

The Gotthard Road Tunnel Fire: 20 Years On

Petr Pospisil, Principal Engineer with HNTB's Ventilation and Fire Life Safety team in North America, was working as a ventilation designer on the Gotthard Road Tunnel's refurbishment when a major fire occurred in 2001. Twenty years later he looks back at the incident and discusses lessons learnt.



Figure 1: Fire in the Gotthard road tunnel 2001

On October 24, 2001, a collision and subsequent fire in Switzerland's Gotthard Road Tunnel resulted in 11 fatalities and serious damage to the tunnel structure and equipment. As one of several major tunnel fires that gained extensive media coverage at the time, the incident prompted many publications on tunnel safety, e.g., The Handbook of Tunnel Fire Safety, Chapter 3^[2] and the report by the Criminal Investigation Team^[1]. The picture of the two burning trucks, taken by a police officer approaching the fire from the south a few minutes after the collision, became an iconic image for road tunnel fires, see Figure 1.

The photo shows some important features of the incident. First, the truck on the left that caused the accident is on the wrong side of the road (not being in the UK). Rather, the driver lost control of his vehicle and swerved into the opposite lane of traffic. Second, the photo was taken from the clear side; all the heat and smoke was driven in the other direction. The south (upwind) side of the fire remained fully accessible. In fact, the back of the truck on the left remained intact until the fire was extinguished hours later. The target conditions of some tunnel ventilation standards, i.e. avoiding backlayering of smoke, were maintained.

I was working as a ventilation designer on a tunnel refurbishment programme for the Gotthard Road Tunnel that was underway when the fire occurred. In fact, the day the incident happened, a technical meeting was due to take place in the Tunnel Operation Centre but was cancelled when the fire broke out. Twenty years later, new tunnel safety standards have been successfully implemented throughout Europe.

Background

The Gotthard Pass, in the Swiss Alps, is situated on an important European north-south transportation axis. In winter, the 2,100m high pass is closed. In 1882, the first (15km long) Gotthard Rail Tunnel opened, providing a shortcut through the mountain and year-round traffic connectivity. It was the world's longest tunnel at the time. In 2016, the 57km long Gotthard Base Tunnel opened, passing through the base of the mountain, significantly increasing rail-bound traffic capacity, and claiming a new record for the world's longest tunnel.

The Gotthard Road Tunnel went into service in 1980, providing bidirectional traffic lanes in a single tube. At a length of 16.9km, it was the world's longest road tunnel at the time. It was equipped with a powerful transverse ventilation system with 22 fans at six stations and had an installed power of over 10MW. The ventilation was designed and operated primarily to dilute exhaust gasses from vehicles to an acceptable air quality, see Figure 2.

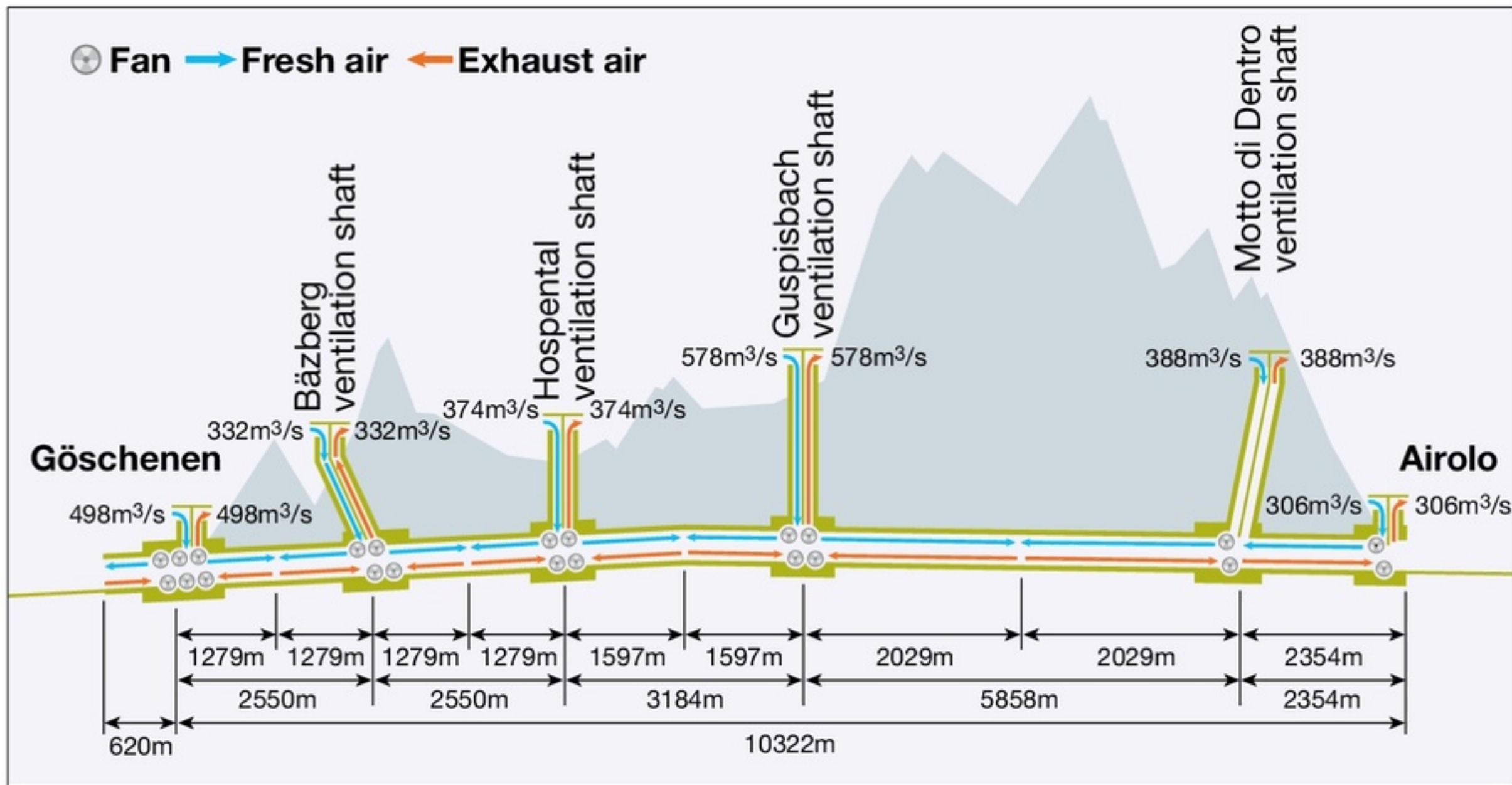


Figure 2: Schematic of the original ventilation system

Over time, the implementation of vehicle emission standards led to a gradual decrease in fresh air demand, but on the other hand traffic numbers greatly increased. In 1981, 2.9 million vehicles drove through the Gotthard Road Tunnel, among them 170,000 Heavy Goods Vehicles (HGVs). By 2000, it was 6.8 million vehicles and 1.2 million HGVs. Since then, traffic numbers have slightly decreased due to strict traffic management measures and a policy of transferring freight from HGVs to rail through the new Base Tunnel.

In the early 1990s, it was decided that the tunnel's ventilation would be operated mostly in semi-transverse mode, to save energy costs. As explained in the Road Tunnel Ventilation Compendium^[4], such ventilation systems are not really useful in tunnel applications, although applied in many tunnels. Air quality in the Gotthard Road Tunnel was mostly very poor during the 1990s and drivers using the tunnel complained of poor visibility and fumes.

The long, narrow, tunnel with bidirectional traffic was quite dangerous for drivers. With a speed limit of 80km/h (50mph), passage through the tunnel takes 13 minutes in a monotonous environment that can cause drowsiness. Accidents and head-on collisions occur regularly. In 1995, 68 accidents were logged in the tunnel. There were on average six to 10 fires per year, mostly insignificant incidents, except for three large HGV fires in 1991, 1994 and 1997, which resulted in serious damage. However, there had not been any fatalities due to fire. Drivers could evacuate to emergency escape rooms, located at distances of 250m, which are connected to an adjacent service tunnel.

For fire ventilation, the line exhaust of a particular section could be ramped up to a maximum air volume of 120m³/s,km to 145m³/s,km and the supply could be reduced to a minimum value. The supply and exhaust in other ventilation sections were operated so that the longitudinal airflow in the fire section was minimised. Ventilation professionals knew that effective smoke control was not possible with the applied fire ventilation concept, which would result in a large part of the tunnel being filled with smoke,

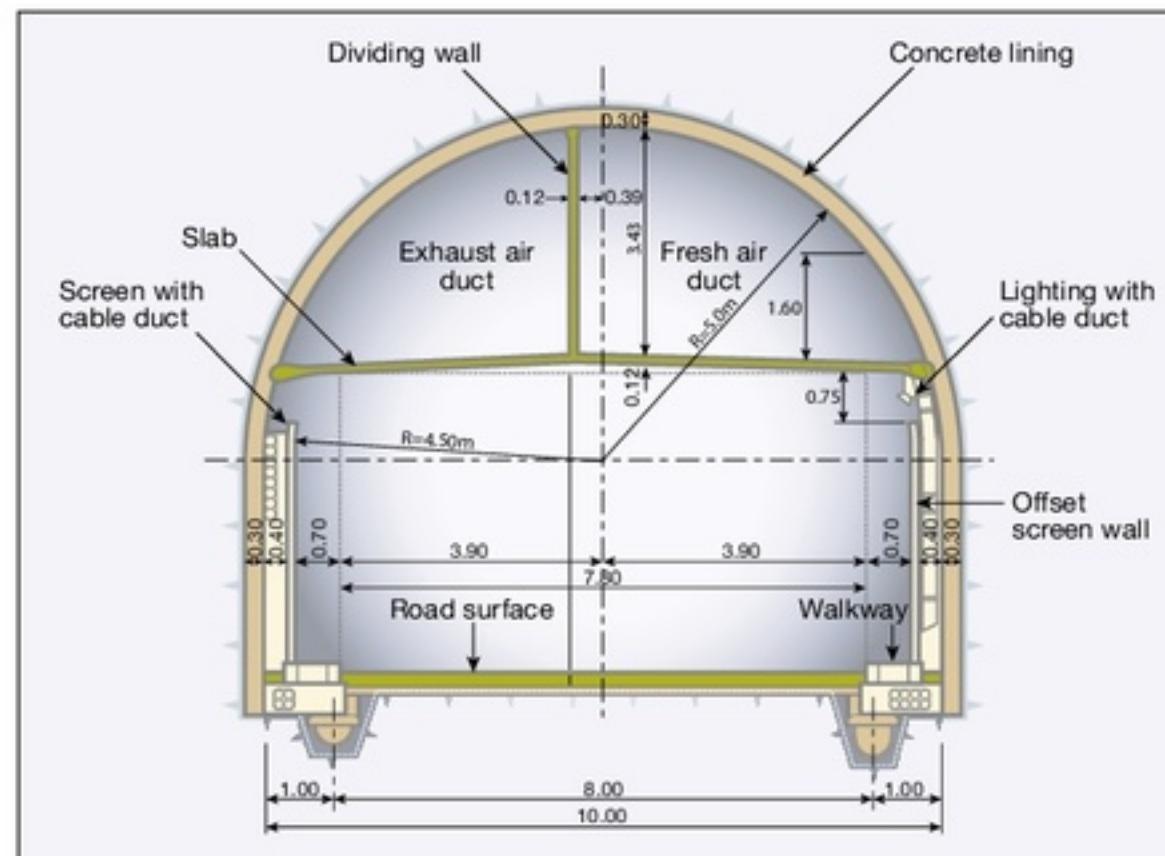


Figure 3: Tunnel cross section with supply and exhaust ducts in the ceiling

but road authorities were reluctant to upgrade the system. Operators did not want equipment in the tunnel that required cleaning and maintenance, for instance controllable exhaust dampers.

The 1997 fire incidents

On 17th September 1997, a coach burnt down to its chassis in the central section of the tunnel, due to an overheated engine. All 47 coach passengers were evacuated by another coach that was coincidentally passing by and took them out of the tunnel. Smoke spread over a length of approximately 625m and fire fighters were able to extinguish the fire within 20 minutes.

On 31st October 1997, a truck loaded with cars caught fire and halted 1km from the southern portal, almost at the same location as the tragic fire four years later. Approximately 60 people were evacuated to the emergency rooms, one suffered from mild smoke inhalation. Most of the people that were evacuated did not want to leave their vehicles and had to be forced to do so by emergency service members. Approaching fire fighters were endangered by spalling concrete. The tunnel equipment and structure was significantly damaged and were refurbished in the following weeks. An investigation resulted in the demand for the following measures:

- The reaction time of the emergency ventilation measures, which took several minutes to commence following the fire alarm, must be improved.
- Emergency exits should very clearly indicated and drivers instructed to find and use them.
- The extraction capacity should be increased by operating the line exhaust in both sections of a ventilation zone, see Figure 2. An important detail in the fire development four years later.

Besides the above, an analysis of improved fire ventilation concepts via concentrated smoke extraction in proximity to a fire was initiated, which later resulted in a refurbishment programme for concentrated smoke extraction by controllable dampers.

In the spring of 1999, fire catastrophes took place in the Mont Blanc Tunnel (Franco-Italian Alps) and the Tauern Tunnel (Austrian Alps) and the subsequent media coverage sparked massive political pressure to improve road tunnel safety. In the Gotthard Road Tunnel, the refurbishment project to transform the transverse ventilation with line exhaust to controllable concentrated extraction was fast-tracked and works were initiated. By the summer of 2001, some of the openings for the future dampers had already been cut into the slab under the exhaust duct and covered temporarily with wooden lids.

The 2001 fire

On 24th October 2001, at 9:39am, about a kilometre into the tunnel from the southern portal, a Belgian truck hit the tunnel wall at a speed of around 40 kilometres per hour and crossed into the opposite lane. Although the oncoming Italian truck driver was able to brake and swerve a collision resulted and one of the truck's tanks burst and diesel spilled out onto the road. A short circuit in a cable then ignited the diesel-air mixture. The two trucks and their loads (including hundreds of tyres) quickly caught on fire. Ten people died due to smoke inhalation, mostly Carbon Monoxide poisoning, and one person burned to death in their vehicle. It took 14 hours to extinguish the fire. The tunnel structure was seriously damaged over a length of 230m, where seven HGVs completely burnt out and the base slab had partly collapsed. Over a section of more than 750m, tunnel equipment such as lighting, signals and instrumentation was destroyed. The tunnel had to be closed for two months for repairs at a cost of approximately 14 million Swiss francs.

Ventilation and smoke spread

The flow velocity at the fire location reached up to 7.5m/s, driving smoke more than 2.5km towards the north, to the middle of ventilation section 9 (see Figure 2). Those excessive flow velocities fanned the fire and accelerated the spread of smoke. That was caused by the following forces:

1. Fire ventilation with line exhaust
2. Piston effect from moving traffic
3. Meteorological forces

Item 1

The fire occurred in ventilation zone 10, but emergency fire ventilation was also initiated in

zones 8 and 9, resulting in a line exhaust over a length of 8km (almost half the length of the tunnel). As explained in the Road Tunnel Ventilation Compendium, a line exhaust generates inbound airflow in the tunnel. A short calculation of air balance, taking the line exhaust into account and reduced supply in all three sections 8, 9 and 10, led to a ventilation induced flow velocity at the fire location of 6m/s northwards.

After approximately six hours of operation, the exhaust in section 10 switched off due to a switchgear failure. The other fans operated continuously for almost 24 hours. The supply ducts were ventilated with fresh air, preventing excessive damage to the equipment in the ducts.

As a point of interest, a few weeks before the fire incident, I had issued a technical report about fire ventilation control specifications for the ongoing refurbishment project. In that document, it was specified that multiple fire zones should not be allowed, and that exhaust should be strictly confined. A basic fire safety principle is that the first verified alarm determines the fire ventilation scenario and subsequent alarms do not lead to additional fire zones. If needed, the fire zone can be manually changed, but there must never be multiple fire zones.

Item 2

The piston effect caused by moving traffic significantly determines the airflow in the tunnel.

When the tunnel is blocked by a fire, vehicles stop at the fire location, but vehicles beyond the fire drive on and leave the tunnel. In the Gotthard Road Tunnel, that can take up to 20 minutes for fires located close to a portal. As the fire incident occurred at the southern end of the tunnel, moving vehicles supported the spread of smoke northwards.

In fact, the lack of controllability of longitudinal flow, taking moving traffic into account, is still a weakness of the refurbished ventilation system with concentrated exhaust.

Item 3

The barometric pressure difference between the North and South portal of the Gotthard Road Tunnel can reach up to 800 Pa. Other meteorological effects, such as wind pressure and natural buoyancy, are in a magnitude lower than the barometric pressure. However, the precise meteorological conditions at the time of the fire incident are unknown.

The importance of emergency shelters

All the emergency shelters (at distances of 250m) are supplied with fresh air, designed for an adequate flow velocity to prevent smoke ingress through open escape doors. The emergency exit doors remained intact throughout the incident although, in the immediate vicinity of the fire, the seals were destroyed. Emergency shelter No. 69 was located next to the fire and suffered the most damage. Drivers that were situated within a 250m radius of the fire were able to escape to the shelter, with one exception. According to witnesses, a truck driver had almost reached the shelter, but returned to his vehicle (apparently to retrieve something he had forgotten) and died as a result.

Figure 4: Exhaust damper blades in the Gotthard Road Tunnel after 10 years of operation



At least 30 people did escape. Ten of the 11 victims died at a distance of 250m to 1,000m from the fire due to smoke inhalation. Many of them stayed in their vehicles. They had the opportunity to escape to shelters but failed to do so due to not knowing correct procedure or irrational behaviour under stress. One person was found next to an emergency exit. The driver that caused the crash was found 300m away from his vehicle. According to the investigation, he had been drunk.

Fire fighters were able to use the service tunnel and emergency shelters to access the smoke-filled tunnel zone north of the fire's location.

Lessons learnt

Extensive media coverage and the subsequent political pressure following the tunnel fires in 1999 led to new national and international tunnel safety rules that focused on the following measures:

- Twin-tube tunnels should have unidirectional traffic when the traffic load exceeds a certain threshold
- Emergency exits to the surface should be provided at minimal distances

Figure 5: Controlled smoke layering during a hot smoke test in a road tunnel



- Fast, reliable, incident and fire/smoke detection should be provided
- Efficient traffic management systems should be provided in- and outside tunnels
- Control of smoke propagation through regulation of longitudinal airflow and, in long tunnels with bidirectional traffic, concentrated extraction
- Drainage systems for the containment of spilled flammable liquids
- Other structural measures, for instance lay-bys in tunnels with bidirectional traffic
- Risk analysis as the basis for conceptual decisions
- Organisational and operational measures in place for emergency scenarios
- Education of drivers, tunnel operators and emergency services personnel

These measures have increased road tunnel safety significantly and also provided business opportunities for the construction industry and equipment suppliers. Billions of Euros were invested in the refurbishment and safety measures in many old and new European tunnels. Today, on average, four fires per year occur in the Gotthard Road Tunnel, and the refurbished ventilation system with concentrated extraction by controllable exhaust dampers is able to reliably limit the smoke spread in the tunnel. Professional fire fighters are stationed at both portals, able to react quickly to all incidents and extinguish the fires.

The most significant impact was provided by the traffic management measures. Following reopening, in December 2001, trucks and HGVs were allowed only as unidirectional traffic in the tunnel, with the direction switching every two hours, and enforcement of a minimal distance between trucks. Cars and light goods vehicles continued in bidirectional traffic mode. However, that affected the road's capacity, and led to huge traffic jams on the adjacent ramps. Transport companies complained about loss of revenues.

In September 2002, the refurbished ventilation system was finally commissioned. After that, bidirectional HGV traffic was allowed again, but trucks were limited by a drop count system. When a safe capacity threshold is exceeded, the whole north-south route is closed. This traffic management system is supported by regular pre-emptive safety checks and automatic detection of overheated vehicles at the tunnel portals.

In 2016, Swiss voters approved the construction of a second tube for the Gotthard Road Tunnel, which will provide unidirectional traffic in the future and significantly improve safety; even though the average daily traffic (approximately 17,000 vehicles) is lower than the threshold value determined by the European Road Tunnel Safety Directive^[3] and considering the recent policy of transferring freight to rail through the prestigious Gotthard Base Tunnel. This leads to the basic question of all risk analysis: How safe is safe enough?^[6]

On the other hand, some sources of risk in road tunnels cannot be solved by technical measures. The 2001 Gotthard Road Tunnel accident was caused by a drunk driver. The driver that caused the 1999 Tauern Tunnel accident that cost 12 lives, was suffering from

sleep deprivation, which negatively affects driving abilities the same way as alcohol consumption.

Many victims would have survived if they had reacted quickly, left their vehicles, and sought the emergency exits, as most drivers that were close to the fire did. From my own experience, I know that the visibility in a smoke-filled tunnel is almost zero, and orientation becomes impossible. In fact, I had problems finding an emergency exit only a few meters away, luckily under test conditions with non-toxic test smoke^[5].

The importance of quick reactions when facing smoke in a tunnel should be conveyed as part of driver education. Drivers must be aware of emergency exits, which should be clearly visible. Emergency shelters, supplied with fresh air, are of utmost importance in single tube tunnels. On the other hand, emergency exits to the surface in the form of escape tunnels or shafts, as required by European guidelines, must be questioned from a cost-benefit point of view.

Regarding tunnel fire ventilation, modern European tunnel ventilation systems focus on rapid incident detection and control of smoke spread by sophisticated feedback control systems. These are based on precise and reliable flow measurements and concentrated exhaust by controllable dampers in long tunnels with bidirectional traffic. Most importantly, the ventilation of emergency exits must prevent smoke entry through open doors. Those systems have proven their worth in many hot smoke tests and real fire incidents and achieve a high level of reliability.

In other parts of the world, ventilation requirements focus on the achievement of critical velocity to avoid backlayering - the state that causes most fatalities in tunnel fires, as in the 2001 Gotthard Road Tunnel fire. The determining effects of traffic movement and meteorological boundary conditions are often neglected, as are requirements regarding smoke-free emergency exits. Hot smoke tests under different boundary conditions to show the functionality of Fire Life Safety measures are rarely conducted. In summary, there is a lot still to be done, and industry professionals should be championing such efforts. 

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