure that road users are quickly notified of the desired behaviour pattern and of the danger they are in.

2.5.3 Communication via the Norwegian Public Safety Network (Nødnett)

When the fire service decided to change the direction of ventilation in the tunnel, the notification had to go via the 110 emergency communication centre, and this delayed the response effort. The AIBN considers direct, uninterrupted communication to be extremely important in emergency situations. When a situation is unclear, different parties will have a different understanding of the situation, and, to ensure the best possible common understanding, direct communication is necessary so that messages and actions can be constantly corrected.

As tunnels are upgraded and cameras and other technical systems installed that are controlled by the VTS, the role of the VTS becomes increasingly important in connection with tunnel incidents. This in turn makes good communication between the VTS, the response teams and the 110 emergency communication centre even more important. The more information the emergency services receive in an early phase, the better prepared they will be when they reach the incident scene, and they will have a better decision-making basis at an earlier stage.

In the AIBN's opinion, it would be an advantage if the VTS had direct communication with the emergency services by being connected to Nødnett. For example, voluntary organisations already have access to Nødnett. The NPRA, Aurland fire service and the Directorate for Civil Protection and Emergency Planning have all expressed a wish for the VTS to be connected to Nødnett. The AIBN submits a safety recommendation on this issue.

2.5.4 Communication via mobile phone networks

During the coach fire, the road user's use of mobile phones proved very useful. The emergency services managed to obtain high-quality information which they used to ask road users to remain in their vehicles and breathe through a moist towel, which proved to be a very appropriate course of action during this particular incident. During the same incident, Aurland fire service experienced problems reaching the VTS by mobile phone, most likely because of the lack of capacity on the 2G network in the area.

The incident demonstrates that mobile phone networks in tunnels clearly have preparedness value and that they are widely used by road users and response personnel. In the AIBN's opinion, the Directorate of Public Roads should consider the possibility of planning a more robust public mobile phone network in tunnels in particular, given that investigations have shown how useful this is in real-life emergency situations.

The incident also demonstrated the need for priority subscriptions on the mobile phone network for the emergency services, particularly in situations where mobile phones may be the only means of communication. Had Aurland fire service had such a subscription, the direction of ventilation could have been changed at an earlier stage. Aurland fire service has since acquired such a subscription.

2.6 Follow-up of safety and learning points

2.6.1 Three tunnel fires: common features and learning points

This is the third of three AIBN report concerning fires in vehicles in long single-bore tunnels: two concerning the Gudvanga tunnel and one concerning the Oslofjord tunnel. The following summarizes similarities and learning points from the AIBN's investigation of the three fires.

- The drivers of the vehicles that caught fire took necessary action when there were indications that something was wrong. They first tried to put out the fire with fire extinguishers from their own vehicles, and then tried to fetch and/or extinguish the fires with the fire extinguishers in the tunnel. The report on the fire in the Gudvanga tunnel in 2013 pointed out that the fire extinguishers installed in the tunnels were unsuitable for stopping the progression of such fires.

- In all three cases, the vehicles were engulfed in flames by the time the fire service reached the scene of the fire in the tunnel. The heat release rates were estimated at: 70–90 MW (Oslofjord tunnel), 25 MW (Gudvanga tunnel, 2013) and 30 MW (Gudvanga tunnel, 2015). In the AIBN's opinion, the fire progression in all three incidents shows that it is inexpedient for the fire service to focus on extinguishing the fire. The fire service should focus on how to best safeguard road users' chances of self-rescue in an early phase and on how to evacuate any remaining road users.

- Fire ventilation was activated automatically and/or its direction was predefined (and activated manually by the VTS) regardless of the location of the fire in the tunnel. In all three incidents, this led to the direction of the smoke from the fire being changed in an early phase without being based on a situational assessment. The smoke was ventilated towards the area where most of the road users were located, which also had the longest escape route. In the AIBN's opinion, the predefined direction of ventilation does not adequately safeguard the principle of self-rescue (see Section 2.4).

- In the Gudvanga tunnel in 2013 and the Oslofjord tunnel in 2011, the road users were not notified in time to evacuate before the tunnel was filled with smoke. In the AIBN's opinion, early notification is essential to safeguard road users' chances of self-rescue and reference is made to previous safety recommendations on this issue (see Section 1.12). In the most recent fire in the Gudvanga tunnel, 19 vehicles managed to turn and exit before getting trapped in the smoke, but in the AIBN's opinion, the notification procedure could nonetheless be improved (see Section 2.5.2).

- The tunnel design and the tunnel's safety equipment did not adequately facilitate self-rescue. An insufficient number of turning bays/lay-bys and poor visibility made evacuation by car difficult. In the Oslofjord tunnel in 2011 and the Gudvanga tunnel in 2013, this meant that many road users passed through the smoke-filled tunnel on foot and sustained severe smoke injuries as a result.

- The three fires show that information to and communication with road users are essential in emergency situations in tunnels. In the fire in the Oslofjord tunnel, the VTS played a decisive role in gaining an overview of the road users, communicating with those trapped in the smoke, and guiding them to safe areas. In the second fire in the Gudvanga tunnel, the emergency services had continuous communication with trapped road users and asked them to remain in their vehicles.

- The deployment and response of the fire service worked satisfactorily during all three fires, but the fire crew in the section of tunnel towards which the smoke was being ventilated were rendered passive because of the smoke. In the AIBN's opinion, this is an operational learning point that the fire and rescue services must incorporate into their response plans, during drills, and when training their response personnel.

- No fatalities occurred in any of the three fires, but more than 60 people were treated for smoke injuries, several of them for severe and very severe smoke injuries. In the AIBN's opinion, this demonstrates the significant injury potential associated with fires in long tunnels. In the AIBN's opinion, coincidence and resolute action contributed to the extent of injuries in all three fires being less serious than its potential.

2.6.2 Operational lesson: ventilation control

The AIBN's review of the sequence of events during the fire in the Gudvanga tunnel in August 2015 shows that the fire service had learned from the previous incident in August 2013. When communicating with the VTS about closing the tunnel, the 110 emergency communication centre asked the VTS to wait before initiating fire ventilation. When the coach driver removed the fire extinguisher from the tunnel wall, fire ventilation was activated in the direction of Gudvangen as a result of an automatic function in the ventilation control system. The VTS did not discover this until eight minutes later. The technical system was thus counter-productive in relation to the updated information and the response of the operative personnel.

During the rescue effort, Aurland fire service decided to change the direction of the fire ventilation. To AIBN's knowledge, this is the first time smoke ventilation has been changed halfway through an operation based on important incoming information about road users trapped in smoke. The fire service quickly reached the scene of the fire from one side, and made sure that no one was in that section of the tunnel. After that, they retreated, at the same time as the other section of tunnel was cleared of smoke due to the direction of ventilation being changed, and another fire service could perform rescue and firefighting tasks from the other side. In the AIBN's opinion, this tactic could be further developed and used in other tunnels.

However, the AIBN is aware that a positive result is dependent on several factors, such as having a fire service available on both sides of the tunnel, response times, expertise and equipment. The fire service must also be familiar with the operating characteristics of the ventilation system, including the ventilation rates that can be achieved in each direction and whether the system has sufficient fan capacity for a change of direction.

A safety recommendation is submitted on this issue.

2.6.3 Knowledge needs

In its reports on the fire in the Oslofjord tunnel and the first fire in the Gudvanga tunnel, the AIBN took a critical view of the use of a predefined direction of fire ventilation and its importance for road users' chances of self-rescue. The AIBN has also been concerned about the lack of traffic information and of the VTS's inadequate overview of the 11.4-

km-long Gudvanga tunnel. The AIBN refers to previous safety recommendations (see Sections 1.12.1 and 1.12.2, where these issues are discussed). The NPRA's draft report referred to in Section 1.13.3.1 discusses some of these issues and previous safety recommendations from the AIBN. In the AIBN's opinion, more emphasis should be placed on the correct use of fire ventilation to safeguard road users' chances of self-rescue.

After investigating several tunnel fires, the AIBN is under the impression that knowledge about fire and smoke dynamics in connection with heavy goods vehicles on fire in long tunnels varies. The AIBN's investigations have uncovered a view among tunnel owners, the Directorate for Civil Protection and Emergency Planning and response personnel that if fresh air is directed towards a burning vehicle – in this case a burning coach – the smoke behind it 'thins out', and that this will also improve the situation for those who need to evacuate. In the AIBN's opinion, sufficient grounds have not been presented to support the view that this will always have a positive impact on the safety of road users.

In the fire in the Gudvanga tunnel in 2015, the emergency services had continuous communication with the trapped road users and asked them to remain in their vehicles. In other fire incidents it is conceivable that this would not have been the best solution. The AIBN sees a need for more knowledge about how road users' safety can best be safeguarded in different situations in a tunnel fire.

The AIBN's investigations of the fires in the Oslofjord tunnel in 2011 and the Gudvanga tunnel in 2013 show that the road users who were trapped in the smoke sustained severe/very severe smoke injuries, even though the smoke behind the vehicle was 'thinned out'. The AIBN refers to Section 1.8.6, which contains extracts from the report prepared by SP Technical Research Institute and the risk analysis prepared by Matrisk. In the AIBN's opinion, there is still a need for more knowledge about fire and smoke dynamics in long tunnels in order to safeguard road users' chances of self-rescue.

2.6.4 Organisational learning points

The AIBN has also noted that, after the fire in the Gudvanga tunnel in 2015, two assessments were conducted: one by the Directorate for Civil Protection and Emergency Planning and another under the auspices of the County Governor (see Section 1.13). These two assessments identified many of the same areas for improvement and recommendations as the AIBN has done, but fail to specify which agency has responsibility for implementing them or for setting deadlines for doing so. Thus, while the will to assess is there, the AIBN sees no implementation or implementation capability. Furthermore, learning organisations are expected to use 'local' findings to assess whether there is a need for measures elsewhere, i.e. in other tunnels or by other fire and rescue services.

Work on fire safety in long road tunnels is significantly different from work done on other types of traffic safety. The fires in the Oslofjord tunnel and the Gudvanga tunnel show that there is a major accident potential associated with fires in heavy goods vehicles in long single-bore tunnels. It also seems as if the frequency of actual fire incidents may be higher than indicated by the NPRA's risk analyses (see Section 1.11.3). Based on safety problems identified in this and previous investigations, the AIBN finds that both the NPRA's management of tunnels and the fire service's supervision of tunnels have potential for improvement.

The NPRA's draft report on measures to improve fire safety in certain tunnels referred to in Section 1.13.3.1 shows that both the NPRA and the Directorate for Civil Protection and Emergency Planning have worked on improvement measures and strategies since the fire in the Gudvanga tunnel in 2013. At the same time, however, many of the safety problems encountered in the 2013 fire in the Gudvanga tunnel and the 2011 fire in the Oslofjord tunnel were also encountered in the 2015 fire in the Gudvanga tunnel. The AIBN therefore welcomes the NPRA's pre-project on safety management in road tunnels (*Sikkerhetsstyring i vegtunneler*) and recommends that the NPRA management follow this up with a four-year research programme. Based on the present investigation, the AIBN sees a need for further improvements to fire safety and road users' chances of self-rescue in tunnels.

3. CONCLUSION

3.1 Important results of the investigation with a bearing on safety

a) The fire could probably have been prevented if the driver had performed a safety check of the coach before entering the Gudvanga tunnel.

b) Automatic fire ventilation on removal of a fire extinguisher and automatic control of fire ventilation, which are used in several of the longest tunnels in Norway, exposed the road users closest to the scene of the fire to greater danger and reduced their chances of self-rescue. It also affected the ability of the VTS and the fire service to gain control of the situation at an early stage.

c) The NPRA's equipment and procedures are inadequate, considering that they can be decisive for the outcome of a tunnel fire. The AIBN calls for technology that can provide a real-time overview of the number and location of vehicles and people in the tunnel, and immediate notification to road users.

d) When the fire service personnel decided to change the direction of ventilation in the tunnel in order to reach the road users who were trapped in the smoke, their response was delayed because of the lack of direct and uninterrupted communication between the fire service, the 110 emergency communication centre and the VTS.

e) The decision to change the direction of the smoke ventilation halfway through the operation shows that Aurland fire service had learned from the 2013 fire in the tunnel and from the AIBN's concerns about how it had been handled.

3.2 Investigation results

3.2.1 Fire progression

a) A fault in the engine compartment occurred before the coach entered the Gudvanga tunnel. The coach driver received no immediate warning via the technical systems on the coach.

b) The leakage in the cooling system, clogged cooling fins in parts of the radiator, and worn splines in the hydraulic pump may have caused an increase in temperature in the engine compartment which may then have contributed to the fire starting. No clear cause of the fire was found.

c) The fire in the engine compartment may have caused short circuiting in the cable running from the battery to the engine. This probably caused the cable to overheat, which in turn may have contributed to spreading the fire towards the front of the coach.

d) The fire in the engine/gear box was not put out by the installed extinguishing system; it continued to spread and set the entire coach on fire.

3.2.2 Rescue operation, ventilation and evacuation

a) The driver notified the police and quickly evacuated the coach. The triple alert notice to the other emergency services worked as intended. The 110 emergency communication centre in Sogn og Fjordane County notified the VTS, which immediately closed the tunnel with road barriers and flashing red stop signals.

b) The fact that the tunnel is equipped with road barriers is an improvement made after the fire in 2013, and is important for preventing more vehicles from entering the tunnel in the event of a fire.

c) During the first telephone conversation between the 110 centre and the VTS, the VTS was asked to wait before initiating fire ventilation.

d) When the coach driver removed the fire extinguisher from the tunnel wall in order to put out the fire, fire ventilation was activated automatically in the predefined direction towards Gudvangen.

e) Aurland fire service was dispatched to the Gudvanga tunnel immediately and arrived at the scene of the fire after approximately 15 minutes.

f) A scenario with many people on foot trapped in the smoke-filled tunnel was avoided because all 32 coach passengers could fit into an empty van (Mercedes Sprinter) that happened to arrive at the scene. The tunnel's stop lights (Turn and exit) were also activated, and 19 vehicles managed to turn and exit.

g) The decision made by the fire service to change the direction of ventilation when notified that road users were trapped in the smoke further inside the tunnel had an important impact on the sequence of events.

h) The five people still in the tunnel were found by smoke divers from Voss fire service after approximately 1.5 hours and taken to hospital to be treated for smoke injuries.

3.2.3 Communication and overview

a) The activation of the automatic fire ventilation was transmitted to the VTS as information only, and not as an audible alarm. It therefore took eight minutes before the VTS operator realised that the fire ventilation had been activated and could initiate measures accordingly.

b) The VTS activated the stop lights (Turn and exit) in the tunnel. The emergency radio message to notify road users inside the tunnel was issued seven minutes later, i.e. 18 minutes after the fire was reported. This is too late, considering that road users must be given an adequate time window to evacuate before the ventilation changes the situation.

c) Three vehicles containing a total of five people were trapped in the smoke in the tunnel, but mobile phone communication with the emergency services helped ensure that no one left their vehicles.

d) The VTS was not connected to Nødnett. Information between the fire service and the VTS had to go via the 110 emergency communication centre because the mobile phone network was unstable. This led to a delay in changing the direction of fire ventilation of approximately 13 minutes.

e) The emergency services' communication network was up and running throughout the incident. The bidirectional feeding of the radiating cable segment that is installed in the tunnel roof was an improvement made after the previous fire.

f) The incident demonstrated that mobile phone networks in tunnels clearly have preparedness value and that a priority subscription for the emergency services in the mobile phone network is particularly important where mobile phones may be the only means of communication. Aurland fire service has since acquired such a subscription.

g) The Gudvanga tunnel is equipped with 14 cameras, but there is no technology that could provide the VTS with an overview of the number and location of vehicles and people in the tunnel. Before the direction of the smoke was changed, Aurland fire service did not know exactly how many vehicles and road users were inside the tunnel on the Gudvangen side of the fire.

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.[7]

The AIBN has previously investigated a fire in a heavy goods vehicle in the Gudvanga tunnel in 2013 (Report ROAD 2015/02). The AIBN proposed six safety recommendations as a result of the investigation. The NPRA's report *Tiltak for å bedre brannsikkerhet i utsatte vegtunneler* ('Measures to improve fire safety in certain road tunnels') takes adequate account of some of the AIBN's safety recommendations. The safety recommendations issued in connection with the current report offer further input on how to improve fire safety and road users' chances of self-rescue in tunnels, and supplement and specify previous safety recommendations.

Safety recommendation ROAD No 2016/03T

The fire in the Gudvanga tunnel on 11 August 2015 could probably have been prevented if the driver had performed a safety inspection of the coach before entering the tunnel. A safety inspection should consist of a brief stop in a suitable place where the vehicle can be inspected for leakages, overheating and smoke development.

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

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration, based on an assessment of what constitutes a feasible and effective solution, take steps to facilitate and issue recommendations regarding security checks before entering certain tunnels.

Safety recommendation ROAD No 2016/04T

When the driver removed the fire extinguisher from the wall of the 11.4-km-long Gudvanga tunnel on 11 August 2015, the fire ventilation started automatically and the pre-set direction of ventilation was towards Gudvangen. This meant that the smoke was ventilated to the most distant exit (in this case, 11.1 km) through the part of the tunnel that held the greatest number of road users. The automatic system, which is used in several of the longest tunnels in Norway, exposed the road users closest to the scene of the fire to greater danger and reduced their possibility of self-rescue. It also affected VTS and the fire service’s ability to gain control of the situation at an early stage.

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration, based on a risk analysis of certain tunnels, change the automatic system to ensure that the ventilation is controlled in a way that facilitates road users’ self-rescue efforts.

Safety recommendation ROAD No 2016/05T

The investigations of the coach fire in the Gudvanga tunnel on 11 August 2015, the fire in the Gudvanga tunnel on 5 August 2013 and the fire in the Oslofjord tunnel on 23 June 2011 have all shown that the NPRA’s equipment and procedures can be decisive for the outcome of tunnel fires. The AIBN calls for technology that can provide a real-time overview of the number of vehicles, their location and the number of people in the tunnel, and an immediate notification from VTS to motorists in the event of a fire.

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration review and improve equipment and procedures relating to tunnel fires. This includes developing technology for real-time information and instructions for VTS that warrant immediate notification of motorists in the event of a fire.

Safety recommendation ROAD No 2016/06T

During the coach fire in the Gudvanga tunnel on 11 August 2015, the fire service decided to reverse the direction of fire ventilation in the tunnel so that they could reach the road users who were trapped in the smoke. This action was delayed because the message to VTS had to go via the 110 emergency communication centre as the mobile phone network was unstable. The AIBN believes that direct, uninterrupted communication is vital in an emergency situation, and that VTS should be able to communicate directly with the emergency services by being connected to the Norwegian Public Safety Network (Nødnett).

The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration in cooperation with the Norwegian Directorate for Emergency Communication ensures that the VTS centres be connected to the Norwegian Public Safety Network (Nødnett) in tunnels.

Safety recommendation ROAD No 2016/07T

The coach fire in the Gudvanga tunnel on 11 August 2015 is probably the first time that the fire service has reversed the direction of ventilation in the middle of an operation based on important incoming information about road users trapped in smoke. In the

AIBN’s opinion, this is a tactic that can be further developed and used in other tunnels, provided that other factors are present, such as fire services being available on both sides, and adequate response times, expertise and equipment.

The Accident Investigation Board Norway recommends that the Directorate for Civil Protection and Emergency Planning (DSB) develop methods whereby the fire service’s response efforts and control of the smoke ventilation can support the self-rescue principle for road users in the event of a tunnel fire.

Accident Investigation Board Norway

Lillestrøm, 5 July 2016