CULTURAL DIFFERENCES IN ROAD TUNNEL FIRE SAFETY

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DOI 10.3217/978-3-99161-087-8-016 (CC BY-NC 4.0)

ABSTRACT

In these days of easy international travel, the world seems to be becoming more homogenous. You can get good sushi in Graz and Brisbane, good steak in Osaka and Graz, and schnitzel everywhere including Osaka and Brisbane. Why then are our approaches to tunnel fire safety so different? For real cultural experiences when you travel, forget the food – go and look at the tunnels. This paper notes differences in approaches to ventilation, fire suppression and tunnel operation and, within the limits of our knowledge, tries to rationalise them. Simply thinking about the differences may assist advancements in any of the jurisdictions, perhaps in a direction not identical to any of them.

Keywords: tunnel ventilation, fire suppression, tunnel operation.

1. INTRODUCTION

We are interested in why different jurisdictions have (sometimes quite different approaches to satisfying the same goal of building and operating tunnels with appropriate fire safety and fire resilience. These are our notes on differences in approach, including impressions on how the differences in approach came about. We emphasise that they are impressions. Reconstructing the background in an academically thorough way would be more involved than genealogical research.

We are not on a mission to prove a right way and a wrong way, as there are many solutions to such multifaceted problems, driven also by competing objectives with different weightings and informed by different knowledge bases. In some areas, there are ways we consider preferable, but we are aware that it is from our lens, with our understanding of the objective functions to be optimised. The important thing is to note the differences, and to think about whether the objective function that is applicable today might lead to a different answer from the one arrived at when the approach was first adopted.

Mathematicians like to optimise functions. Our view is that optimisation is generally easy if you can truly identify the objective, but that in the real world, objective functions are really really hard.

With that viewpoint as a basis, we look at the differences, focusing primarily on fixed fire suppression, ventilation, and operational management. We look at Japan, Australia and Europe as revealing interesting differences that may be usefully considered by others.

2. FIXED SUPPRESSION SYSTEMS

2.1. Europe

European tunnels eschewed fixed suppression systems until relatively recently, with PIARC taking a largely critical view in 1999 (for some plausible and some doubtful reasons), adopting a non-committal position in 2007, and offering cautiously favourable commentary in 2016. The European industry, driven by asset protection, has moved ahead in patches. Europe has a lot of older tunnels, and the lowest common denominator (least onerous on the budget) approach necessary in such an agglomeration of countries has likely contributed to the patchiness. On top of that, as the suppression in road tunnels is primarily an asset protection measure (once sufficient egress is provided), it is an economic decision rather than a public safety one.

There is also the issue of regulatory inertia. Whether or not suppression is beneficial to asset protection, business continuity or safety, where design requirements are set by regulation, those requirements will be followed. It is generally difficult to justify to financial oversight bodies any additional expenditure beyond the mandated standard. For example; German regulations, as at 2025, do not require suppression in road tunnels, and consequently such systems are typically not incorporated into German tunnel designs.

With mist being more effective than deluge (more on that later) and being far easier to retrofit to existing tunnels, their adoption has increased steadily. There are now 19 or more mist systems in European tunnels, both refits and new builds, after the first installation only in 2004. We understand that the road tubes of the Fehmarn Belt Tunnel will have a mist system.

2.2. Australia

Significant Australian road tunnels since Sydney Harbour Tunnel in 1992 almost all have 10 mm/minute deluge systems. Some bus tunnels have a lower application rate. One twin-tube road tunnel that missed out in 2000, the Heysen Tunnels in South Australia, was fitted with low pressure misting in 2024.

2.3. Japan

Japan also has a long history of road tunnel building and Japanese road tunnels have had deluge systems for so long that very few practitioners remember why they are sized the way they are (more on the design later). The answer is that the currently applied arrangement of deluge nozzles and piping is born from an extensive testing campaign in the 1960s. Although the reasons are not entirely clear to us, it seems that in the 1960s, and probably earlier, funding was available to support significant work on improving fire protection methods This led to extensive research on water spray systems, and helped establish the design principles that later shaped road tunnel fire suppression practice. The water application rate (around 7 mm/min), and the fundamental implementation techniques are generally understood to have changed little up to now (2026).

2.4. Business continuity considerations

On the benefits of suppression for business continuity, there may also be cultural differences in the acceptability of traffic disruption. As an example, on the 9th January 2026, a truck crashed and burnt entering the Brentenbergtunnel on the A10 in Austria. It was reopened with all lanes on the 17th January (8 days later) with some follow-on night works to be done. Regardless of whether the economic arguments about that period of closure and the structural damage caused due to the high heat exposure justify a suppression system, there are cultural matters around the inconvenience. It could be seen as acceptable to close a tunnel for a week or two due to fire perhaps every 5 or 10 years. Where, in some European jurisdictions, that closure outcome may be accepted as just what happens, being the consequence of an extraordinary event, Australians might say that the closure should definitely have been kept to an hour or two by the (simple) measure of a suppression system. Japanese people, also used to suppression systems, might also think so, but probably wouldn't comment out loud like the sometimes blunt Aussies. The Australian view also comes out of a culture in which fewer question the level of expenditure than perhaps is the case in Europe. That is the case for anything presented as a safety feature, even if primarily for asset protection, with spending money seen as a reasonably practicable thing to do. So, the level of adoption of tunnel suppression systems may have quite a bit to do with a cultural view of knowing what could happen and dealing with it if it does, versus preventing it happening with some up-front and on-going expenditure.

2.5. Acceptability inertia

There is also an effect of 'acceptability inertia'. It is clear that society, with increasing standards of living (mostly), of wealth, and of infrastructure over the last lifetime has also changed its appetite for risk in many areas. Europe has had significant tunnels for longer than living memory. The acceptability of risk (to life and business continuity) was arguably quite different when the European cultures (there are several) around tunnel safety were established. In the absence of realised risk, there is not sufficient incentive to revisit approaches, despite that society generally has been creeping toward a more conservative risk view over decades. In the case of Europe, the impetus to revisit matters and overcome the inertia was a series of major incidents (Mont Blanc 1999, Tauern, also 1999, Gotthard 2001). They led to European Directive 2004/54/EC on minimum safety requirements for tunnels in the Trans-European Road Network. It also led to changes in perceptions generally.

The same circumstances could occur in Japan, but perhaps because there were already suppression systems in many tunnels, they haven't, and so there has been no need to revisit acceptability in that context. Australia is comfortably smug that they do water-based suppression better than anyone. That (cultural) comfort and smugness, together with the typical tunnel procurement processes, gave the status quo enormous inertia in Australia, and kept misting systems from being seriously looked at for at least a decade.

2.6. Implementation

Japanese deluge systems have a single distribution pipe along only one wall of the tunnel, with 2- or 3-part nozzle assemblies to throw the water across two or three lanes. There is the possibility of a tall truck shielding a large zone of the tunnel, with the hope in that case being that the fine droplets do what fine droplets do, and blow from upstream in sufficient density to suppress the shielded fire. There are of course reasons for accepting what seems an odd compromise. Installation is much simpler and cheaper with a single wall-mounted line of nozzles, but it is in the testing that the arrangement has the most benefit. Tokyo roads are quite heavily trafficked at all hours, and alternative routes are not always just a minor inconvenience, so the preference to keep one lane open is very strong. That is similar in other urban areas in Japan. The standard approach for nozzle testing is to capture the nozzle flow in a hose and measure the flowrate. A number of trucks equipped with arms to do that are used, such that flow from each of the nozzles (spaced at 5 m) can be captured separately. With the nozzles from one zone only on one wall of the tunnel, and the testing trucks in place, the zone may be tested end-to-end without the risk of wetting the traffic that is continuing to drive in the far lane. So, the typical Japanese installation is driven directly not only by history, but also by lane closure policy and the need to test performance of the whole chain right to water delivery.

Australian tunnels generally have surface routes that are reasonable in quieter traffic times, and so tube closures are possible. Deluge systems are zoned arrays up to 30 m long, with the nozzles in a grid pattern directly above the traffic space. The nozzle pattern is not so different from a high hazard building, which is where the scheme came from. With sufficient closures to exercise all zones once per year, there is no need to avoid having water on the roadway. In fact it is useful, to rinse off the road surface after the wall-washing truck has been through and left suds around.

2.7. Corollaries of suppression policy

If you have a system for applying Niagara Falls to any incident in your tunnel within 30 seconds or less, you can be confident of the rarity of seeing high temperatures in the tunnel more than just immediately above the truck that is on fire. That means that you don’t try particularly hard to move services out of the way. In Australia, that is assisted by having no tunnels in areas with weather below 0ºC. Consequently, most Australian tunnels have local cabling exposed on tray above the traffic, and some have water main pipework exposed (obviously the suppression delivery pipework is exposed).

Provision of a fixed suppression system also means giving operators in-tunnel camera vision, controls, and training on when to operate the system.

2.8. Mist vs deluge

As Australia adopted of deluge for road tunnels in 1992, 5 years before the first ever road tunnel mist installation which was on the opposite side of the globe, deluge has become the default, and so ‘acceptability inertia’ meant that misting was not looked at too seriously. Contracting approaches, time pressures and frankly laziness contributed to that, and mist was often disparaged as a technique, probably that dealt with considerations without further ado.

Europeans had no such attachment to deluge, and so when mist came along, it had half a chance of being considered. That, plus the greater ease of installing the smaller valves and pipework in existing tunnels, has seen many tunnels adopt misting. Of course, the inertia in most of Europe makes having no suppression still quite likely, but where suppression is called for, it is more likely to be a mist system.

Japan has had deluge for so long, with good outcomes, that there has been little incentive to consider mist. There is some thought in Japan recently that maybe it is time to have another good look.

Besides the space saving, installation speed, and reduced water requirements, the comparable test data we have been able to find says that mist is better at both suppression and cooling than the larger droplet version of the same concept (deluge), so, as we see it, deluge systems will only be installed from now due to acceptability inertia.

3. VENTILATION CONTROL

In discussing ventilation control, we are not talking about model-based predictive control or inverter systems, we are talking about control policy. That is; what is the desired oncoming tunnel airspeed, possibly varying over time.

Australia has had a fairly simplistic approach mainly following the US (NFPA 502) policy of ensuring critical velocity to prevent backlayering. In US custom and practice, thinking about risk is essentially forbidden – you will do what 502 says. Following a critical velocity approach is made easier by the lack of significant bidirectional tunnels, and the generalization that even heavily congested traffic is above the smoke speed (~10 km/h). Ventilation responses can be invoked automatically as there is no harm in keeping the air moving in the traffic direction, but potentially significant harm if it is allowed to reverse. It is noted that over-ventilating a minor fire will assist de-stratification of a smoke layer, and will of course make matters worse if there are any people downwind. In tunnels with flatish grades, an early stage response with low airspeed can be considered until the downwind area is known to be clear of people.

Of course, there are also great benefits to a simple approach. Trying too hard to tailor the response to specific scenario details can produce very bad results if the scenario is slightly different to what is sensed or expected. We have seen, in Japan, automatic sensing of traffic congestion used to decide between ventilating with traffic or stopping all air movement. That is great in theory, but when the cars stopping behind the fire are interpreted by the sensors as congested traffic and the algorithm stops all tunnel airflow, the stopped traffic can become immersed in smoke.

Policies in Europe mostly have air speed targets that are lower than critical velocity as a default, with an option to increase if clear downwind. The numbers are generally hard-coded into standards rather than being calculated based on fire sizes etc.. The result is expected to be a good outcome for all possible incidents, rather than a perfect outcome for any exactly specified incident. In that way, the European approach embodies the robustness of simplicity, but with a different view on the simplified optimum to that prevailing in the US, and also largely Australia.

When there are no people downwind, most Japanese tunnels target a view of critical velocity, which it seems has never been harmonised with any of the versions in the west. In the period 2017 to 2025, that was probably very wise, with NFPA 502 being grossly misled over that period. Recent thoughts in Japan are toward target airspeeds below critical velocity, considering also the time taken for a fire and backlayer to grow to be threatening, and the speed with which evacuation is likely.

4. OPERATIONAL MANAGEMENT

Some European tunnels have only an alarm to the local fire service. Here we are interested in heavily trafficked tunnels, which are usually monitored 24/7 by staffed control rooms. There are many such control rooms in Europe, Australia and Japan. Control rooms operators have some level of induction, and on-the-job training with early supervision. Australia may be unique in having a training and accreditation, organised externally from the tunnel operation, which gives formal training and accreditation as a Road Tunnel Operator. There are seven required units of competency in the Road Tunnel Operator Skill Set. In addition to that, there is training specific to the control room and tunnels where they are employed.

So, throughout Australia, tunnel operators are trained in the procedures and the risks, and are expected to make judgements and implement an appropriate response (which may be a pre-programmed one). The situation in Japan is not uniform. Some tunnel owners also expect operators to respond appropriately to emergencies, while at least one owner believes that it is appropriate to allow pre-programmed responses to be implemented automatically in an emergency. We do not fully understand why operators are expected to take an active role in in managing traffic and dispatching road patrollers, etc., but are then required to adopt a hands-off approach when operational demands become more critical. The answer apparently lies in legal liability. They cannot make a mistake that they are liable for if they are not involved in the response. It would be interesting to understand if the system designer and the PLC programmer have the same appreciation of the approach reducing the operator's legal liability.

Providing operators with the knowledge to make judgement calls, and the training to implement resulting actions, is consistent with the view that a trained human will deal with complex decisions and actions better than an automated system. Certainly, in the sensed congestion in the Japanese tunnel noted earlier, a human operator would have realised that the only stopped vehicles (and tunnel occupants) were upwind of the fire (the video had been available from the start) and so the human judgement would not have permitted zero-flow control to be invoked.

Another example of automatic VS human response is in the Australian policy of having an 'unresponsive operator' timer on deluge activation. The idea is that if an operator makes no response to fire within 90 to 180 seconds, it should be discharged where the heat detector detected the fire's location. We have never seen an instance in which that was a useful fallback, with the operator always responding to multiple notifications (traffic, stopped vehicle, perhaps smoke and pedestrians) and taking command of the systems before the heat detection timer expires, and generally before the linear heat detector even alarms. However, automatic activation, even with a delay, can be problematic. There have been false activations of deluge in several tunnels also on live traffic. It can be because there was maintenance being done on the system by technicians, so the operator ignored the warning, or because there was a secondary back-door signal transmission in the system that couldn't be seen by the operator. Whatever the underlying reason was, there is always a chance of accidental operation in complex systems, and the system complexity conspired to dump deluge on live traffic. Without automatic activation being programmed in, that would not have happened. You cannot see out of your windscreen under 10 mm/min deluge. And to be surprised like that when driving in a tunnel at 80 km/h is not safe. Fortunately, no harm came from those incidents, but they were arguably more dangerous than a car burning unsuppressed in previously free-flowing traffic. Consequently, we do not include automatic deluge, or mist, release in designs.

5. SUMMARY AND CONCLUSION

You may never understand the culture of a country unless you were born there. Even then, there will be pockets you don't know about. You would think it would be easier to understand a country's tunnel fire safety culture, but the decisions hidden by the mists of time, and the sometimes random walk of systems development in a particular jurisdiction make logical explanations of why things are done as they are very difficult. Japan, Europe, and Australia have distinct differences in approach to a very similar fundamental problem, which is keeping people and the asset safe from fire.

This is in no way the end of a journey to explore and understand the differences. We hope to learn more over the next years. It is hoped that our thoughts so far might prompt new thoughts from practitioners in any jurisdiction. If so, we would love to hear them.