Crossing points

Eva Chan and **Fathi Tarada** describe the risk assessment for the new Tyne road tunnel, set to be the first in the UK with a fixed fire suppression system

IN OCTOBER 2008, the New Tyne Crossing project established permanent works for the construction of a second vehicle tunnel under the River Tyne in Newcastle, which is due for completion in December 2010. Once the new tunnel is in service, the project will refurbish the existing tunnel, which is now more than 40 years old. By early 2012, both tunnels are due to open to traffic and serve as a uni-directional flow tunnel.

To advise on tunnel safety issues, the Tyne and Wear Passenger Transport Authority formed a Tunnel Design and Safety Group (also see *Fire Risk Management,* April 2008, p.51). In addition to looking at a wide range of active and passive fire protection systems for the road tunnels, the group considered whether a fixed fire suppression system should be installed, and its members held diverse views on the subject. The current fire safety guidelines and standards in the UK have not recommended the installation of fixed fire suppression systems in tunnels, and no such system has been installed in any UK tunnel to date.

The authors were therefore appointed as independent experts by the group, to advise on whether such a system should be recommended. Based on the results of a quantitative risk assessment and a cost-benefit analysis, the decision was taken to go ahead. The New Tyne Crossing will be the first road tunnel in the UK to incorporate a fixed fire suppression system.

Assessment approach

The World Road Association (Permanent International Association of Road Congresses) recommends that where a fire suppression system is under consideration for installation in a road tunnel, the following should be undertaken:

- a feasibility study
- a risk analysis, as outlined in European Directive 2004/54/EC: *Minimum Safety Requirements for Tunnels in the Trans-European Network*
- a cost-benefit analysis

A quantitative risk assessment was developed to determine the likelihood and consequences of fire incidents of differing severity occurring in the tunnels. Subsequently, a cost-benefit analysis was conducted for the provision of a fixed fire suppression system, which took into account the cost of installation, maintenance and repair costs, and also the likely financial benefits measured in terms of potential lives saved, savings in tunnel repair costs and traffic delay costs.

Cost-benefit method

This article focuses on the cost-benefit analysis. In order to estimate the frequency of fire events, historical data was obtained from the existing Tyne tunnel and from other tunnels worldwide. Consequences were then assigned to events, and monetary values assigned to reflect the direct costs of a potential fire incident, the associated cost of any casualties, and the cost of traffic delays and tunnel repairs.

The quantitative cost-benefit analysis calculates the net benefit (expected net value) of a fixed fire suppression system based on a comparison of benefits and costs over an assessment period of 60 years. This assessment period is a compromise between the design life of the tunnel structure (120 years) and the typical life of a fire suppression system (15 to 20 years). Benefits are based on an assessed reduction in the frequency and associated impact of tunnel fire incidents, and these are reported over the assessment period.

Because of the variability in input data to the model, it is not appropriate to report the net benefit as a single figure, and a sensitivity analysis was used to aid decision-making by presenting benefits using a probabilistic approach.

Theoretical model

The parametric sensitivity test is an integral part of the risk assessment model and is carried out using a Monte Carlo simulation to model the likelihood of different fire events. This simulation generates a set of input parameters for the model from a specified range of possible parameters.

The New Tyne Crossing will provide a second vehicle tunnel under the River Tyne in Newcastle, northeast England

A baseline model is then set up and used to calculate the costs associated with different levels of fire event as a reference point against which to compare the proposed fire suppression system. The benefits of the suppression system are considered to be a combination of the reduction in personal injuries and fatalities, the delay to road users, and the damage to the tunnel structure (*see Figure 1*).

This is represented by the model by means of a reduction in the number of fires, which progress from minor to severe, severe to very severe, and very severe to catastrophic. However, assuming that an operational safety strategy would require water discharge to be delayed until after evacuation, damage-only fires and the proportion of such fires that progress to become minor fires will not be reduced.

'The analysis calculates the net benefit of the system over a period of 60 years'

In the model, it is assumed that the fire suppression system can have influence on all fire-related incidents. Any persons unwilling or unable to provide for their own safety by self-rescue to the escape passageway in the tunnel would benefit from the reduced size and rate of fire spread.

The benefits of fire suppression manifest themselves in the model as a reduction (compared to baseline) in the number of fires that progress from one level of severity to the next. Fire suppression was assumed to reduce both the cost of delay and damage, and the cost of injury, with the former accounting for twice the saving of the latter.

There are two main reasons for assuming a modest life safety benefit of fire suppression:

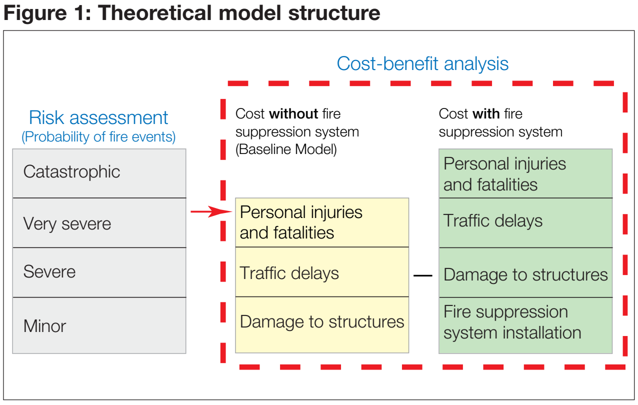
- a significant number of injuries and fatalities may be due to vehicle impacts, rather than the actual effects of a fire
- the delay in operating the fire suppression system, which is normally required to evacuate the tunnel prior to water discharge, may mitigate against saving lives and injuries. For example, tunnel fire suppression systems in Japan and Australia are not normally activated until after all road users have been evacuated (although there are exceptions based on dynamic risk assessments, and Japanese standards now recommend discharging water minutes after fire detection in uni-directional traffic and after 10 minutes in bi-directional traffic)

Data analysis

Where possible and appropriate, the economic principles adopted in the development of the quantitative model were aligned with the UK Highways Agency's published methodologies for cost-benefit analyses (the COBA manual). Variation in some costs over future years was taken into account by increasing those costs in line with the forecast variation in Gross Domestic Product.

The potential costs of traffic delays due to tunnel incidents were provided by a transport consultant. The traffic delay modelling included consideration of the value of time for

Figure 1: Theoretical model structure



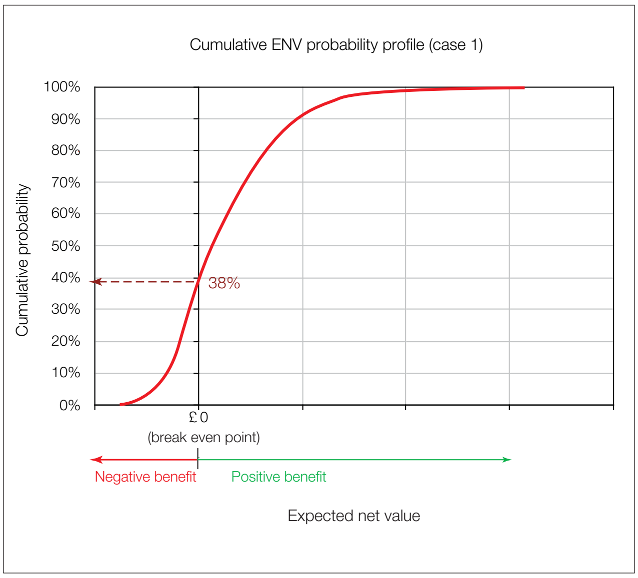


Figure 2: Expected net value of the fixed suppression system

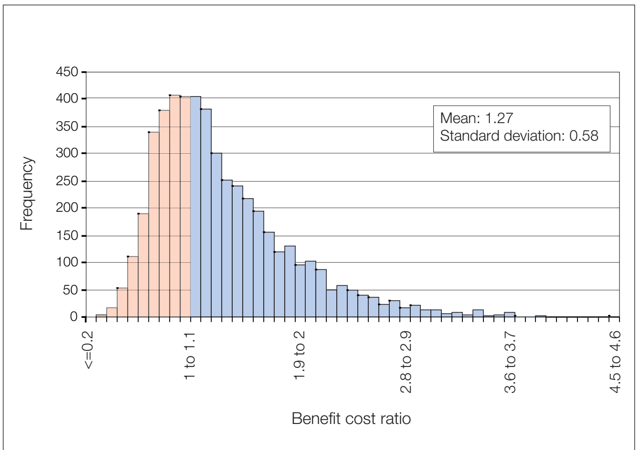
different vehicle occupancies, such as commuter vehicles and business cars. Because traffic flow changes over time, the costs associated with any delays due to tunnel closures will also vary.

As it is assumed that the cost of damage to the tunnel structure remains static over time, as a result of improvements in construction and maintenance efficiency, this cost item is only affected by incident rate.

The costs of casualty (injury and death) from tunnel fires are considered to have the same monetary values as the costs arising from a traffic accident. Rates are based on economic appraisals of the benefits from the prevention of road accidents, according to the Highway Economics Notes issued by the UK Department for Transport.

Given the limitations on available historical data, it was necessary to derive the frequencies of different types of fire incidents in tunnels from a variety of sources, and to exercise judgement when applying figures to the New Tyne Crossing.

Figure 3: Benefit-cost ratio for suppression system



The COBA manual gives an assumed decrease in accident rates over time for the surface road system. The cost-benefit assessment adopted a similar rate of decrease, applied to all fire incidents within the tunnel.

Assessment results

As discussed, the Monte Carlo simulation generates a set of input parameters for the model from a specified range of possible parameters. This is done a large number of times (over 5,000 runs), generating a smooth and consistent profile of probable outcomes from the model.

Results show a broad spread of the expected net value curve with a positive mean benefit, even though there is a possibility that the system would not provide a net benefit. For an assessment period of 60 years, there is approximately a 38% chance of a negative benefit. In other words, the probability of a tunnel fire suppression system providing a net positive benefit to society is 62% (*see Figure 2*).

For the net benefit gained, the key types of fire incident for which the model predicts significant cost saving are:

- 42% due to severe fires
- 29% due to very severe fires
- 28% due to catastrophic fires

The key types of costs where the model predicts significant benefits are:

- mean reduction in traffic delays due to tunnel closure (71%)
- mean reduction in injuries, fatalities and emergency service attendance costs (18%)
- mean reduction in damage to tunnel (11%)

As far as the benefit-to-cost ratio is concerned, the fire suppression system has an average ratio of £1.27. The result indicates that for every £1 of investment, the fire suppression system is likely to bring £1.27 of economic benefits to society. The benefit-to-cost ratio levels equal to or over 1 are shown as blue bars in Figure 3.

Taking into account the net benefit to society calculated from the quantified risk assessment, it was recommended that a fixed fire suppression system should be installed in the New Tyne Crossing. This recommendation was reviewed by the stakeholders in the Tunnel Design and Safety Consultation Group, and accepted by the Tyne and Wear Passenger Transport Authority, as well as the Highways Agency.

Limitations

The authors' decision on whether or not to recommend a fire suppression system in the New Tyne Crossing was based purely on a cost-benefit analysis. Intangible benefits – including protecting of the reputations of, and public confidence in, the Tyne and Wear Passenger Transport Authority and the concessionaire, TT2 (appointed to design,

build, operate and maintain the tunnels) – were not therefore included in the decision-making process.

The financial analysis was based on societal costs and benefits. For this reason, the loss of toll income to the concessionaire was not included in the analysis, since this is considered a private arrangement that does not directly impact on the rest of society. In contrast, the refurbishment costs following damage due to fire are included in the analysis, since society would have to pay (perhaps through higher insurance premiums) for the reinstatement of the tunnel.

It may be controversial that the decision to install a fire suppression system was based on a benefit-to-cost ratio above unity, since most of the benefits accrue from the reductions in traffic delays, rather than life safety benefits. The Highways Agency normally approves projects with a benefit-to-cost ratio above unity that have life safety benefits, but the predicted life safety benefits here were relatively small.

Only the marginal costs and benefits of installing a fire suppression system as an additional safety measure were considered by the assessment. It did not take into account possible cost savings derived from, for example, reduced operator presence, relaxed passive fire protection requirements, and reductions in insurance premiums. Nor did it consider cost increases from, for instance, improved lighting and evacuation systems to compensate for diminished visibility after activation of the fire suppression system, and any additional fire detection system ■