

TRANSPORTATION CONFERENCE 2026 PRACTICE PAPER

TUNNEL VISION: SCENARIO PLANNING FOR SMART RISK DECISIONS

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ABSTRACT

Homer Tunnel, on State Highway 94 (SH94), is the only road access to Milford Sound Piopiotahi. Located in a remote alpine environment, the tunnel is 1,270 m long with a steep 10% gradient. Road users are exposed to various hazards, primarily:

- tunnel fire,
- rockfall,
- avalanche.

While SH94 Milford Road carries relatively low volumes of traffic, it plays an important role in the national and local economy. Domestic and international visitors represent most road users; however unconstrained visitor growth is putting pressure on the UNESCO World Heritage Area and National Park. The Milford Opportunities Project (MOP) has been exploring ways to manage the number of visitors and influence the time of day and how they travel.

This paper explains the use of a scenarios planning approach to understand how changes to travel demand could change both the exposure to, and the consequence of, risks associated with the hazards at Homer Tunnel. It outlines how scenarios tested the efficacy of risk reduction options to inform the Quantified Risk Analysis.

The paper concludes by explaining the value of adopting a scenario planning approach when the future is uncertain, and suggested considerations for application to other complex situations.

INTRODUCTION

Fiordland New Zealand is renowned internationally for its exceptional natural scenic beauty. The region is characterised by towering mountains, extensive glaciers, tall forests, untamed rivers, and profound fiords and lakes. Nestled within Fiordland is Milford Sound Piopiotahi, Aotearoa New Zealand's premier tourist attraction.

While Milford Sound Piopiotahi stunning isolation attracts visitors, it also brings risks: the only access, SH94 through Homer Tunnel, exposes road users to rockfall, avalanche, and tunnel fire, hazards that could cause serious injury, death, or cut off the route entirely.

To address these life safety and resilience risks, NZ Transport Agency Waka Kotahi (NZTA) explored improvements for Homer Tunnel and its approaches. Simultaneously, the Milford Opportunities Project (MOP) was developing options for ways to manage increasing visitor numbers and influence travel modes to reduce pressure on the UNESCO World Heritage Area and National Park. There was significant uncertainty about future travel demand, traffic composition and profile.

The outcomes of the MOP had the potential to change both the exposure to, and the consequence of, the hazards. This could in turn influence how NZTA decided to address these risks. NZTA wanted to be able to inform the MOP recommendations by providing information on the risks to road users.

This paper explains how a scenarios planning approach was used to overcome the uncertainty and enable evidence-based decision making. It describes how scenario planning was used to understand the implications of different demand scenarios and to test the efficacy of risk reduction options. Finally, this paper explains the advantages of scenario planning when the future is uncertain, and shares considerations for application to other situations.

THE TECHNICAL CHALLENGE

To determine the appropriate investment decision for Homer Tunnel and its approaches, NZTA ideally needed certainty on the future traffic demand, composition, and flow profile. The challenge was that this is highly uncertain. NZTA either needed to be able to influence future travel patterns or identify interventions that could be effective regardless of the travel patterns. This section explains the risk model applied and factors that generated uncertainty and complexity.

Risk framework

Risk, or consequence, is commonly defined as:

$$\text{Risk} = f(\text{Hazard}, \text{Exposure}, \text{Vulnerability})$$

where:

- **Hazard:** The event or condition that can cause harm (e.g., rockfall, avalanche, fire).
- **Exposure:** The number of people, vehicles, and assets present in the hazard zone and the duration of their proximity to the hazard.
- **Vulnerability:** The likelihood that those exposed will suffer harm, influenced by infrastructure design, emergency response capability, and mitigation measures.

The overall risk is a function of the multiple hazards present at Homer Tunnel and the traffic composition of SH94 Milford Road. Each hazard poses a risk on its own, yet their interaction and overlap combine to create a complex and challenging risk environment. The following sections provide an overview of the risk related to the main hazards at the tunnel and on its approaches.

Tunnel fire

The likelihood and consequence of a fire in Homer Tunnel is influenced by traffic composition (how likely a vehicle is to catch fire, the number of people in each vehicle in the tunnel), and the location

of the fire in the tunnel. The steep terrain on the approaches to the tunnel can cause vehicle engines to overheat. People within the tunnel at the time of a fire are at risk of smoke inhalation and asphyxiation, rather than the fire itself.

Coaches, and older vehicles, are more likely to be on fire within the Homer Tunnel than newer and smaller vehicles. Older coaches, as well as being more likely to catch fire, can increase the consequence given the higher vehicle occupancy compared to cars. Currently approximately half of all visitors to Milford Sound Piopiotahi travel by coach. The MOP was exploring ways to encourage all visitors to travel by coach.

The outcome of a tunnel fire depends greatly on where the fire occurs. The most dangerous scenario is when a coach traveling downhill catches fire and blocks the tunnel, trapping vehicles behind it. Because the tunnel is narrow, vehicles will be unable to pass the burning coach. As a result, people uphill of the fire may not be able to escape before smoke fills the tunnel, especially given its length and steep gradient (see Figure 2).

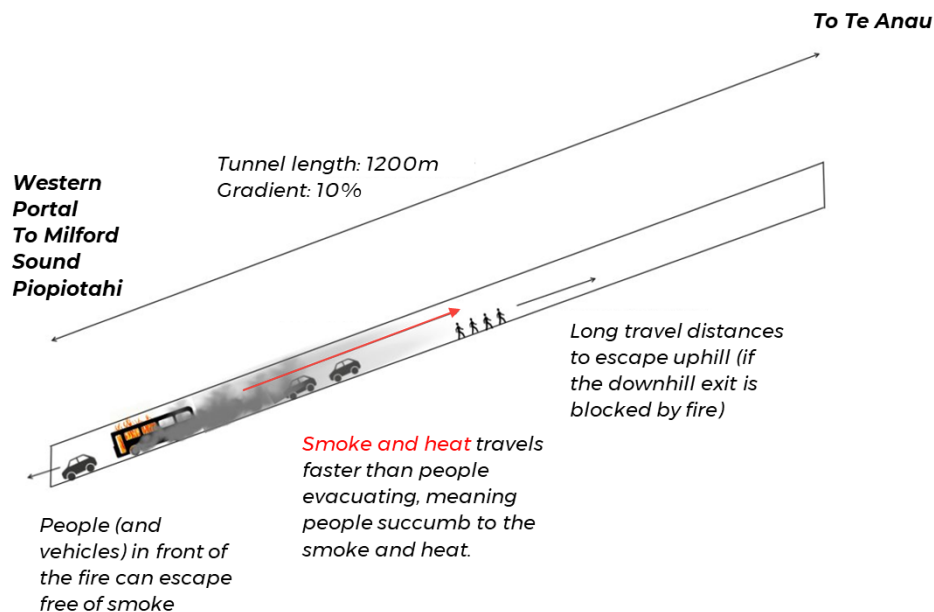


Figure 1. Fire in Homer Tunnel

After a tunnel fire in 2002, traffic lights were installed so only one direction of traffic can use the tunnel at a time, reducing the number of people exposed to fire risk. Other operational risk mitigations include controls on the age and maintenance of buses and coaches permitted to use SH94, thermal imaging cameras in the tunnel, and coach driver training. Overall, the likelihood of a tunnel fire is very small however the consequence is very high.

Rockfall

The risk posed by rockfall is greatest on the approaches to the tunnel portals. Road users may be harmed either by large rocks falling and striking vehicles or when vehicles collide with rocks that have already fallen. The risk is influenced by the volume of rock falling, by the likelihood that the rock material reaches the road and by the likelihood that a vehicle (people) is present. Figure 3 shows examples of historic rockfall that has affected the tunnel approaches. The assessed risk level (ARL) in several locations in the Project Area is ARL 1.

During the height of the summer visitor season, visitors can encounter delays of approximately 20 minutes at the traffic signals that control access to the tunnel. This delay is due to the temporal distribution of the daily travel demand profile at Homer Tunnel, which is colloquially known as “the race to the boat”. Peak demand occurs at midday as visitors booked on a morning cruise start to return from Milford Sound and those arriving for early afternoon cruises are still en-route. The tunnel’s one-way operation leads to queueing at the tunnel portals. While the one-way operation reduces exposure to tunnel fire, the queueing and extended waiting times on tunnel approaches

increase exposure to rockfall hazard.



Figure 2. Rockfall at Homer Tunnel (Supplied)

There is a greater likelihood of rockfall in spring and autumn due to freeze-thaw action than during the summer period. Over the last 10 years there has been a proactive rockfall management programme of planned inspection and targeted risk reduction work involving mechanical scaling and rock removal operations. Subsequently, most of the rockfall risk within the Project Area have already, or are being, managed. Risk can be reduced further by managing where traffic queues form and their length.

Avalanche

The risk of avalanche is influenced by the season, the number of people exposed, and the duration of time that people are stationary. There are nearly 50 avalanche paths that threaten SH94 Milford Road either side of Homer Tunnel. Avalanches in the Project Area occur during June to October, as well as during the “shoulder” season from May to November. Avalanche consequence is greatest in the shoulder season as the number of road users is still high before dropping off in winter.

Avalanche risk increases following an initial event. Overseas experience is that death or harm occurs after a road is blocked by avalanche and queuing vehicles become trapped in adjacent avalanche path. The time it takes to clear the initial avalanche or release queued vehicles influences the likelihood of harm. The number of vehicles on SH94 Milford Road, and hence the rate at which queues form and their length.

Like rockfall hazard, the longer people are waiting at the tunnel portals waiting for the traffic signals, the longer they are exposed to avalanche hazards. A mitigation measure for avalanche risk could be to increase the proportion of people that travel by coach. This would reduce congestion and delays at the tunnel portals and reduce the length of queues that could form after an avalanche. This ‘mode shift’ to coaches would however increase the likelihood and exposure to tunnel fire.

Avalanche risk is managed by the Milford Road Avalanche Control Programme which is world renowned for expertise in avalanche prediction and hazard mitigation. The Programme employs methods such as avalanche bombing and closing the road during periods of high avalanche risk.

Work was also done in 2024 to replace the existing avalanche and rockfall shelter at the eastern tunnel portal. This reduces the risk of avalanche but does not eliminate the risk entirely.

Summary

Preceding sections have presented some of the key factors influencing risk at Homer Tunnel and on its approaches under current conditions. The likelihood of a tunnel fire is extremely low, yet the consequences are catastrophic. There is a higher likelihood of rockfall occurring but, except in a major earthquake the consequences are more manageable. The risk posed by frequently occurring avalanche is adequately managed by the Milford Road Alliance's world leading management activities.

Growth in visitor numbers and travel demand will change the exposure to, and consequence of, the hazards. Increasing visitor numbers and changes proposed by the MOP had the potential to reduce risks associated with some hazards while at the same time increasing the risk associated with others. Furthermore, climate change could increase the likelihood of rockfall and avalanche.

These create additional uncertainty about the future likelihood of hazards, level of exposure, and magnitude of consequence. To help mitigate this uncertainty, future travel demand scenarios were developed to understand the implications of different demand scenarios and to test the efficacy of risk reduction options.

INFLUENCE OF THE MILFORD OPPORTUNITIES PROJECT ON FUTURE DEMAND

In parallel with NZTA's risks assessment, the MOP was working to develop sustainable tourism strategies for Milford Sound Piopiotahi. The MOP's aim was to improve visitor experience, manage environmental impact, and plan for growth.

According to MOP, in an unconstrained demand scenario, annual tourism visitors to Milford Sound Piopiotahi may grow from 1 million visitors to 1.6 million by 2050. The MOP Masterplan proposed changes that would affect traffic volumes, vehicle composition, and arrival rates at Homer Tunnel. However, despite support from stakeholders, implementation details remained uncertain. For NZTA to move forward with its risk assessment for Homer Tunnel, NZTA needed to understand:

1. how MOP's potential changes could affect either the exposure to or consequences of risks facing road users, and
2. what this meant for the effectiveness of any future investment in tunnel resilience.

Table 1 lists key MOP recommendations likely to affect travel demand on SH94 and at the Homer Tunnel.

Recommendation	Discussion
Charge international visitors an access fee.	This may reduce the total visitor demand if the fee exceeds people's willingness to pay.
Visitor numbers are proactively managed through access control including hourly limits (1,000 inbound visitors per rolling hour) and a reduction (60 percent) in car parking at Milford Sound Piopiotahi.	This would influence the travel demand profile through incentivising a more uniform distribution throughout the day, as well as spreading the summer peak into the shoulder seasons (when avalanches are more likely).
Introduce a zero-emission coach-based transport model.	This influences the vehicle composition and occupancy profile by limiting self-drive options.
Establish a new tourism hub, additional accommodation and park and ride facilities at Te Anau.	This could result in more trips originating in Te Anau (as opposed to Queenstown). This could reduce the intensity of the midday peak hour.

Table 1. Milford Opportunities Project recommendations

HOW SCENARIO PLANNING WAS USED

The outcomes of the MOP had potential to influence NZTA's investment decision making by changing both the exposure to, and the consequence of, the hazards on SH94 and at Homer Tunnel. The form and timing of the MOP's interventions and subsequent impact on the risk profile for SH94 Milford Road and the Homer Tunnel was therefore highly uncertain. The Project Team adopted a scenario planning approach to:

- assess how alternative future demand scenarios could affect risk to road users from multiple hazards;
- assess the performance of different risk reduction interventions, ideally identifying those that performed well regardless of the future demand;
- inform a flexible, staged implementation plan allowing timing to be adjusted as conditions change, for example trigger points for revisiting decisions if certain indicators (like traffic volumes) exceed thresholds.

The scenarios

Four *plausible futures* were developed by the Project Team to represent travel patterns for journeys to and from Milford Sound Piopiotahi. These are presented in Table 2. All future scenarios assume growth in visitor numbers to 1.6 million annually. The MOP estimated this will be realised between 2050 – 2060, or by 2070 if access charges for overseas visitors are enacted.

These scenarios were not intended to prescribe a preferred outcome for SH94 Milford Road. Rather, they serve to illustrate what could happen to explore the implications for the risk profile. The practicalities of delivering the changes being considered by MOP were not considered.

Scenario	Description
Status Quo Growth	This scenario would see growth in visitor numbers while status quo travel behaviours are retained (i.e. the proportion of light vehicles and coaches is unchanged and highest traffic flows are in the middle of the day). This scenario would be likely if there are no external interventions to affect travel demand.
Coaches + Growth	This scenario would see growth in visitor numbers and assumes that there is no change to daily arrival flow profile (measured in people) but that all visitors travel by coach.
Smoothflow + Growth	This scenario would see growth in visitor numbers and no change in traffic composition but a uniform arrival profile for visitors (measured in people) is achieved across the day.
Smoothflow Coaches + Growth	This scenario would see growth in visitor numbers and a uniform arrival profile for visitors (measured in people) with all visitors arriving by coach.

Table 2. Future travel demand scenarios

Application of the scenarios

Ultimately only two of the scenarios, Status Quo Growth and Coaches + Growth were used to inform the risk assessment. These two scenarios represented the 'bookends' of possible outcomes. From a traffic management perspective Status Quo Growth served as the worst-case scenario and Coaches + Growth a best-case scenario. The scenarios were, however, able to highlight the implications for risk from the various hazards. Selecting only two scenarios reduced the work to assess intervention options and simplified the communication of the results.

HOW DID THE FUTURE SCENARIOS AFFECT RISK

Operational controls already reduce risk in the Project Area. It is expected that they will continue to be utilised in the future. The tunnel is operated as a one-lane / one-way tunnel during the day (6am – 8pm) and then bi-directionally in the evening when traffic volumes are lower.

Table 3 shows that if visitor numbers increase as anticipated by MOP without any change in arrival times or mode of transport (Status Quo + Growth), there will be significant increases in queue lengths and expected delays at the western and eastern portals. This will significantly impact customer satisfaction and increase exposure to rockfall and avalanche hazards because visitors spend lengthy periods of time queuing in areas that currently exceed acceptable levels of risk (being at ARL 1 or 2).

Coaches + Growth would see significant growth in visitor numbers with all visitors travelling by coach. In contrast, this scenario was forecast to see material reduction in delays and queue lengths at the tunnel portals during the summer peak of the peak.

Scenario	Western Portal		Eastern Portal	
	Queue Length (max)	Average Delay	Queue Length (max)	Average Delay
Base (2019)	320m	20 minutes	280m	19 minutes
Status Quo + Growth ¹	> 1.3km	> 34 minutes	> 1.2km	> 32 minutes
Coaches + Growth	70m	4 minutes	60m	4 minutes

Table 3. Traffic performance at Homer Tunnel (summer peak of the peak)

Figure 3 shows queue lengths and delays for the base 2019 traffic volumes, Status Quo + Growth, and if visitors arrive solely by bus (Coaches + Growth). A Coaches + Growth scenario shows that even with future demand, queue lengths could be managed so they are shorter than the current worst case at the peak of the summer period (using base 2019 figures). A Coaches + Growth scenario, however, results in poor outcomes from a fire risk perspective.

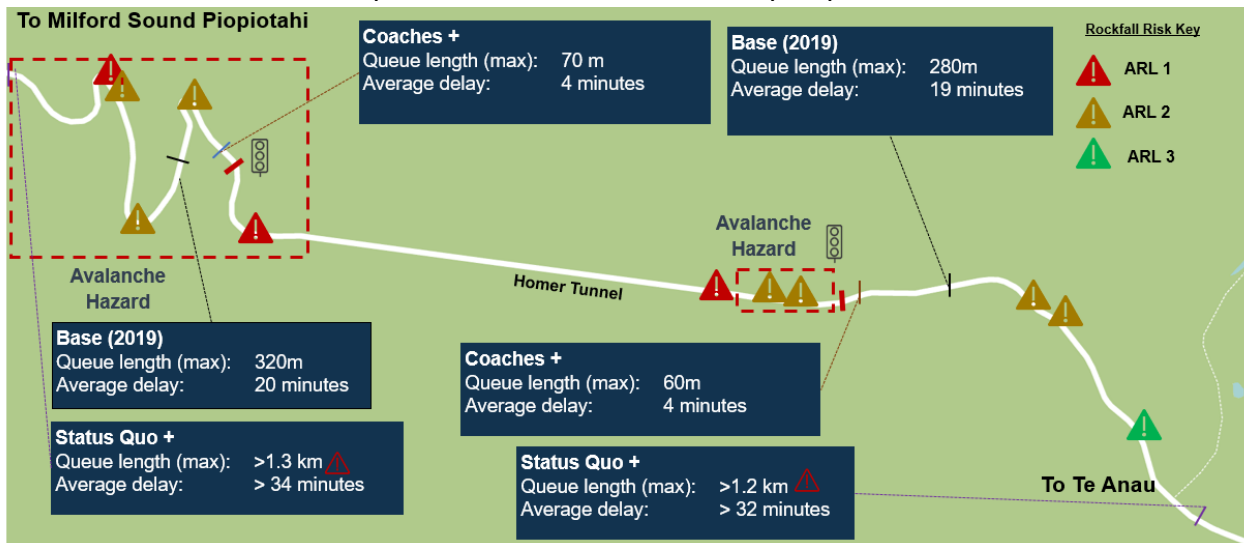


Figure 3. Travel demand scenarios and exposure to rockfall and hazard areas

¹ The traffic model could not successfully process the demands of the Status Quo + Growth scenario. This means that more traffic was arriving than could pass through the tunnel during the modelled period.

The future risk of harm resulting from a fire in the tunnel was assessed using an updated version of a Quantitative Risk Assessment (QRA) initially developed for the NZTA by others². Figure 4 shows how the collective risk³ could be expected to change if visitor numbers continue as anticipated by the MOP (1.6m annually by 2050 - 2060) for the two future demand scenarios.

It shows that the collective risk increases substantially more if visitors travel only by bus. It also shows that the future collective risk is approximately ten times more for Coaches + Growth than for the 2019 base case.

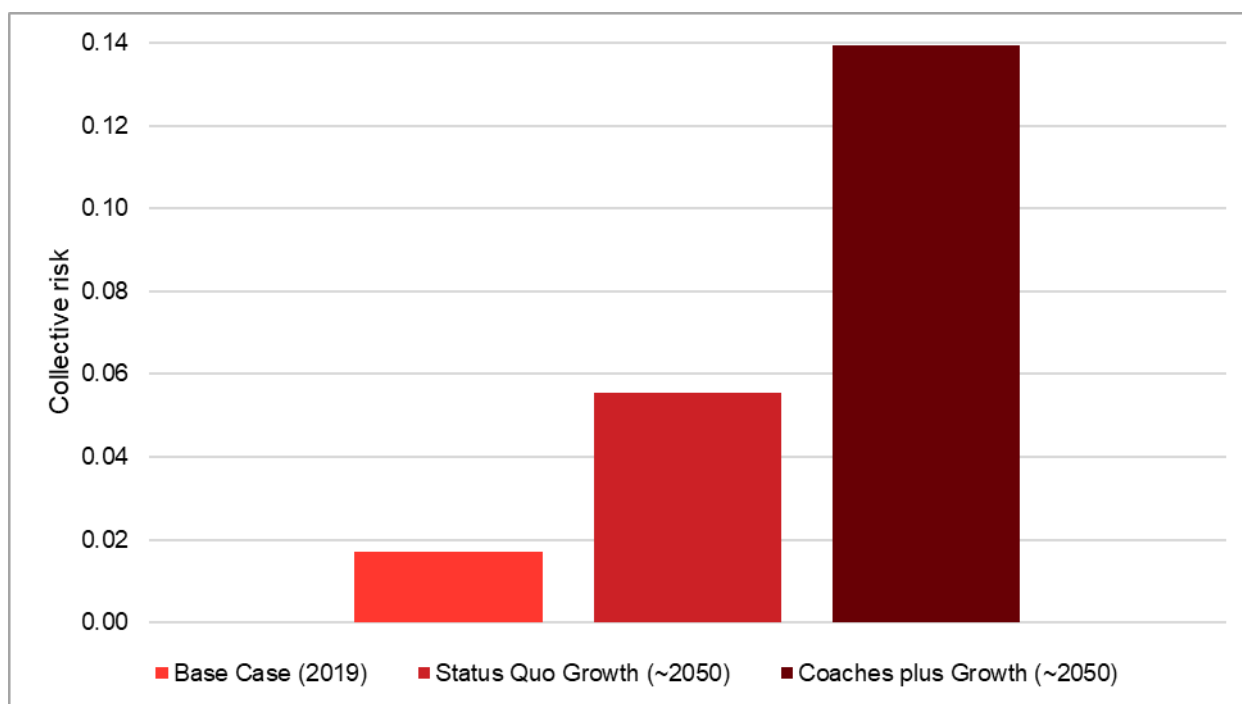


Figure 4. Collective risk from fire for future demand scenarios with no intervention (Do Nothing)

The basis for the higher collective risk was:

- increases in the number of people and vehicles travelling through the tunnel increases exposure if a fire were to occur.
- coaches are assessed as being more likely to catch fire than light vehicles in mountainous environments. This is due to the power required to move heavier vehicles up steep inclines.
- a coach, travelling downhill within the tunnel, which is trapped behind a burning vehicle, would be carrying a greater number of people who would be exposed to smoke than if a light vehicle were to become trapped.
- in a mixed traffic environment, an increase in the number of coaches travelling through the tunnel would both increase the potential of a fire occurring, and the number of people exposed.

Assessing the effectiveness of intervention options

The NZTA Resilience Response Framework guided the development of risk reduction interventions. Families of options to improve resilience and address risk of death or serious harm were established. After filtering a long list against qualitative assessment criteria (expected effectiveness, feasibility and proportionality of the cost to the assessed risk) the assessment of a short list was informed using quantitative means and for fire hazard using the QRA.

Figure 5 shows the collective risk for each option for the 2019 Base Case and the two selected

² Aurecon, 2017

³ While the analysis also considered personal risk this paper is focused only on collective risk.

future demand scenarios. It shows that the “Buses Last” and the Egress Passage options were most effective at reducing collective risk, yet the degree to which the collective risk was reduced differed by the demand scenario.

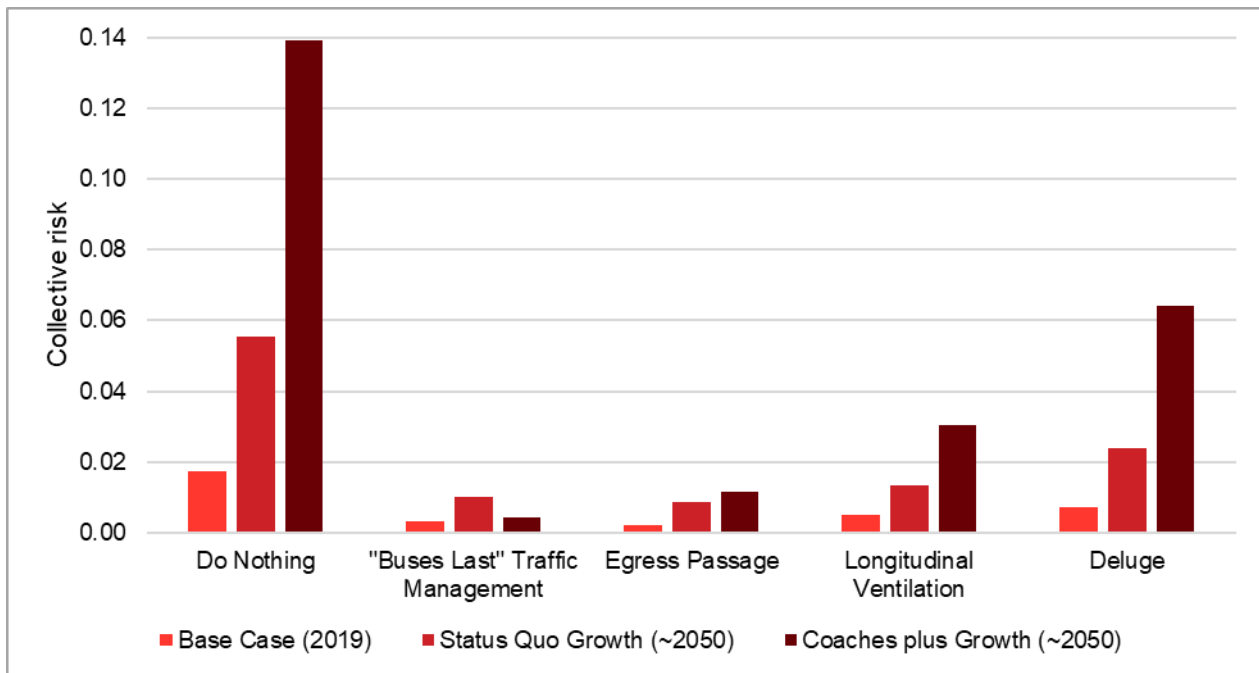


Figure 5. Collective (societal) risk for the fire risk reduction options in each future demand scenario.

Of the shortlist options, a Deluge System was assessed to be least effective. The aim of a Deluge System is to suppress the fire to prevent or delay the fire from becoming significant or from spreading to adjacent vehicles. It is effective at protecting tunnel assets but does little to prevent smoke filling or asphyxiation of people within the tunnel.

The QRA findings indicated that in theory, Longitudinal Ventilation could reduce the risk of death or harm. In practice the steep grade and extended length of Homer Tunnel would make this a technically challenging option as the ventilation system would need to be able to suck or blow a large amount of smoke downhill.

The “Buses Last” option would control bus entry into Homer Tunnel so only one bus enters at a time, and westbound (downhill) buses are always at the back of the traffic platoon. Special signs, sensors, and lane markings would keep buses separate from other vehicles in the queue. The option would seek to reduce the chance of people becoming trapped behind a burning bus when heading downhill. Signals at the western portal (eastbound, uphill) would not require platoon control and could be optimised for vehicle flow. Among the options tested, “Buses Last” had the lowest collective risk for the Coaches plus Growth scenario, and unlike the other options had lower risk than the Status Quo Growth scenario.

While in theory, the “Buses Last” option was effective at reducing collective risk, further analysis found that it was highly sensitive to input assumptions within the QRA. Sensitivity tests using the 2019 Base demands, were undertaken to assess option performance for:

- an “upper estimate” with bus fire probability doubled and tunnel occupancy doubled;
- a “lower estimate” with bus fire probability halved and tunnel occupancy halved

The tests (see Figure 6) acknowledge the uncertainty inherent in the QRA and with future demand scenarios. The tests were designed to “bookend” the residual risk associated with each option. They demonstrate that the egress passage is the best performing option even if the most influential assumptions are “wrong”.

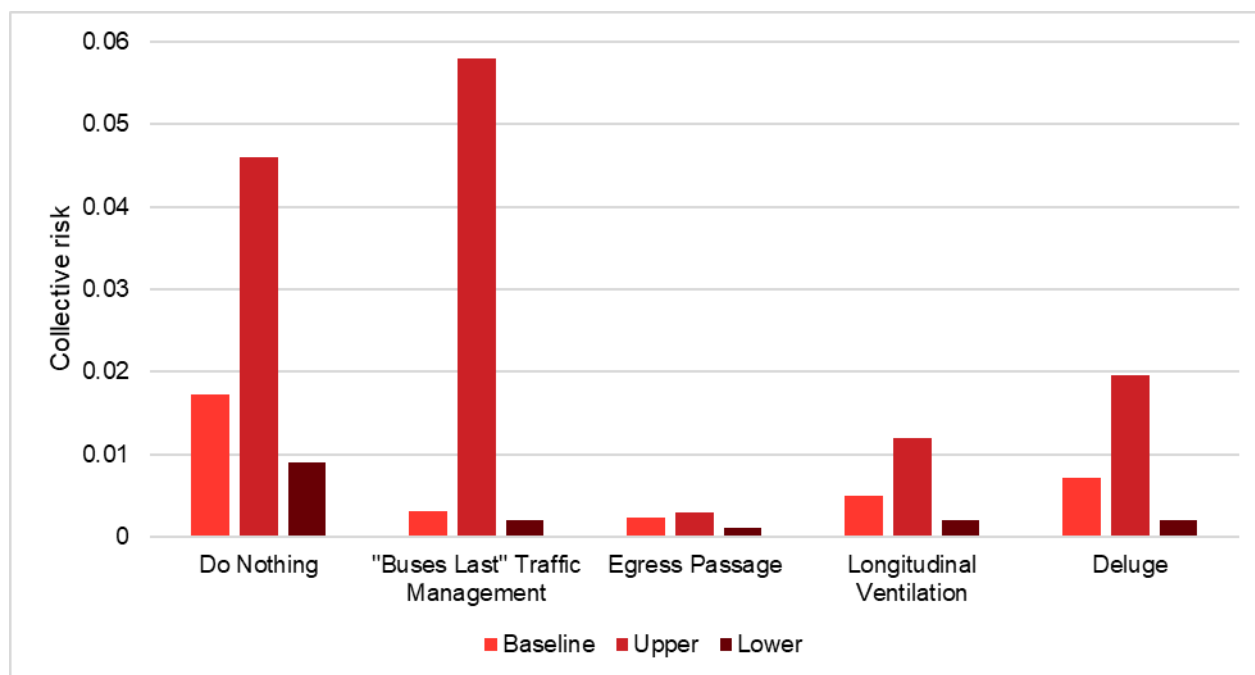


Figure 6. Collective (Societal) Risk – Sensitivity Tests.

Figure 6 shows that the expected performance of the egress passage is significantly less sensitive to the QRA assumptions than that for the other options. This suggests that the egress passage remains the most reliable (least sensitive), best performing (largest reduction in risk) option and is the most easily adjusted to suit the required risk level.

On the basis of the risk assessment, informed by the alternative future demand scenarios, a package of measures that could be implemented incrementally was recommended to address avalanche, rockfall and fire hazard. The recommended programme was accepted by the NZTA for inclusion in their long-term planning.

NZTA decided to proceed with works to avoid or mitigate rockfall risk:

- implement queue detection to enable real time optimisation of the existing traffic signals and reduce queue lengths and the number of vehicles stationary on sections of road exposed to rockfall.
- closure of the Loop 2 carpark– this would remove a stopping place popular with visitors for taking scenic photographs photo but reduce the numbers of people who stop beneath an established rockfall path.
- strengthen the eastern tunnel portal by placing additional talus cover over the historic arch structure – this is expected to improve resilience by making it more likely that people will be able to escape the tunnel following a major seismic event.

It was ultimately decided that an egress passage within the existing tunnel bore should not be progressed. Over the last 10 years, there have been several improvements including operational controls and additional safety measures (improved lighting, bus driver training, and installation of fire extinguishers). These have already reduced the risk substantially.

While an egress passage could further reduce risk, it would also impact the operation of Homer Tunnel. For example, the safety issues associated with red light running, which has increased as delays at the tunnel portals have increased would be exacerbated were the tunnel width to be reduced preventing errant drivers to pull over to make way for oncoming traffic. It would also further limit the movement of over dimensioned (wide) loads.

Ultimately NZTA concluded that the implementation costs, construction risk, disruption during

construction and operational implications were considered disproportionate to the residual risk. They considered that while the consequences of a fire in a tunnel may be extreme, the likelihood remains very low. On balance, the history of incidents within the tunnel and the mitigation measures currently in place point to a conclusion that “reasonably practicable” measures are already in place.

WHAT WE LEARNED

This paper has outlined how future travel demand scenarios were used:

- to explore the influence of initiatives driven by the Milford Opportunities Project on risk to road users.
- understand the performance of alternative interventions to reduce risk and the extent to which the demand scenarios affected their effectiveness.

While quantitative risk assessments are not now required when assessing life-safety risk in existing tunnels, they helped provide confidence in the recommendations by benchmarking other risks on NZ Transport Agency’s network.

The application of future demand scenarios was largely successful and helped navigate future uncertainty. It demonstrated that our forecasts of the future do not always need to be correct and that there is value in asking ourselves “how wrong do our demand forecasts need to be before the recommended response is wrong”.

While four future demand scenarios were initially identified, it was quickly recognised that made it hard to communicate the results. With so many combinations of scenarios and options, the information became overwhelming, and the audience struggled to follow and to buy into the conclusions. The key lesson is that you don’t need to cover every possible scenario, at least in your reporting - just enough to test your analysis. Using fewer scenarios makes the findings clearer and can reduce the amount of analysis needed.

Despite using only two future demand scenarios, some felt uncomfortable and would have preferred reporting that did not acknowledge the level of uncertainty. There is an inherent desire for certainty. These reservations were overcome by demonstrating the impact of the uncertainty and the implications of hiding the uncertainty.

AUTHOR CONTRIBUTION STATEMENT

Peter Routledge - conducted the Quantified Risk Analysis.

Mark Gregory – instrumental in the development of the demand scenarios, supported development of the business case and led the traffic simulation modelling