THE CAUSES, EFFECTS & CONTROL OF REAL TUNNEL FIRES

An examination of what actually happened in recent incidents and the reaction of fire and rescue teams to these incidents.

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As the last two major incidents in Europe concerned road tunnels, this abstract is not going to go into detail on railway tunnels. It is presented as a combination of investigation and practical experience.

Overview on the traffic situation in European tunnels

Traffic is still increasing in Europe and there is no end in sight. A dramatic increase can be seen in HGV traffic when we look at some selected figures on traffic development of the Mont Blanc tunnel and Tauern tunnel.

Tunnel/Year	Cars; Motorbikes; Buses	HGVs	Total
Mont-Blanc/1998	1.221.085	776.604	1.997.689
Mont-Blanc/1966	548.000	45.000	593.000
Tauern/1998	4.494.567	1.039.513	5.534.080

Many of the important roads and tunnels were built between the 60's and the 80's. Some of them have been planned with two tubes; resident's protests were the reason that the second tubes were never finished. The longest European tunnel is the Gotthard tunnel. It is the only single tube tunnel that has a separate rescue tube. At both ends there is a small, but professional, fire brigade.

Tunnel (Country)	Length [km]	Opening year
Gotthard (CH)	16,3	1980
Arlberg (A)	13,9	1978
Frejus (F - I)	12,9	1980
Mont Blanc (F - I)	11,6	1965
Plabutsch (A)	9,8	1987
Gleinalm (A)	8,3	1978
Karawanken (A)	7,9	1991
Pfänder (A)	6,7	1980
San Bernhardino (CH)	6,6	1967
Tauern (A)	6,4	1975
Großer St.Bernhard (CH)	5,8	1964
Felbertauern (A)	5,2	1967
Bosruck (A)	4,8	1983

The security equipment in the tunnels varies. At the moment there is no European standard available for tunnel security.

Landscape of Alpine Tunnels (motor-presse-online; 1999)

Approaches to a Risk Assessment of Tunnel Fires

According to a study done by the Austrian „Kuratorium für Verkehrssicherheit“ (committee for Transport Safety) there is

- 1 accident per 1.1 Mio Veh km on main roads
- 1 accident per 3.0 Mio Veh km in tunnels with 2 tubes
- 1 accident per 6.0 Mio Veh km in tunnels with 1 tube

It seems that tunnels are safer than roads. But there is a well known definition of risk:

Risk = Probability x Damage

The probability of a tunnel fire has not been well investigated. There are about 2 vehicle fires per 100 Mio Veh km in Europe. Some data are available for single tunnels but there is no reasonable, global statistic. Although the probability of a tunnel fire is small, the extent of the damage is very high.

Tunnel	Loss of income	Costs of repair and improvement	Total
Eurotunnel	211 Mio €	87 Mio €	298 Mio €
Mont Blanc tunnel	203 Mio € (estimated)	189 Mio €	392 Mio €
Tauern tunnel	18,5 Mio €	6,2 Mio €	24,7 Mio €

The costs of a train fire outside a tunnel would be much less. The damage to the rails or road is easily repaired. Normally only hours after the fire accident the track can be used again.

The only recent fire in a railway tunnel occurred in the Euro tunnel, the safest railway tunnel of Europe. As it happened on a HGV train, there were only a few slightly injured persons. Nevertheless, the material damage was high.

But what is the value of a life or personal damage? The public has become used to casualities as a result of traffic accidents. Whereas, being killed by fire has always been one of the basic fears of mankind. Consequently, a new definition of risk has to be introduced. There is a risk acceptable to the public which is not necessarily the same as the technically defined risk. Especially after the tunnel fires of the last year, people's acceptable risk level has fallen dramatically.

Selected Risk Values 1997 (I.R.T.A.D. 1999)

Country	Killed per 100.000 Population	Injury Accidents		Killed per 1 billion Veh Km	
		per 1 Mio Population	per 1 Mio. Veh Km	All roads	Motorways
Austria	13,7	0,492	0,58	16,1	8,3
France	14,4	0,214	0,24	16,4	5,7
Germany	10,4	0,464	0,62	13,8	5
Japan	8,9	0,618	1,06	15,3	5
Switzerland	8,3	0,311	0,42	11,3	3,6
United Kingdom	6,3	0,418	0,53	8,1	2,5
USA	15,7	0,916	0,6	10,2	5,5

Causes of Tunnel Fires

The following is a selection of spectacular tunnel fires, their causes and effects.

Year	Tunnel, location	Length [m]	Tubes	Cause, fire load	Injuries	damage
1949	Holland-Tunnel New York, USA	2600	2	Lorry fire (Carbon disulphide)	66 poisoned	10 Lorries, 13 Cars
1968	Moorfleet Tunnel, Deutschland	243		Lorry fire (14 t Polyethylene) Brake failure	none	1 Lorry-trailer
1975	Guadarroma-Tunnel, Spanien	3345	2	Lorry fire, pine resin	none	1 Lorry
1978	Velsen-Tunnel Holland	768	2	Collision	5 Killed, 4 Injured	2 Lorries, 4 Cars
1979	Nihonzoka-Tunnel Japan	2045	2	Collision Cars, Lorries (Ether)	7 Killed, 2 Injured	87 Cars, 102 Lorries
1982	Caldecott-Tunnel Kalifornien, USA	1028	3	Collision gasoline bulk tank fire 33000 l petrol	7 Killed, 2 Injured	2 Lorries, 1 Bus, 1Car
1984	Gotthard-Tunnel Schweiz	16321	1	Lorry fire (Plastic foil)	none	1 Lorry
1984	Felbertauern-Tunnel, Österreich	5130	1	Bus, brake failure	none	1 Bus
1988	Herzogberg Tunnel, Österreich	2007	1	Lorry	none	Lorry
1987	Gumefens Tunnel, Schweiz	340	2	Collision 3 Lorries, 5 Cars; spilled petrol	2 Killed, 5 Injured	3 Lorries, 5 Cars
1995	Pfänder Tunnel, Österreich	6750	1	Collision, 1 Lorry (Bread), 1 minibus, 2 Cars	3 Killed	1 Lorry, 1 minibus, 2 Cars

1998	Gleinalm Tunnel, Österreich	8320	1	Bus	none	Bus
1999	Mont-Blanc Tunnel, Frankreich	11600	1	Lorry (Margarine, flour), Technical defect	39 Killed	23 Lorries, 11 Cars, 2 fire engines
1999	Tauern-Tunnel, Österreich	6041	1	Collision, 2 Cars, 1 Lorry	12 Killed	24 Cars, 16 Lorries

Basically there are two main causes of tunnel fires. Fires caused by a technical defect or fires caused by an accident. Technical defects occur more often. Fires caused by technical defects usually develop quite slowly so that the maximum heat release rate of a single burning car will be reached after about 15 to 25 minutes. Experiments and practical experiences in garages have shown that fire seldom jumps over a distance of 0,4 to 0,8 meters between the cars. But one has to remember that in garages there are no HGVs parked. After an accident, spilled petrol is often the reason for a fast fire development. Nearby vehicles start to burn at almost the same time. High heat release rates are reached early.

In the Mont Blanc tunnel the fire spread quickly at the HGV itself. The HGV was loaded with margarine and flour. Due to this high fire load and the ventilation conditions the fire spread rapidly to other vehicles. The increasing use of plastics in car assembly causes heavy smoke production and high fire loads.

If there is no heavy traffic, single burning cars are usually extinguished without major problems in Austrian tunnels, either by the staff or the voluntary fire brigades.

The comparison of the probability of a fire in train tunnels to road tunnels is 1:20 to 1:25. In recent years there has been no fire in train tunnels with major personal damage. Nevertheless, if there is a fire there could be hundreds of people endangered. Although there are only a few fire sources in passenger trains, fire could spread rapidly.

The following picture shows the interior of a modern passenger wagon which caught fire during welding. Although the fire was attacked immediately by staff with 3 hoses, the wagon burned out in 10 minutes.

Vienna Fire Brigade

The Fire in the Mont-Blanc Tunnel on 24th March, 1999

The Mont Blanc tunnel was opened on 16th July, 1965. The French company ATMB and the Italian company SITMB each independently manage and control one half of the tunnel.

The tunnel is equipped with the following safety facilities:

- Every 100 m portable fire extinguishers
- Every 300 m garages
- Every 600 m pressurised shelter for about 40 persons, fire resistant for 2 hours, constructed in 1991
- Video surveillance, installed in 1995
- Fire detection system, installed in 1997
- Ventilation system: semi transverse
  Supply air: maximum 600 m^3/ s (52 m^3/s km)
  Exhaust air: maximum 300 m^3/s (26 m^3/s km); (can be reversed and be used as supply air)

France Soir

Since 1965 there have been 17 lorry fires which were extinguished by the staff of the companies or by the fire brigade. The duration of the fires was about 10 to 15 min.

On Wednesday 24th of March 1999 a Belgian HGV loaded with 9 t of margarine and 12 t of flour entered the tunnel on the French side. As it proceeded through the tunnel, smoke became visible. The lorry stopped at the garage 21 (about 6,5 km from the French entrance) at 10^{53}. The smoke rising under the cabin quickly turned into a fire. The driver was not able to

extinguish the fire and fled towards the Italian end of the tunnel. The fire developed rapidly and spread to other vehicles. A few vehicles on the Italian side managed to turn around and drive out of the tunnel. 33 vehicles were involved. The number of vehicles and persons involved in the incident was never known at any time during the intervention.

The burning zone was about 1200 m, temperatures reached over 1000 °C.
The ventilation played an important part in the spread of the fire and the intervention of the rescue teams. At the moment of the incident there was an air-stream of an average speed of 1,5 km/h from Italy to France. There was no efficient collaboration between the two control centres with regard to the adjustment of the ventilation system in order to improve conditions and facilitate an intervention. On the French side the ventilation was turned on maximum extraction and the air supply was reduced, while the Italian control centre left all the ventilation systems on maximum air supply.

French operations:

The alarm was given at 10^{54}. All attempts by the French fire fighters to proceed to the burning cars and the trapped people failed because of the dense smoke and the intense heat. The light pump water tender of the ATMB with a 4 man crew left at 10^{57} and the rescue vehicle manned by 2 people from the ATMB at 10^{59}. Both were blocked by the dense smoke at garage 17, 1200 m away from the burning lorry. The heavy pump water tender from Chamonix Fire Brigade manned by six crew arrived at the entrance at 11^{10} and was blocked at garage 12 (2700 m from the burning lorry). The vehicle only carried 4 BAs, therefore the crew took refuge in shelter 12. A second light pump water tender from Chamonix Fire Brigade fully equipped with BAs and reserve sets arrived at 11^{39} and was blocked at garage 5 (4800 m from the burning lorry). Because of the dense smoke and the intense heat it was not possible to advance to the burning vehicles or to return to the tunnel platform. A rescue operation was started at 12^{55}. All the trapped fire and rescue teams were rescued at 18^{35}. In the afternoon 98 fire fighters with 26 vehicles were on duty on the French side. 10 fire fighters were equipped with SCBA.

Italian operations

The staff of the SITMB has no fire fighting formation. The alarm was given at 10^{54}. Between 10^{57} and 11^{01} two members of the SITMB proceeded up to garage 21 and were able to see the burning lorry. They rescued 12 lorry drivers. The heavy pump water tender from Courmayeur Fire Brigade manned by 3 crew arrived at the entrance at 11^{11} and was blocked at garage 22. They advanced until garage 24 where they had to take shelter. They were followed by 2 other fire fighters who entered the tunnel with a light pump water tender. After 3 hours the 5 Italian fire fighters were evacuated through the ventilation duct. In the afternoon there were 9 vehicles, 10 fire fighters equipped with 2 SCBA and 19 BA. in duty. The Italian Tunnel Alarm Plan was not proclaimed. AP Photo

The fire and rescue teams were reinforced by teams from Marseille and Switzerland. 53 hours after the outbreak of the fire it was extinguished. Afterwards cooling down the tunnel took several hours.
23 lorries, 11 cars, 1 motorcycle and 2 fire engines were destroyed. 39 people were killed. 29 victims were found in their vehicles. Obviously they did not try to flee early enough. 7 people tried to flee and died from intoxication. 2 people were trapped and killed in shelter 20. One of the trapped French fire fighters died after being rescued. Only 12 people survived all of them on the Italian side.
The tunnel was badly damaged on a zone of 1200 m. The bitumen of the road melted. Due to the high temperatures the concrete severely spalled and the reinforcement was damaged. After intensive investigations, several improvements concerning the security installations and the organisation were proposed. The tunnel will not be reopened before the end of the year 2000.

The Fire in the Tauern Tunnel on 29th May

This was not the first severe fire in an Austrian tunnel. In 1995 an accident caused a fire in the Pfänder tunnel in the west of Austria. The fire brigades could only reach the scene of the fire with great difficulty. The fire fighters walked in front of their fire engine all wearing breathing apparatus. The fire killed 3 people. Some lessons were learned and the equipment of the fire brigades was improved i. e. thermal image cameras.

Tunnel fires are not that seldom. If there is not heavy traffic, single burning cars are usually extinguished by the staff or the voluntary fire brigades without major problems.
The Tauern tunnel was opened in 1975.

The tunnel is equipped with the following safety facilities:

- Every 106 m hydrants and fire fighting equipment
- Every 212 m emergency shelter with 2 portable fire extinguishers and a telephone
- Every 848 m garages
- Video surveillance
- Fire detection system
- Ventilation system: transverse, 4 sectors
  - Supply air: maximum 190 m^3/s km
  - Exhaust air: maximum 115 m^3/s km

LVF

Salzburg

Since 1975 the fire brigade has had to intervene to deal with 1 car fire and 4 lorry fires. Fire has never spread to a second vehicle.
After the fire in the Mont Blanc tunnel the Fire Brigades of Salzburg proclaimed that there are two very dangerous tunnels in Austria. The Tauern tunnel and the Katschberg tunnel. Only two months later, this turned out to be very true.

At a distance of about 600 m from the portal there was a repair site inside the tunnel. The traffic was regulated with traffic lights. At 04^{50} the automatic fire detection system set off an alarm. A lorry had not stopped at the red light and had crashed into four cars. The cars were squeezed between two lorries and the tunnel wall. Presumably because of spilled petrol the fire spread rapidly. Two people were able to leave the crashed cars and survived. 8 persons inside the crashed cars died as a consequence of the accident. The voluntary Fire Brigades Zedernhaus and St. Michael received the alarm at 04^{57} and entered the tunnel from South at 05^{15} with a light fire vehicle and a heavy pump water tender. As the air-stream had been directed to North the fire fighters wearing BAs proceeded towards the fire scene. At 06^{00} they found three people trapped in an emergency shelter (km 4,7) and rescued them. Another person was found on the lane, he was already dead. In order to move forwards they had to extinguish 7 lorries and about 12 cars. Every emergency shelter was searched for survivors. At 09^{15} it was decided to withdraw the fire fighters from South and attack the fire from North. For this purpose the direction of the airflow was changed. The voluntary fire brigade Flachau had been stationed at the North portal since the alarm. Up until this point there had been no chance to attack the fire because of the amounts of smoke and the intense heat. During the afternoon a caterpillar cleared the road of spalled concrete. A heavy pump water tender equipped with a remote water cannon using foam extinguished one vehicle after the other. The fire was extinguished at 21^{00}.

LFV Salzburg

At the northern portal 15 fire brigades with 44 vehicles and 248 fire fighters were on duty during two days. On the south side 8 fire brigades with 22 vehicles and 147 fire fighters. They used 99 BAs and 19 SCBAs.
114 persons escaped from the tunnel. 47 injured people needed medical treatment. 21 doctors and 164 ambulance men with 34 vehicles and two helicopters were on the scene and cared for them.

16 lorries and 24 cars were destroyed. 12 people were killed, 8 as a consequence of the accident 4 people because of the fire. 3 victims were found in their vehicles. Obviously they did not try to flee. One Lorry driver escaped towards South and died from intoxication.
The tunnel was damaged at a zone of 1000 m. Due to the high temperatures the concrete severely spalled and one part of the intermediate ceiling collapsed. The tunnel was reopened three month after the incident.

Comparison of these tunnel fires

There are a few similarities in these two incidents. The speed at which the fire spread, the intense heat, the lack of information about the number of vehicles involved in the incident. In both tunnels the video surveillance and the radio system broke down very early.
As mentioned before, fires caused by an accident may spread very rapidly because of the spillage of petrol. The fast propagation of the fire in the Mont Blanc tunnel could be an effect of the ventilation system and the load of the Belgian HGV.
Communication plays an important role during an intervention. A breakdown may cause important delays and endanger the fire and rescue teams.

The Mont Blanc tunnel is managed and controlled by two different companies. Even the organisation and equipment of the rescue teams differ from each other. The Tauern tunnel is controlled by a single control centre. There was a good collaboration between the control centre and the fire brigades.

In the Tauern tunnel the fire was near the northern portal. All but 4 tunnel users managed to escape. Because of the information about the incident in the Mont Blanc tunnel the people seemed to be aware of the dangerous situation. The Mont Blanc tunnel fire was the largest incident in an European tunnel. The fire started in the middle of the tube. Many tunnel users did not even try to flee.

The ventilation system played an important role during both fires. The rate of exhaust air extraction in the Tauern tunnel is much higher than in the Mont Blanc tunnel. The ventilation system was automatically set on maximum extraction by the fire detection system. It was possible to change the direction of the exhaust fumes. Therefore the fire fighters had the chance to search for persons and attack the fire from both sides.

Conclusions

As a result of the fires in the Mont Blanc and the Tauern tunnel some proposals can be made in order to increase safety for tunnel users:

- Information about the right way to behave should there be an emergency in the tunnel
- Short escape routes
- Adequate ventilation systems and safety facilities
- Quick intervention of fire brigades
- Adequate equipment for the fire brigades

- Improvement in the collaboration between the different organisations
- Joint exercises
- Research into new technologies (fire detection system, fire extinguishing system)

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