# REFURBISHMENT, RISK AND RESPONSIBILITY – DECISIONS WHEN UPGRADING TUNNEL FIRE PROVISIONS

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## ABSTRACT

This is a paper as much about the governance and contractual management approach to refurbishing tunnels as it is about the treatment of risk.

In new road, rail or bus tunnels in Australasia, a variety of factors has caused a ratcheting-up of fire safety provisions, often leading to every conceivable measure being included at the project conception stage and not critically questioned at later stages. The 'FEB Process' is then often a charade in which we (the project) pretend, via the "process", that we don't know by inspection that the tunnel is safe enough and we (fire engineers) spend a lot of time on sometimes questionable analysis to 'test the trial design' before concluding it is OK.

If there is wasted expenditure in any over-provisioning, it is hidden by the massive civil costs of tunnelling. In a refurbishment, the mechanical and electrical plant is closer to 100% of the project cost, and so there is more focus on justifying the fire safety design and its cost. There is also generally a contractual framework which facilitates such questioning. Consequently, the decisions for tunnel refurbishment projects can be very different, particular in tunnels which have a very high access cost because they are already in heavy use.

We also know that, for most modern tunnels, the absolute risk cannot justify half the gear we put into them, yet the community has a heightened perception of the risk and an understandable aversion to major incidents or entrapment, however low the probability. Those responsible for the judgments on risk and expenditure have a difficult task. This paper discusses the flaws inherent in the common fire engineering approaches to tunnel fire safety and seeks to offer a new simpler perspective for the governance and project decision making around the provisions to be included in a refurbishment design. The thoughts offered may be useful in getting to the right answer for project teams, giving context for a clear justifiable decision basis in the project's format.

*Keywords: tunnel refurbishment, decision, fire, safety, risk*

## 1. THE CONTEXT

There are a number of points to be made about the risk from fire in road tunnels which set the context for the fire safety design.

### 1.1. Very low relative risk

The first point is that the fire risk to occupants in modern unidirectional road tunnels is in fact very low. A study for the 4.7 km Clem Jones Tunnel in Brisbane indicated a risk due to fire which is at least three orders of magnitude lower than the risk from all causes on open roads. (It is noted that the Clem Jones Tunnel has a smoke duct which most Australasian tunnels don't have). There will be other differences between the Clem Jones Tunnel and any other project, however the order of magnitude estimate is considered relevant. Similar results have been seen for other tunnels.

### 1.2. Economic rationalist approach

At such risk levels, and with competing demands for funds to reduce risk or provide benefit elsewhere, it is not justifiable to spend noticeable sums to further reduce the risk. Indeed, at that level of risk, on an 'economic rationalist' value for money basis, the reduction of risk has probably absorbed too much investment already. Government (or private) funds would better be spent on 'black spot' road programs, hospitals or perhaps more tunnels.

### 1.3. Community perception of risk

Counter to the economic rationalist approach, the community generally, the media, and political leaders have a heightened sensitivity to fire incidents in tunnels. The community is generally more sensitive to risks in tunnels than say open roads. We saw an example of this heightened sensitivity after the 2007 Burnley Tunnel incident. In that incident, three people died and Melbourne had extraordinary congestion during the three days for which the tunnel was closed. The loss of three lives is tragic, but, seen in the context of the 333 road deaths that year in Victoria, and 1616 road deaths for 2007 Australia-wide, it is peripheral to the overall road safety statistics. And yet, the incident was the subject of a coronial inquest lasting many years.

Other parts of community expectation include the attitudes to catastrophic events and the need to facilitate response. The community generally expects strong measures to be taken to avoid catastrophic events, regardless of how unlikely they may be. That is; the focus is more on consequences than on risk (which is the product of consequences and probability). Measures directed at avoiding catastrophes, and which have a community cost out of proportion with the risk reduction, may well still receive community support. That is; a rapidly growing fire event in a tunnel full of stopped traffic, which might have more severe outcomes than the 38 fatalities in the Mont Blanc fire, should perhaps be 'prevented' at any cost.

The prospect of an event proceeding with no ability for emergency services to effectively intervene is also seen as unacceptable, again without particular reference to likelihood or real risk. The community expect that, if people or critical assets are threatened, the intervention of the fire brigades to effect rescue or preserve the tunnel will be facilitated in reasonable ways. The prospect of being helpless in a developing emergency may be more frightening than the final consequences and evokes an emotional response which supports enhanced provisions being made, again with diminished regard to the probability of the situation.

There is also the question of informed risk acceptance. Risk acceptability varies with the level of prior knowledge about the risk, and with the person's own level of control of the risk. On the open road, there are considerable risks. Some are 'random' and some are related to the skill of the driver. All of them are well known to all in the community. When driving out onto the road, we do so in full knowledge of the risks, both those in our control and those visited upon us. If there were additional risks unknown to us, but known to an authority or designer, we might reasonably expect those risks to be controlled to a level below the risks we had knowingly accepted. It could be argued that fire risk in tunnels is a risk that the community is aware of; however it still seems reasonable that the risk level be brought below that on roads generally.

That the individual's control of risk factors, knowledge of the risks and acceptance of the risks has an impact on acceptability can be demonstrated by a comparison at Mont Blanc. In 1999, 38 people died in a fire in the Mont Blanc road tunnel. It made world news for weeks. In 2008 on Mont Blanc, there were 58 deaths, with 10 missing presumed dead. The difference was that the 2008 deaths were all people who thought they knew of the risks, that they were in control of them, and had accepted them. They were climbing the mountain. The people who died in the road tunnel perhaps did not make such a conscious decision to accept a risk.

If we are to design tunnels in response to community perceptions and not as economic rationalists, and the Burnley and Mont Blanc responses are indicative of community perceptions, then a risk from tunnel fire three orders of magnitude lower than other driving risks might not be inappropriate.

There are also reputational, operational and service continuity risks which may change the perception of value and hence alter the above conclusion. Whatever risk is considered, it is recognised that reduction of risk comes at a cost and that the community acceptability of risk must ultimately be related to the costs, either financial or otherwise, of further reducing risk.

## 1.4. Fire Engineering prior practice

In Australasia, the assessment of tunnel fire safety had fallen into a fairly narrow approach, driven by building code “performance-based design” practitioners. Analysis is often done in a deterministic way to show that the ‘available safe egress time’ (ASET) exceeds the ‘required safe egress time’ (RSET) by some margin, for a range of ‘worst credible’ parameters. However, the nature of tunnel fire risk, in that very rare but very severe scenarios contribute the majority of the remnant risk, leads to problems in 'proving' tunnel safety by applying such deterministic approaches which are commonly applied in less complex situations. Comparing RSET against ASET falls down for a couple of reasons. The first is in selecting the "design fire".

The huge range in possible fire sizes and growth rates in road tunnels means that it is possible to argue for adoption of design fires which either don't threaten anyone, or which will almost certainly cause fatalities when applied in parallel with conservative egress models. Selecting a design fire which makes the method work for tunnel configurations believed to be "safe" is then only making the method suit the answer and not really proving an answer.

The second way in which the ASET vs. RSET approach falls down is in the statistical nature of the input parameters. If there are only two or three parameters (time to respond, walking speed etc) in a simple case, then taking conservative or limiting values for each gives a highly unlikely scenario. If there are a dozen or so parameters, the chance that all of them will be at their worst value is so low that an already very rare major fire case will be taken to extremes of probability where a much lower level of overall system performance is acceptable.

That is; combinations of Normally distributed parameters taken at their 3σ value do not give a scenario which is at the 3σ value in overall severity. In fact the case is so improbable that it should not be considered as a design case for pass/fail judgement of the systems. It does not take all parameters to be at their extreme values to make an already improbable situation extreme. Choosing more central estimates is also not particularly informative as, for example, the 50 percentile fire might be around 1 MW and not a threat to anyone. Such analysis may be carried out in order to understand likely response limits and inform response planning, however it is not appropriate that it form the central part of the design acceptance criteria.

The ways to handle such variability in parameters are via an event tree style assessment, or better still, through Monte Carlo simulation. In the author’s experience, the answers, for all modern, reasonably well-equipped tunnels, will show that risk is so low that no further expenditure should be considered. That is where the discussion in this context section started.

## 1.5. ‘Ratchetting-up’ of safety measures

As it seems that the economic rationalist optimum expenditure on risk cannot, on its own, guide the design, we are left to work with the less defined 'community expectation'. However, there is a danger that in relying only on community expectation, provisions and costs increase with each project, without proper assessment of need or value. Whether or not the measures implemented on earlier projects were justified at the time, their very existence creates a community expectation that they are more than justified, and are in fact the minimum essential measures for a new project.

Community expectation can also have a politico-legal amplification. It is often politically difficult to say that a new project does not need as many risk reducing measures as an earlier project. In the continuous spectrum of community attitude to risk, there will always be some who are close to the high expenditure end, calling for every conceivable measure to be in place. There are many issues to be addressed politically for a new tunnel project. If the extra fire safety provisions only add a few percent to the cost of a new tunnel, it is easy politically to put them all in, effectively removing risk from the project debate. While the few percent cost change is swamped by other issues in the public eye, it could still be tens of millions or even a hundred million dollars on a major project.

The legal amplification comes about from the fear of a claim. In adding a design feature, an employee or a consultant will be aware that they are spending the owner's money. They will also be aware that, should there be an incident with the feature in place, they cannot be criticised (or sued) for leaving the feature out. There might be considerable work involved in documenting and arguing the case that the feature has minimal benefit and is not justified. Going down that path may cause them to run over the design budget, which causes immediate pain. It is not common for employees, consultants or contractors to be given grief for going too far (spending too much client money) on public safety. The path of least resistance is then to put the particular feature in and complete the documentation quickly.

The contracting framework often contributes to a monotonic increase in provisions and cost with each new project. At project inception, an owner’s consultant can prepare conservative documentation, leaving the ‘optimisation’ to bidding Design & Construct teams. Those D&C teams then have short tender periods, difficult change approval processes, and client perceptions to manage, so are very unlikely to ‘optimise’ far from the established path. The last contracting issue is drawn in by contractual phrases such as: “to the satisfaction of the fire brigade”. The fire brigade will be equally nervous about criticism for leaving a feature out, they have no responsibility for expenditure by any other party, and, even if they were responsible for cost-risk trade-off, not all fire brigades have the expertise to make the risk judgements which we are grappling with here. Without the benefit of constraining guidance from the government parties, such contract clauses push the design in only one direction; decreasing an already low risk, and increasing cost.

The alliance project delivery method, properly run, can assist in promoting rational and holistic decision making and the author has seen good examples.

### 1.6. Brownfield sites

Refurbishments are generally severely constrained in the changes that can be made. Engaging in any civil or structural work would typically increase the project cost several-fold, and so typically the tunnel internal cross section is fixed and any new drainage, equipment or egress provision must fit within the available envelope. Even where the envelope is altered, there will be geometric and logistical constraints which would not be present were the refurbished tunnel being designed from scratch as a new tunnel.

The refurbishment of an operating tunnel is also more expensive than a new build as the work must be done with the traffic operation in mind. If that does not restrict the work to shifts late at night and over weekends, then there may also be an economic cost attached to the tunnel unavailability.

These factors increase costs and change the cost-benefit in favour of doing less work, and making fewer provisions. Whereas the civil costs may mask the fire safety costs in a new build, in a refurbishment, the fire safety costs are clear. For these reasons, in refurbishments, there tends to be a sharper focus on what level of provisions are really required.

### 1.7. Traffic operations

Significant tunnels in Australasia are generally monitored and controlled 24 hours a day. The diligent operation and supervision of tunnels, particularly the traffic control and incident response, is probably the most significant feature in ensuring the safety of tunnel users in a fire incident. Besides ensuring that incidents are noticed and responded to intelligently, traffic control can almost completely eliminate stopped traffic in unidirectional tunnels, taking the probability of people being downstream of a fire to almost zero. A key element of refurbishments is often modernising the communications, supervision and control systems, perhaps involving a control room for the first time in the tunnel's operation. Thus the planning for the refurbishment and the overall safety case needs to be operator focussed.

### 1.8. Safety in Design

Addressing fire safety in tunnels often results in more equipment being installed. That introduces additional risks for workers during construction and also through maintenance. Such risks need to be weighed up against fire risk reduction. For example; are the construction safety risks from smoke duct construction actually greater than the corresponding reduction in fire safety risk?

### 1.9. Context Summary

The absolute risk, given by a quantitative risk analysis, of tunnels resulting from conventional design practice is generally so low that it cannot guide the design decisions.

Prior project provisions are not sufficient justification for any design approach, as the reference project(s) may have been over-provisioned and may have a different cost structure and opportunities. However prior projects may give useful reference points.

Community expectation is a complex thing, and one which most of the project participants are not equipped to, or empowered to, make judgements on. (Note though that it is our profession's responsibility to advise the project leaders of our view on such matters.)

Tunnel fire risk can be very strongly influenced by traffic management and there will be a strong interface between the developing fire safety design and the separately detailed traffic management and incident response plans.

## 2. THE PROBLEM

The problem is how to decide what goes into the refurbished tunnel. How safe does it need to be? How do we justify costs? Or alternatively, how do we justify omitting features to give a lower expenditure? In the absence of a unified field theory type of resolution to tunnel fire safety, how do we organise the governance framework and technical assessment to arrive at an answer, particularly for the less clear-cut case of refurbishment?

## 3. THE ANSWER

The following approaches have worked for the author on tunnel refurbishment projects.

### 3.1. Risk - keeping it simple

In explaining the approach within projects, I have sometimes found it helpful to borrow and adapt the 'fire triangle', which has been used in public education to explain fire risk minimisation through noting that fires must have three components; air (oxygen), fuel, and heat and that loss of any one will eliminate the fire. In tunnels, given a fire occurrence, life safety risk is created by having people on both sides of the fire (bidirectional or stopped traffic), having smoke descend to roadway level, and having no apparent escape. Thus the three sides of the tunnel smoke risk triangle are traffic state, smoke logging and entrapment. Eliminating any one of these nominally gives zero risk to all occupants not intimately involved with the fire. Eliminating two triangle sides is clearly a preferable approach, giving some redundancy to cover for any failure to successfully or completely eliminate one or the other. By seeking to eliminate all three with sufficient vigour to ensure a reasonable probability of success at each, the risk from an already rare event (major fire) falls to levels that comfortably meet community expectations and are orders of magnitude lower than our benchmark open road risk.

### 3.2. Responsibility

From the above, the first part of the answer is that the project must make reasonable efforts to:

- prevent stopped traffic (by design and by operational management);
- appropriately manage and, if possible, remove or blow away smoke, and;
- provide opportunity through egress paths, lighting and signage for people to rescue themselves.

What constitutes 'reasonable efforts' will be addressed later. Outside the efforts to dismantle the triangle of smoke risk, there are two other design responsibilities related to community expectations. The project must also make reasonable efforts to:

- facilitate the intervention of emergency services (firemen), and;
- protect the structure and fittings to provide for rapid resumption of traffic operations after the fire.

These last two points are the real drivers for installing fire suppression in tunnels. Water-based suppression may have life safety benefits when the smoke risk triangle remains intact (traffic on both sides, no smoke control and no egress) and also for any people trapped in the incident vehicle(s). If there has been any success in dismantling the smoke risk triangle, the benefits of water-based suppression are no longer related significantly to life safety.

### 3.3. Refurbishment

The brownfield nature and the geometric constraints of refurbishment sites may prevent the effective achievement of some of the above five points in Section 3.2. Here 'prevent' means that the cost is such that the funds are not realistically going to be made available. This places more emphasis on addressing the other points well.

For most tunnels, there will be a number of refurbishment options, consisting of combinations of different approaches to addressing the five points to various extents. The exception is bidirectional single-tube tunnels over say 300 m long. Of course older tunnels needing refurbishment are more likely to be in this class. In such tunnels, the traffic case cannot be effectively addressed, with vehicles almost guaranteed to be on both sides of the fire for any significant traffic flows. If the smoke control can only be longitudinal, and there is also no cross section available to build a separate egress passage, the smoke risk triangle is intact. This situation then requires emphasis both on the reliable operation of equipment to suppress the fire, and on the systems to monitor the tunnel and facilitate rapid evacuation of motorists out to the portals. The author is involved in the refurbishment of two tunnels with these characteristics; one a 460 m long tunnel with large, high cross section, and one a 610 m long tunnel with a smaller cross section. It is the author's opinion that the 460 m long tunnel is about at the length limit where suppression, egress planning and vigilance can be seen as sufficient compensation to allow long term operation. For the more restricted 610 m tunnel, those measures are seen as only interim, with either effective smoke capture or additional egress, or both, to be planned as part of a subsequent upgrade. Additional egress provisions would necessarily involve mining works.

### 3.4. Design and decision methodology

Experience in cost-constrained tunnel refurbishments has given rise to a detailed decision approach, with a number of elements that can be included to varying extents depending on the owner's needs. As they will vary for each project, and this paper is specifically about the discharge of responsibility in managing risk, it is sufficient here to note steps in an overview form, with some elaboration on key risk-related steps.

1. Natural opportunities

   The very first step is to creatively explore opportunities and possible synergies that may allow the five critical points to be addressed economically. For example;
   - Is the duplication likely to be in time to provide better egress? or;
   - Can the local swimming pool be the suppression reservoir (the level might only drop seriously every hundred years or so)?, or;
   - What can the existing water system deliver and is that useful?

   This is a creative activity, requiring that all contributing disciplines have not only good senior level insight (as opposed to journeyman capability) but also enthusiasm for jointly seeking good ideas.

   Since the blank sheet of a new design is not available, and we know that the absolute risk justifies almost nothing, we must look hard for natural opportunities for addressing the key five points.

2. Chase down and verify inputs and requirements

   It is surprising how often the assumed immutable client or third party requirements morph or dissolve when the ultimate authority is checked in the context of the likely consequences of the stated requirement. This step is often missed.

3. Identify scheme options

   There may be combinations offering different strengths, for example excellent egress and nominal smoke control, or full smoke extraction and lower standard egress.

4. Eliminate schemes not seen as making reasonable effort on the five points

   Here the test of reasonableness comes up again. The only real arbiter of this is the government as representatives of the community. Generally this responsibility will be borne by executive staff of a government agency charged with delivering the project. The project fire engineers can advise and argue the case, but final decisions can only be made by the government officers who act for the community both in accepting outcomes and in laying down cash.

   The biggest mistake is in confusing the responsibility and authority of the project's government 'owner' with the comments and input from other third parties, and assigning each similar weight. There is a trend in Australia, supported by a document interestingly called "International Fire Engineering Guidelines", to append: "...as agreed by stakeholders" to decision approaches. With the exception of some legislative fire service responsibilities (or Authority Having Jurisdiction in the USA), this is of course a nonsense, as all other third parties need only be accommodated to the satisfaction of the sponsoring government agency. Generally these other parties ('stakeholders') will be new to tunnels and should comment and question, but will not understand the issues in sufficient depth to make determinations. They certainly are not in a position to assess cost-risk trade-offs.

   Occasionally, if third parties seek to exert influence beyond their authority or expertise, the sponsoring agency might need to bring the decision process back on track, and the project should not be backward in requesting such involvement.

   The judgement of reasonableness of the response to the five points can now be clarified. With the decision authority structure clearly understood, the sponsoring agency receives advice on which refurbishment options are reasonable in terms of the effort made against the five key points. The agency then makes a determination after asking whatever questions and making any other enquiries they see fit. Options where the effort is not reasonable are eliminated from consideration. It can be that straightforward.

5. Compare and score options.

   One option may have a slightly different risk profile to another, and that could be bundled-in and assessed, scored and weighted as part of the options comparison. However, if the risk difference is such that it has a materially different monetary value, then the risk is really too high and would not meet community expectations. The higher risk option should be discarded. The project team is then left only with options which have acceptable (and quite low) fire safety risk. The options assessment can proceed without risk as a parameter.

### 3.5. Governance

Sensible decisions require good project governance. Some well intentioned projects lose direction through having 'mediocrats' in the leadership structure. Mediocrats are those who preside over a mediocracy and for whom any decision is OK as long as there is one and the timesheets are in order. Matters of technical principle are then negotiable and may be buried for political purposes. Obviously, the outputs of a mediocracy are mediocre.

## 4. SUMMARY

Based on the arguments above, it is the author's contention that:

Quantitative Risk Analysis (QRA) will not get to the answer on how a refurbishment should provision a tunnel. While time consuming and hence lucrative for an hourly rates consultant, the fact that it gives such low risk outcomes and points to a level of provisions much lower than the owners and regulators would accept means that it is excluded from meaningful contribution. Further, as QRA will necessarily be accurate to an order of magnitude at best, it is difficult to realistically compare options which involve different types of risk calculation inputs.

Asking third parties, including fire brigades, what level of risk they would accept (eg: expected fire fatalities for the 100 year life) is not productive. Despite most fire service legislation giving some role to advise on fire risk reduction, fire brigades are not generally equipped to nominate such a figure, despite their government's treasury departments generally maintaining figures with names such as 'the economic value of avoiding a fatality' (not 'value of life'). Only the sponsoring government agency can decide that. Given the point above, the decision will be made on assessed "reasonableness" and not on an absolute risk figure.

Responsibility can be discharged by making reasonable efforts to:

- prevent stopped traffic (by design and by operational management);
- appropriately manage and, if possible, remove or blow away smoke;
- provide opportunity through egress paths, lighting and signage for people to rescue themselves;
- facilitate the intervention of emergency services (firemen), and;
- protect the structure and fittings to provide for rapid resumption of traffic operations after the fire.

While the project must offer advice, the decision as to whether efforts to address fire safety are 'reasonable' can only be made on behalf of the community by the government agency sponsoring the project, as only they answer to the community for both safety and cost.