# Current safety issues in traffic tunnels

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ABSTRACT: In addition to the manner in which tunnels are furnished, improved control of the state of vehicles and the composition of their loads could better safety standards in traffic tunnels. Joint efforts are imperative to arrive at enhanced and harmonised standards throughout Europe.

## 1 STARTING SITUATION

A modern industrial society requires an efficient and reliable transportation infrastructure. This applies to road as well as rail. This becomes evident from the statistics applying to Germany alone (Tables 1 + 2) (Verkehr).

Table 1: Passenger transportation figures in Germany (1997/98)

| Type of traffic | Billion Pkm |
|---|---|
| Pkw | 787 |
| Tram, Underground, Bus | 77 |
| Railway | 64 |
| Plane | 27 |
| Σ | 955 |

Table 2: Goods transportation figures in Germany (1997/98)

| Type of traffic | Billion Tkm |
|---|---|
| Lorry | 293 |
| Railway | 68 |
| Inland shipping | 65 |
| Pipeline | 15 |
| Plane | 1 |
| Σ | 442 |

In 1997, some 626,000 km of roads of varying categories was available for road traffic (Table 3). The German rail network on the other hand, amounts to roughly 44,000 km (without connecting systems or trams, industrial and works railways). Some 40,000 of this total is accounted for by the DB AG and 4,000 by railways which are not state-owned. Furthermore, inner urban railway systems (Underground trains, urban railways, and trams) have a network of approx. 2,100 km.

The construction and operation of efficient transportation tunnels is increasingly being called for to ensure that traffic can flow speedily without hold-ups. This is by no means a new recognition. After all, the first European rail tunnels were built more than 150 years ago and the first Underground systems towards the end of the 19th century. The high-speed rail routes (Fig. 1) and inner urban commuter rail systems, which are being constructed in our age, above all require a high percentage of underground alignment. At present eg, around 600 km of tunnel for Underground, rapid transit and urban railways with a total of around 500 subterranean stops is being operated in Germany alongside around 450 km of main line tunnels and roughly 150 km of road tunnels (Haack, 1998).

Table 3: Public road network in Germany (as of 1997) [1]

| Road class | 1,000 km | No. of tunnels |
|---|---|---|
| BAB (motorway) | 11.3 | 42 |
| Federal roads | 41.4 | 91 |
| Regional roads | 86.8 | 14 |
| District roads | 91.5 | 4 |
| City/local roads | 395.4 | 33 |
| Σ | 626.4 | 184 |

Fig. 1: ICE travelling out of a tunnel

The road tunnels for which the federal government is responsible for building are to be seen in Table 4.

Details are also provided pertaining to whether the tunnels are two-way (GV) or one-way (RV).

Table 4: Number of road tunnels built on behalf of the Federal Government (as of 1998) [1]

| Length [m] | RV | GV |
|---|---|---|
| < 300 m | 33 | 54 |
| 300 m – 500 m | 13 | 11 |
| 500 m – 1000 m | 17 | 11 |
| 1000 m – 1500 m | 6 | 5 |
| 1500 m – 2000 m | 1 | 2 |
| 2000 m – 2500 m | 0 | 0 |
| 2500 m – 3000 m | 1 | 2 |
| 3300 m | 1 | - |
| Σ | 72 | 85 |

At present, the overall length for operational transportation tunnels throughout the whole of Europe is well in excess of 10,000 km.

It goes without saying that high safety and reliable availability are essential for such tunnels. This particularly applies to fire incidents in tunnels, which unfortunately cannot be entirely excluded. Such fires are characterised by the danger they pose to the persons affected and also in many cases by the considerable extent of damage they cause (Fig. 2). Serious cases of fire accidents resulting in persons being hurt or killed are eg. Known from Azerbaijan, the UK, France, Italy, Japan, Canada, Austria and the USA. A number of major fires have also occurred in Germany as well. In this connection, the confined space available, which made escape and rescue conditions even more difficult, was of particular significance for the consequences.

Fig. 2: Hamburg's Moorfleet Tunnel on the federal motorway following the lorry fire in 1968

## 2 RECENT FIRE ACCIDENTS

Fire incidents in tunnels immediately catch the public's attention and this is quite natural. The media report at length in particular when people come to harm. The disastrous London Underground fire at the Kings Cross Underground station in November 1987, which cost 31 persons their lives and the catastrophic outcome of the Baku Underground fire (Azerbaijan) in October 1995 resulting in 289 deaths, are mentioned as examples. The Channel Tunnel fire between the UK and France on Nov. 18, 1996 (Fig. 3), where fortunately all the tunnel users escaped with their lives as well as the 2 terrible fires in road tunnels on March 24, 1999 below Mont Blanc in France [3-5] and on May 29, 1999 beneath the Tauern range in Austria, resulting in 39 and 12 deaths respectively, had also serious consequences.

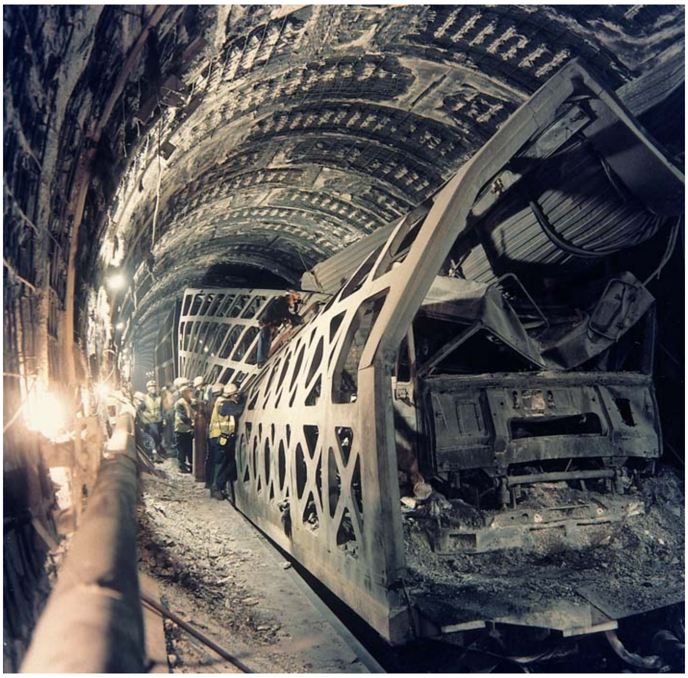

Fig. 3: Burnt out lorry transporter in the Channel Tunnel between the UK and France (fire incident on Nov. 18, 1996)

The 11.6 km long Mont Blanc Tunnel was opened for traffic in 1965. At the time of the accident, its ventilation and safety concept thus corresponded to design standards of 40 years ago. As in the case of all longer transalpine tunnels, the Mont Blanc is operated on a bi-directional basis. Until March 1999, 2 national companies ran it, one French, the other Italian. Table 5 displays the development of traffic for the Mont Blanc Tunnel since it was opened.

Table 5: Development of traffic in the Mont Blanc Tunnel since it opened in 1965 until 1998 (Domke, 1999)

| Type of vehicle | 1966 | 1998 |
|---|---|---|
| Cars x $10^3$ | 503 (92 %) | 444 (36 %) |
| Lorries x $10^3$ | 45 (8 %) | 777 (64 %) |
| Total vehicles x $10^3$ | 548 | 1221 |

The tunnel was equipped with accident bays set 300 m apart and with 18 safety chambers at 600 m gaps. These chambers were provided with fresh air and constructed to withstand the effects of a fire for roughly 2 h. 17 fires have occurred in the tunnel since 1965, 5 of which required the fire brigade on the scene. In 4 of these cases, a heated-up engine was determined as the cause of the fire. There was not a single incidence of the fire spreading to neighbouring vehicles.

On March 24, 1999, a refrigerator lorry carrying 9 t of margarine and 12 t of flour caught fire. It was coming from France and stopped at station 6,700 m. A fully-fledged fire soon developed, which spread to involve 23 lorries and 10 cars (Fig. 4).

Fig. 4: Burnt out lorry in the Mont Blanc Tunnel (fire incident on March 24, 1999)

The fire lasted a total of 53 h. 29 of the 39 dead were found in their vehicles, 9 in the tunnel or in the safety chambers which did not afford sufficient protection. One fire officer died as a result of the injuries he received.

Only some 2 months later, a further terrible fire occurred in the 6,400 m long Tauern Tunnel on May 29, 1999. This tunnel is also operated bi-directionally. It is fitted with 30 emergency call bays set 212 m apart, 61 fire extinguishing bays every 106 m and a total of 7 breakdown bays every 750 m. In 1998, this tunnel had to cope with 5.55 million vehicles. Including almost 1.05 million lorries (= 19 %). This corresponds to an average daily frequency (DTV) of 15,160 vehicles, including 2,850 lorries in both directions. At the time of the accident, there was a construction site in the tunnel with signal lights regulating traffic, which was confined to a single lane. A lorry travelling from the south drove into the end of the tailback at high speed and pushed 4 cars under the lorry stopped in front of them. This incident cost 8 lives and resulted in the lorry catching fire. Attempts to extinguish the blaze were unsuccessful. As a result, the flames spread to a lorry carrying a variety of goods. Its load included aerosols containing hair spray. Altogether, 14 lorries and 26 cars were destroyed by the conflagration. Apart from the 12 dead, 49 others were injured.

## 3 ACCIDENT STATISTICS

Against the background of these serious fire incidents, the issue of vehicle fire frequencies and the attached risks is inevitably raised. The following data and assessments provide a relevant overview. First of all, vehicle fires in general not simply those in tunnels are dealt with.

The following 2 examples from Germany reveal that a vehicle fire incident is not at all rare. For instance, over the past 10 years in Dortmund, an average of 250 vehicle fires have taken place annually with a fluctuation rate of roughly ± 20 incidents. In Hamburg, the appropriate figures amount to around 700 vehicle fires per year with a fluctuation rate of about ± 80 incidents. For Central Europe in general, the statistics pertaining to the entire road network relate to roughly 2 vehicle fires per 100 million driven km.

What about the situation relating to fires in road tunnels? Here are some examples:

In Norway, a total of 41 vehicle fires occurred in tunnels during the period from 1990 to 1996. 20 % of this total was caused by collisions and occurred as a follow-up incident.

The figures provided by the Gotthard Tunnel in Switzerland are of particular interest. This tunnel is 17 km long and is operated bi-directionally like all other trans-Alpine tunnels. In 1998, the traffic volume amounted to 6.5 million vehicles, including 1 million lorries (= 15 %). In that year, 55 accidents took place in the tunnel, including 4 which resulted in fires (Haack, 1996). Altogether, 42 vehicle fires resulted in the Gotthard Tunnel between 1992 and 1998. Cars were involved in 21 cases, buses in 7 cases and lorries on 14 occasions. During the same period, 5.7 fires occurred in each case per 100 million driven km. Another long-term set of statistics relating to the operation of the Gotthard Tunnel comes up with the figure of 4 fires per 100 million driven km, related to all vehicles or 6 fires per 100 million driven km related only to lorries.

The statistics pertaining to the Elbe Tunnel as part of the A7 federal motorway in Hamburg (Table 6) are also most revealing. They indicate that on average 1 fire incident occurred practically every month within the tunnel from 1990 till 1999.What stands out is the over-proportional involvement of lorries amounting to almost 25 % in total fire incidents, although they merely account for some 15 % of the traffic volume. Thus the Elbe Tunnel statistics clearly show that lorries pose a considerably greater danger than cars not simply on account of their substantially higher fire load but also owing to their over-proportional involvement in incidents.

Table 6: Vehicle fires in the Elbe Tunnel, Hamburg (1990 to 1999) (Statistik-Verkehrsentwick-lung)

| Year | Annual traffic million vehicles | Total | Cars[1)] | Lorries[2)] | Motor cycles |
|---|---|---|---|---|---|
| 1990 | 37,0 | 13 | 8 | 5 | - |
| 1991 | 37,3 | 9 | 5 | 4 | - |
| 1992 | 37,6 | 12 | 9 | 3 | - |
| 1993 | 38,0 | 7 | 5 | 2 | - |
| 1994 | 39,1 | 14 | 13 | 1 | - |
| 1995 | 40,5 | 14 | 10 | 4 | - |
| 1996 | 40,6 | 15 | 14 | 1 | - |
| 1997 | 40,5 | 9 | 7 | 2 | - |
| 1998 | 38,5 | 9 | 5 | 2 | 2 |
| 1999 | 40,3 | 7 | 7 | - | - |
| Σ | 389,4 | 109 | 83 | 24 | 2 |

1) Accounting for 85 % of total
2) Accounting for 15 % of total

The Elbe Tunnel is Germany's busiest road tunnel and is numbered among Europe's most highly frequented tunnels alongside the Dartford Tunnel beneath the Thames (to the east of London).

The available data clearly indicate that although fire accidents in road traffic constantly occur in tunnels, their frequency is, however, relatively low when related to the overall amount of traffic on all roads.

In this connection, it is frequently discussed whether tunnel sections should perhaps be basically assessed as more dangerous than open roads. Far-reaching analyses by the Ruhr University of Bochum, Institute for Road and Traffic Studies provide a clear picture for roads as such (Lemke, 1999). It is shown that the accident risk on the open road is generally far higher than the risk in a tunnel. This is easy to accept when it is considered that normally an 80 km/h speed restriction applies in a road tunnel. In addition, dangerous climatic influences such as frozen snow or black ice, heavy rain, fog, gusts of wind or blinding sunlight do not feature in tunnels. The Ruhr University survey examined a total of 784 accidents during the period from 1993 to 1997 in 46 motorway tunnels with directional traffic and 22 trunk road tunnels with 2-way traffic. Tables 7 + 8 provide details of the survey results.

Table 7: Accident statistics for road tunnels in Germany

| Cause of accident | BAB tunnels (1-way traffic) | Regional road tunnels (2-way traffic) |
|---|---|---|
| Driving errors | 17 % | 32 % |
| Rear end collisions | 69 % | 34 % |
| Misc. | 13 % | 32 % |

Table 8: Accident rates for road tunnels in Germany 1993 to 1997 (Lemke, 1999) (figures in brackets relate to the open road)

| Type of tunnel | Accidents/ 1 million | | DM/1,000 vehicle-km |
|---|---|---|---|
| | Personal injuries | Damages to property | Personal injuries and damages to property |
| BAB with hard shoulder | 0.074 (0.147) | 0.328 (0.619) | 12.78 (35.00) |
| BAB without hard shoulders | 0.130 (0.202) | 0.354 (0.923) | 21.16 (45.80) |
| Regional road with 2-way traffic | 0.141 (0.315) | 0.249 (0.983) | 19.88 (89.40) |

The figures for rail traffic are generally considerably more favourable than for road traffic. Tunnel fire statistics by Prognos dating form 1987 as well as corresponding evaluations by STUVA arrived at roughly the same conclusions. They show that the probability of tunnel fires in rail traffic lie by a factor of 20 to 25 below those for road traffic. This can be mainly explained by the exclusive employment of professional drivers and the high degree of control for the systems applied in rail traffic. Furthermore, the technical standards relating to fire protection for rail vehicle construction has had a positive effect in Germany for roughly the last 10 years in the form of DIN 5510. A comparable guideline is lacking as far as car making is concerned.

In a nutshell, it can be determined that: In spite of considerable technical improvements also when it comes to building cars and lorries, above all, through using fire-resistant materials for their interiors, an increasing number of fires in tunnels must be reckoned with. There are a number of important reasons for this:

- increasing traffic frequencies and the growing number of hazardous goods transports; in Germany alone, the transportation of hazardous goods amounting to more than 50 million tonnes per year accounts for around 10 % of the total quantity carried by lorry (Verkehr, 1999).
- increasing driving speeds and in turn, the growing kinetic energy on road and rail
- the already very large and - mainly for environmental protection reasons - constantly growing number of tunnels with increasing individual lengths both for road as well as rail transportation; at present, the 7.9 km long Rennsteig Tunnel as part of the federal motorway crossing the heights of the Thuringian Forest, which will be Germany's longest road tunnel, is under construction. The Landrücken Tunnel, with almost 11 km, is Germany's longest rail tunnel
- the growing risk of arson extending to attacks by terrorists; at present, some 50 % of the fire incidents occurring in public commuter transportation in Germany result from the fires being laid deliberately. As far as terrorist activities are con-

cerned, the events in London (attacks by the IRA), Paris (explosives set off in the metro) and Tokyo (gas attacks in the Underground) are brought to mind.

## 4 THE EFFECTS OF FIRE

In the early 1980s, STUVA undertook far-reaching investigations at the behest of the Federal Transport Ministry designed to improve fire protection in tunnels for Underground, urban and tram railways (Heffels, Marquardt, Staub, 1984), which resulted in important recognition's. They were, by and large, confirmed through major fire tests in Norway within the framework of the Eureka research project (Haack, 1996, Brande in Verkehrstunneln, 1998) and can thus still be regarded as valid today:

a) as far as the flashover of a fire is concerned, this point is reached after some 7 to 10 min by the vehicles normally used in commuter traffic
b) the fire duration of a vehicle varies considerably depending on the external conditions and fluctuates between 30 min and a number of hours
c) even small fires can release considerable amounts of smoke gas and lead to a critical situation for the passengers and the train staff (Fig. 5)
d) in a number of cases, the entire tunnel cross-section was filled with smoke after a short time to such an extent that the visibility was less than 1 m even using searchlights
e) combating fires in tunnels is made considerably more difficult by the restricted accessibility, the amount of smoke and the enormous heat radiation


Fig. 5: Rapid transit railway fire in Hamburg (Dec. 11, 1986)

f) the, in some cases considerable damage to property (Fig. 6) is due to the high fire load caused by the rail vehicles used in commuter traffic. This normally amounts to between 60 and 80 kg of timber equivalent load per m 2 of passenger space.

Fig. 6: Underground railway fire at the Hansaring station in Cologne (Oct. 24, 1978; Source: BF Cologne)

In comparison, for residential buildings, the figure of 30 to 60 kg of combustible material normally applies per m 2 of living space and for stores an average of around 100 kg of combustible material per m 2 of sales area.

Serious fires not only endanger persons to a high extent and often result in the total loss of the vehicles involved; they also frequently cause extensive damage to the tunnel facilities. This is primarily due (Fig. 7) to the major development of heat in conjunction with, in some cases, widespread flaking of the concrete close to the surface as well as through aggressive fire gases. Although so far such fires have not affected the stability of the tunnel section concerned, it can always be assumed that the tunnel cannot be operated for weeks or even months on end, on account of the redevelopment measures, which are necessary. The Tauern Tunnel for example, was out of commission from May 29, 1999, when the fire took place until the end of August that year - all of 3 months. In the case of the Mont Blanc Tunnel, the period of closure will amount to well over 18 months mainly on account of the lengthy investigations undertaken by the public prosecutor's office. The consequences of such operating hold-ups should not be underestimated. The closure of important tunnels or tunnel sections for weeks or months on end inevitably leads in the case of inner urban tunnels to considerable disturbances to traffic in densely populated city areas or when it comes to tunnels on busy transit routes such as at present, the Mont Blanc Tunnel, where the alternatives are, by and large, only the Fréjus Tunnel further to the west or the Alpine passes. Both situations lead to added traffic congestion and in turn, to a further rise in accident risks.

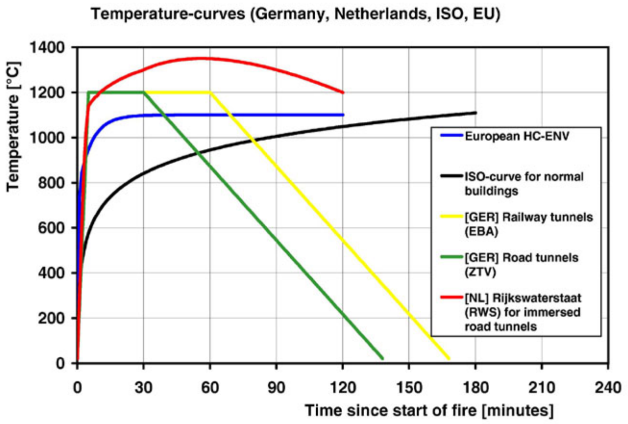


Fig. 7: Fire dimensioning curves currently applied in various European countries

## 5 FIRE PROTECTIOIN MEASURES

As a result of the recent fire disasters, experts are discussing issues relating to the basic appraisal of existing safety standards in tunnels. At stake are preventative constructional as well as operational protection measures together with those designed to combat fire.

Preventative constructional measures initially embrace the choice of suitable materials to be used. In this regard, concrete can be classified as a material with a high fire safety factor. It in no way contributes to the fire load. If anything, the problems affecting this material relate to explosion-like flaking occurring on the affected surface in the event of rapidly rising, high temperatures (Fig. 7). Such flaking endangers tunnel users attempting to escape as well as the rescue and extinguishing crews rushing to help. In individual cases, the flaking reached considerable depths of a number of decimetres so that the inner reinforcement was exposed and burnt out (please see Figs. 2 + 3). When pre-stressed concrete structures are involved, this can also lead to the prestressing elements becoming completely detached (Fig. 2) resulting in a total loss of the bearing effect.

The geometrical design of the tunnel cross-section, the installation of the intermediate ceiling for separating the air intake and outlet channels above the carriageway zone and in particular, their side abutment and in many cases, fire protection linings specially set up in the wall and ceiling zones (Haack, 1994) in the case of road tunnels or subterranean stops in the case of Underground, rapid transit and urban railways are all numbered among preventative constructional fire protection measures. The newly developed fire protection system on the basis of perforated sheets designed to create an insulating layer presented in Fig. 8 provides among other things, the advantage that the tunnel lining remains visible for inspection and maintenance purposes compared with conventional

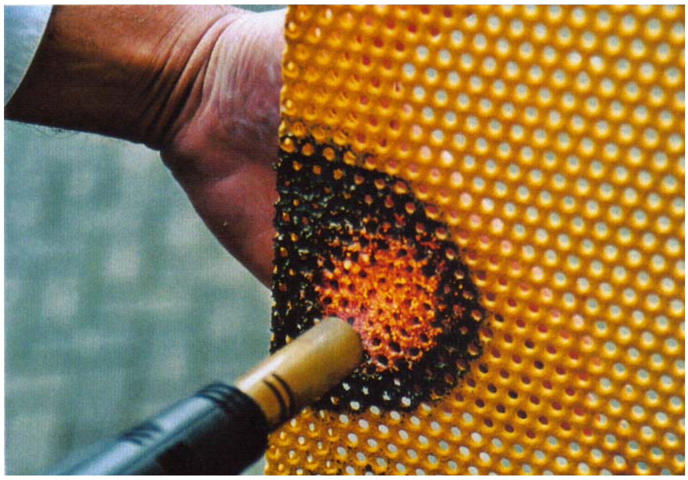

Fig. 8: New transparent fire protection system on the basis of an insulating layer of perforated plates (Haack, 1999)

systems comprising plates on a mineral basis. The rear ventilation of the fire protection lining resulting from the perforated structure avoids water pressure building up in the event of leaks or the formation of mould fungus. The changeover from suction and pressure loads when bulky vehicles are passing by at speed is also precluded from the very outset through the perforated structure (Haack, 1999).

The setting up of special escape ways such as for instance, for the Gotthard Road Tunnel in Switzerland and breakdown bays in the case of long tunnels is also numbered among constructional fire protection measures.

In the case of road tunnels, operational fire protection primarily relates to mechanised ventilation including its operating concept. In modern tunnels, these are geared to extreme traffic situations with high traffic densities and above all, to vehicle fires in the tunnel. Control is carried out either manually or automatically, triggered by corresponding fire alarm systems. Both versions have their pros and cons. Manual control enables the existing tunnel control room to act in accordance with the situation shown by the television cameras. It goes without saying that as in the case of all processes controlled by man, excessively slow reactions and misinterpretations of the development of the fire cannot be excluded. Automatic systems are devised in advance for certain scenarios at the planning stage and in some cases, exclude necessary adjustments designed to support escape and rescue actions. Against this background, it appears wise to use systems, which combine both types of control.

The way in which a vehicle is constructed also plays its part in operational fire protection. The use of materials, which are not easily combustible especially for the interior, is essential as well as fire-retarding zones, overheating displays and the like.

Then of course, specially devised alarm plans and instructions informing rail staff what to do in the event of fire are of particular importance for operational fire protection. Thus for example, rail vehicles should move on to the next station when the alarm is sounded or (better still) into the open as the rescue/escape of passengers and combating the blaze can be carried out much more effectively than in a tunnel section. Special operational guidelines should also be compiled for transporting hazardous goods through long road tunnels, eg. Travelling through in a convoy with accompanying vehicle and at determined distances or closing the tunnel to hazardous goods transports at particular times of day.

The carrying of manual fire extinguishers aboard rail cars and railway carriages as well as in the driver's cab of lorries and on buses continues to belong to operational fire protection measures. These are supported by the setting up of hydrants or stationary water lines with hose connections for the speedy provision of extinguishing water, drainage with the aid of slotted or hollow gutters (Blennemann, 1998), the establishment of emergency bays with telephone, fire alarm and extinguisher in the tunnel. Last but not least, television monitoring, loudspeaker units, radio cables and signal light systems round off modern operational fire protection in tunnels.

Fire combating measures are undertaken by professional and voluntary fire services. It goes without saying that the personnel must be provided with special equipment for use in tunnels. Furthermore, the alarm and deployment concepts have in each case to be geared to the local conditions. Moreover, the fire crews under must carry out regular drills as real as possible conditions in the tunnel. In this connection, it is essential to practice collaboration with the tunnel operators, the transport companies, and other rescue and emergency services. Such drills must on no account be carried out in conjunction with deliberately simulated hot fires. This would involve an excessively high risk for those taking part. Instead they should be undertaken using cold smoke generators or dimmed vision on breathing masks.

All these precautions are taken into consideration and applied nowadays in the design, construction and operation of modern tunnel facilities [15, 16]. Nonetheless, absolute safety in tunnel traffic can never be taken as the basis.

## 6 HOW TO BEHAVE

Should a fire occur in a tunnel, the situation is definitely far worse than out in the open. Escape and rescue possibilities are restricted in terms of the geometry. However, rapidly rising heat radiation, the fast release of fire gases and a related decrease in visibility, above all, form potential risks (Fig. 9). The fact that many motorists misinterpreted this situation during the Mont Blanc Tunnel fire largely contributed to its catastrophic outcome. Against this background, it is essential that the following code of behaviour is passed on to motorists who intend using a road tunnel:

Fig. 9: Fire test with a heavy lorry within the scope of an European research project with substantial German participation (Brande in Verkehrestunneln, 1998)

a) When driving through the tunnel:
- switch on lights and remove sun glasses
- make sure you observe the speed restriction
- keep a safe distance to the vehicle in front
- never overtake in tubes with two-way traffic and drive as far to the right as possible
- drive with increased attention
- switch on the radio

b) Should you have a breakdown:
- move over as far to the right as possible - ensure you use the available hard shoulder, otherwise use the footpath and stop in the breakdown bay if possible
- secure your vehicle ( warning flasher, warning triangle)
- immediately inform the tunnel control room via emergency call bay (or the emergency centre via mobile phone)

c) In the event of a tailback in the tunnel:
- stop as far to the outside as possible
- keep your distance to the vehicle in front (do not edge up bumper-to-bumper)
- switch off engine at once
- do not get out
- switch on radio and listen for loudspeaker messages
- on no account turn
- do not reverse

d) In the event of a vehicle fire in the tunnel:
- stop as far to the outside as possible
- keep your distance to the vehicle in front (do not edge up bumper-to-bumper)
- switch off engine at once

- switch on warning flasher at end of tailback
- get out at once, do not lock car door
- escape at once by moving away from the smoke direction
- use specially marked emergency exits
- on no account turn
- do not reverse.

This code of behaviour, which could well be lifesaving, should regularly be published by the media (press, radio, TV), the automobile clubs, the highway patrol authorities and also even by the government. In this way, tunnel users can be made aware and trained to face all contingencies. Basically, an effort must be made to convince the motorist that he only has a few minutes available to extinguish the blaze or make a successful escape should a fire occur in the tunnel. On no account should he feel secure within his vehicle or stay in it simply to protect his property. The false appraisal of these 2 aspects presumably led to 29 tunnel users losing their lives in their vehicles during the Mont Blanc Tunnel fire disaster. Permanent training aimed at making motorists aware of how to act is certainly more useful than the repeated publication of "rankings`` on tunnels and their fire safety standards [17, 18].

## 7 CONSIDERATIONS PERTAINING TO THE DESIGN OF FUTURE TRAFFIC TUNNELS

The recent fire incidents touched on earlier have triggered an intensive debate among the general public [17--20] and expert circles [21-23], pertaining to just how the potential risk of driving through a tunnel should be generally assessed and which possible improvements exist for safety in tunnels.

When contemplating the relevant issues, it is imperative that one should not simply consider the worst conceivable situations, for example, a collision between a bus and a tank truck or even a passenger train and a tank truck within a single-tube road or rail tunnel with bi-directional traffic in each case. Such incidents, which are highly improbable, would exclude tunnel traffic altogether if they were deemed to be the standard. They cannot be controlled. The consequence would be that tunnel traffic in general would be banned or at least, it would become extremely expensive thus signifying that tunnelling could no longer be financed. Everyday alleviations associated with tunnels, e. g. in road traffic and in turn, in the life of a big city, the foundations of modern mobility over long distances, watercourses and obstacles posed by mountain ranges, would disappear.

It is obvious that this cannot be the objective of these deliberations. Tunnels are far rather an important component of and the prerequisite for a well functioning, reliable infrastructure in a modern industrial society. Seen from this point-of-view, realistic scenarios are required from considerations aimed at improving safety in tunnel traffic. In this connection, everything must be geared to the fact that an absolute zero risk can never be attained in our everyday lives. If anything, we should orientate ourselves to coastal protection measures. Here, nobody would ever propose designing dykes for the absolutely highest flood mark ever recorded (e. g. the "Große Manndränke“ in 1634 along the north German coastal area). Such facilities could not be realised - neither technically nor financially. When it comes to coastal protection measures, a degree of protection, which will most probably be adequate is determined, and a defined residual risk accepted.

This should also be the benchmark when assessing tunnel traffic. Hundreds of vehicle fires in road tunnels all over the world prior to the 2 conflagrations in the Mont Blanc Tunnel and the Tauern Tunnel did not lead to these disastrous incidents. In this connection, it should be remembered that 8 persons in the Tauern Tunnel lost their lives directly on account of the pile-up and not because of the fire incident. In the open, they could not have been rescued either given the same accident situation. Against this background, the Mont Blanc incident in particular should never be taken into consideration as an example for the design and setting up of future tunnel structures. This incident was if anything, an out of the ordinary catastrophe with an unforeseeable development. This is also confirmed by the various vehicle fires, which have taken place in the interim since March 24, 1999 and May 29, 1999, in road tunnels - without lives being lost or a fire flash over from vehicle to vehicle occurring.

A frequently discussed question relates to the permissibility of operating a long tunnel with bi-directional traffic. There is no doubt that 2 parallel tunnel tubes with one-way traffic constitute a considerably lower potential risk on account of their better escape and rescue possibilities than a single tube with 2-way traffic. Notwithstanding, the demand for operating tunnels exclusively with directional traffic cannot generally be put forward without proper scrutiny of each individual case. It must be considered, for instance, that a 10 or 15 km long tunnel with high rock overburden and a relatively low anticipated traffic volume cannot always be replaced in economic terms in the form of 2 parallel single tubes. In spite of 2-way traffic exacerbating the situation, a single-tube tunnel with an absolute ban on overtaking and a speed restriction of 80 km/h, which are standard practice, undoubtedly clearly reduces the potential risk compared with the situation before tunnels were built, where cars and above all, lorries were forced to use the steep pass routes, mostly with never-ending narrow bends, in summer and especially in winter. The money required for a parallel tube can again be used more effectively to relieve a further pass against the background of the low traffic density scenario through a single tube with 2-way traffic. It is precisely this concept, which has been generally applied in the Alpine countries in the last 3 to 4 decades. In this connection, the building of a second tube was and is planned in the long term from the very outset in many cases, regardless of the traffic development. Thus all long tunnels crossing the Alps have so far only been constructed with a single tube. It goes without saying that the rescue concept in such tunnels is considerably enhanced if at least a parallel ventilation tunnel, which can also be used for escape purposes, is excavated should there not be a parallel tube designed to carry traffic. This situation exists at the Gotthard road tunnel in Switzerland (Fig. 10). Germany's motorway tunnels generally have 2 tubes and provide a high safety standard in conjunction with their furnishing, which has to comply with RABT specifications.

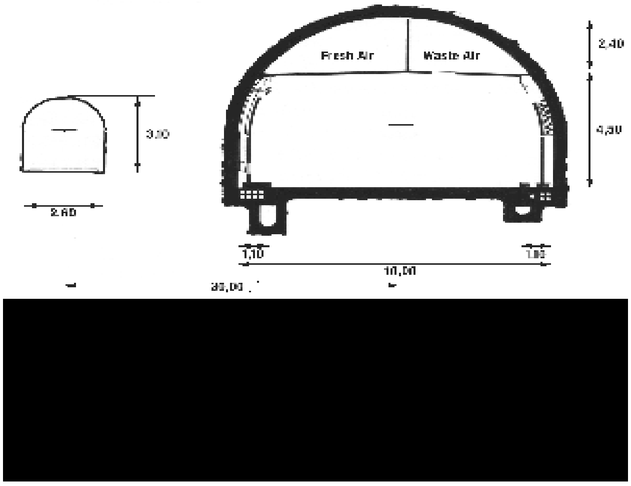


Fig. 10: Cross-section of the Gotthard Road Tunnel (Switzerland) with parallel ventilation and escape tunnel

It is also essential that the guidelines relating to preventative constructional, operational fire protection as well as combating fire is harmonised to a high degree in the states of the European Union (Rat der European Union, Memorandum der franzosischen Delegation vom 28.9.1999). Currently, entirely different regulations exist in the various countries pertaining to the distance between escape exits, the rating of mechanical ventilation systems, the installation of lights, the maximum gradients etc. International research as well as the systematic analysis of previous fire incidents must be used here to arrive at the decisive principles for harmonised European legislation. This of course means that the governments have to cough up the required funds to a sufficient degree. In addition, there is the need to create the infrastructural prerequisites for rapidly translating into practice the longstanding political objective of increasingly transporting goods traffic by rail. This is a pan-European task, which is both essential and cost-intensive. Switzerland with the regulations it has consistently applied at federal level can serve as an example here.

In summing up, it should be said that safety technology in traffic tunnels has made considerable progress since the Mont Blanc Tunnel was opened in 1965. Decisive improvements have also been undertaken in vehicle construction also with the objective of enhanced fire protection. Nonetheless, there are a number of important issues relating to improved safety concepts for traffic tunnels, which still have to be properly clarified. Apart from tunnel fumishing, these include better controls for the state of a vehicle and the composition of what it is carrying. It is essential that all these questions are tackled jointly so that improved and harmonised standards for tunnel traffic safety are realised all over Europe.

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