TUNNEL SAFETY – MORE THAN THE SUM OF THE INDIVIDUAL PIECES OF SAFETY EQUIPMENT

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ABSTRACT
Tunnel safety is more than the sum of the individual safety systems or components of the tunnel design. Inherent safety is the highest priority while the system response in the event of an emergency must be timely and accurate. The incorporation of new technologies without sufficient regard to their impact on timely and accurate safety system response undermines tunnel safety despite providing a superficially attractive list of tunnel safety features.

Keywords: safety, tunnels, systems, life cycle cost

1. INTRODUCTION
Safety theory clearly states that the safety of any infrastructure tunnels or otherwise, is a function of the built structures, the behaviour and equipment of the users and the effectiveness of the control systems.

The highest level of safety is of course achieved when there is no adverse event and the infrastructure is safe by design. But in a tunnel the confined environment coupled with limited alternative access following an emergency makes an effective response essential for achieving an appropriate level of safety.

The raft of equipment available to tunnel designers and operators claiming they make tunnels safe is broad and rapidly growing. With the expediential growth in new tunnel projects globally and the vast number of aging existing tunnels the challenges for tunnel safety engineers have never been greater and the opportunities for significant safety improvement more pronounced.

Tunnel safety is a function of sound engineering, systems analysis and integration. Tunnel safety is much more than the sum of the individual safety equipment used.

2. THE FIRE
There is always a great deal of expert speculation about fire growth, smoke generation and heat release rates when considering the functional performance of the tunnel. It is important to recognise that such scenarios are used as a tool to design the safety systems and that they may be applied to other scenarios requiring active ventilation to enhance tenability such as intentional security breaches and other undesirable events.

The most informative review of fire growth tests was performed by Ingason (2004) as part of the Swedish Road Administration review of the use of sprinkler systems.
The review by Ingason of fire growth rate data (Figure 1) dramatically illustrates the practical importance of effectively responding within the first 5 minutes or so of an incident. Experience from catastrophic fires coupled with the experience from countries using fire suppression systems suggests that the opportunity to effectively control the growth of fires and the consequent dramatic increase in the volume of smoke is limited to the first few minutes after an incident.

No matter what systems are installed unless they are effectively operated during this short time window the prospects for safe evacuation and even asset protection will be severely compromised. Speed and accuracy of event detection and location are essential for tunnel safety.

**Figure 1:** Summary of test data on fire growth rates (note importance at first 5 minutes).

### 3. DEVICES

Devices which are claimed to positively affect safety almost always focus upon one particular aspect of the risks to users of tunnels. A selection of safety equipment follows with brief examples of this point.

<table>
<thead>
<tr>
<th>Device</th>
<th>Risk mitigated</th>
<th>Results from real emergencies</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency telephone</td>
<td>Inability for tunnel user to talk directly with tunnel controller.</td>
<td>Usually not used</td>
<td>If used they would help confirm incident location and provide a method to talk directly with tunnel control. In an emergency they are usually overlooked and the tunnel controller so busy that dealing with such phone calls would most likely be problematic.</td>
</tr>
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<tr>
<td>Linear heat detectors</td>
<td>Rapid and exact location of fire</td>
<td>Slow to operate</td>
<td>Difficult to tune for both road and rail tunnels. Once activated often signal a cascade of alarms. Often too slow and too inaccurate for rapid emergency ventilation response.</td>
</tr>
<tr>
<td>Closed Circuit Television (CCTV)</td>
<td>Operator cannot see in tunnel.</td>
<td>Unless coupled to other alarm systems they are mind numbingly boring to monitor and prone to loss of vision downstream of an incident.</td>
<td>To be useful spacing should be close, yet close spacing creates a high number of images which need to be monitored. Without computer aided analysis such images become little more than visual noise in a control room as image after image cycles through the operators display. They are useful for traffic flow management.</td>
</tr>
<tr>
<td>Fixed suppression systems</td>
<td>Rapid fire growth rate and smoke release rate.</td>
<td>Rapid and accurate activation is essential if they are to be effective. Failure to maintain or lack of familiarity with their operation will compromise their effectiveness. When properly integrated, maintained and operated perform well. Delay or inappropriate application may compromise safety.</td>
<td>Extensively used in Japan and Australia to good effect. Currently installed in A86 Paris Ring Road, Madrid Calle 30, Madrid Metro but limited operational experience to date. Wrongly often described as making a tunnel safe without reference to the importance of integration in the operational safety systems.</td>
</tr>
<tr>
<td>Smoke extraction</td>
<td>Confined environment highly toxic to users.</td>
<td>When rapidly activated at the correct location can provide or maintain a tenable environment for a longer period over a greater portion of the tunnel.</td>
<td>Widely heralded as providing new levels of safety in tunnels but is subject to similar limitations to other complex engineered systems in that it must be rapidly activated at the correct location and integrated in the overall emergency ventilation response to provide the safety outcome sought.</td>
</tr>
<tr>
<td>Emergency escape routes</td>
<td>Users trapped in untenable environment.</td>
<td>Users choose not to avail themselves of these safe places. Despite their attractive engineering performance many people observed to remain either in their car or within the tunnel in preference to using these places.</td>
<td>Despite the improvements in the identification and ‘attractiveness’ of cross passages and other escape pathways, people still choose to stay in the areas they are familiar such as their vehicle or the tunnel.</td>
</tr>
</tbody>
</table>
The six features chosen above are selected to be illustrative of the fact that just because systems are installed in a tunnel it does not follow that the tunnel is safer than if they were not.

A fire suppression system which solely relied upon linear detection systems to positively locate an event will be slow and potentially inaccurate. An emergency ventilation extraction system which relied upon such heat detection systems would likewise suffer similar limitations.

4. **SPEED OF RESPONSE**

To respond rapidly demands timely incident detection coupled with accurate incident location and precise system activation.

This performance requirement is more than a simple engineering matter. It involves complex interactions between a range of technologies and most often the input of the tunnel operators.

The greater number of safety devices the higher the integration burden for a systematic response.

The demands upon the SCADA system and the associated computer systems to execute such a task in a timely manner must not be underestimated. This situation may be compounded if a series of minor incidents requiring more routine responses occurs prior to the major incident.

The magnitude of the task of controlling these many safety elements is depicted in the following photograph. Each line represents a command to a device, the many pages being generated over a period of single digit minutes. The computers unexpectedly burdened by the task. This can (and has) severely impacted the timeliness of emergency responses.

![Figure 2:](image)

**Figure 2:**
Printed computer logs from a computer responsible for some electromechanical systems during the tunnel incident. Each new piece of equipment adds an incremental burden on the control systems ability to rapidly control critical equipment. These commands are dealt with sequentially. The computer does not recognise priority tasks.

4.1. **The Operators**

The more equipment that requires monitoring, interpretation or control - the greater the potential burden on the operator. While the importance of the human machine interface is often discussed in reality – during an emergency – the operators’ task is complex and the time frames for decisions unrealistic. In this way the addition of equipment in the name of safety can compromise the effectiveness of the response through delay and potential operator error.
5. THE PHYSICAL REALITY

An analysis of any tunnel usually includes a checklist of its physical features. As with equipment, the underlying rationale is that the more features the safer the tunnel will be.

The effective integration of different physical features is critical to their performance in an emergency. The following two photographs are taken in two ‘new’ tunnels. One is a European Union country and the other is in Japan. Both have emergency egress to cross passages and escape-ways to the surface. Both use similar evacuation time criteria. Both use transverse ventilation and smoke extraction. Both offer protection for critical electro-mechanical control circuitry. Both abide by local regulations on signage and other emergency evacuation criteria. However as is evident from the photographs the Japanese example is more likely to perform because of the reality of the finished product.

Figure 3: Depicts two functionally different emergency egress pathways.

The above photographs show two functionally very different approaches to emergency egress. Both taken in February/March 2008 – they show two different ‘realities’ for emergency evacuees. In Japan stairway lengths are limited to only 10 flights in deep tunnels, and great attention is paid to the resultant functionality. In the EU example high voltage cables share the escape path in a poorly constructed egress passage.

These photographs highlight the importance of not only incorporating safety features in a design but ensuring that they are truly integrated to provide the functional response. The European tunnel photographed above has many more safety features than its Japanese cousin however it is likely that the Japanese tunnel will perform better in an emergency.

On this basis more safety features does not mean a tunnel is safer.

6. SAFETY TRADING

One justification for including more safety ‘devices’ is that other expensive aspects of the civil works can be made more cheaply. For example the use of a fire suppression system may be justified due to less expenditure on fire protecting aspects of the infrastructure. Although such a process can be valid it is essential that it be coupled with a thorough engineering analysis and not merely be used as a polite cost saving exercise.

Integration of safety systems – and recognition of the importance of ongoing upgrading, training and maintenance must be factored into the costs associated with their adoption. Life cycle analysis is demanded.
7. CONCLUSION

The safety of the tunnel is not the sum of its individual safety components or features. A well managed, maintained and controlled tunnel will easily provide superior safety to a modern tunnel equipped with a vast array of safety equipment and features which are poorly understood, barely commissioned and effectively uncontrollable.

A systems approach to delivering safety with a life cycle perspective is essential when safety is the ongoing objective over the life cycle of the infrastructure.

Tunnel safety is not academic and cannot be measured like the amenity of a new car by referencing the number of accessories as a barometer of its safety performance.

8. REFERENCES

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