The design fire size for a road tunnel has far-reaching implications on the design and costs associated with the tunnel structure and the fire and life safety systems.

My presentation looks at:
• the process of determining the design fire size for road tunnel projects,
• what the approach was previously,
• what alternative approaches are now available,
• and how a risk review process, as used on the Tugun Bypass project, has significant benefits in obtaining a lower cost, tailored, fire and life safety solution which meets the broad requirements of the project stakeholders.
The design fire size for a tunnel has direct influence on the fire engineering analysis, the tunnel structural design (or its resistance to failure due to fire) and the design of the fire and life safety systems such as the tunnel ventilation, fire detection and fire protection systems.

Up until the last four to five years, the maximum tunnel design fire size had traditionally been quantified in the design criteria of client briefs for road tunnel projects. This was based on the fact that most tunnels within Australia were in urban areas, the speed limit was generally limited to 80km/hr, and no dangerous goods were permitted to travel through.

The authority stipulated maximum design fire size for road tunnels was typically 50MW, and by comparison, for Bus and Rail Tunnels was typically 30MW.

With the introduction of tunnel projects such as the Tugun Bypass project having parameters outside these usual norms, the standardisation of design criteria was no longer a valid option. An alternative approach was necessary which took into consideration the unique risks associated with each project.
Before we look at the alternative approach, let's have a brief look at where Australian fire safety design has come from.

Prior to the design of the Sydney Harbour tunnel in 1992, little consideration was given to the fire safety design in tunnels. The design of the Sydney Harbour tunnel fire and life safety systems was based on limited US and PIARC data available at the time.

In 2001, the Australasian Fire Authorities Council produced the Fire Safety Guidelines for Road Tunnels. This document included relevant fire safety issues designed to provide information and guidelines to those Fire Brigades who may be involved in providing comment or requirements to road tunnel developers.

Recent tunnels up to year 2006 were ‘fire engineered’ mainly for smoke management and egress provisions in line with the designated maximum design fire size.

Since 2006, the risk review process has enhanced the fire engineering process and considers the maximum credible fire scenarios unique to the project location and operating parameters.
On the international scene, I was fortunate enough in May this year to attend the Tunnel Fire Safety & Ventilation Conference in Graz in Austria, and following that was a guest at the PIARC Ventilation Working Group Meetings.

It was interesting to observe that of the 20 or so countries represented in the PIARC Working Group, each had various local Authority requirements to follow either a performance based or prescriptive approach to fire engineering.

This group is currently working on a technical report titled “Design Fire Characteristics for Road Tunnels” in relation to determining the design fire size for road tunnel projects. The aim of the report is not to advocate that a performance based approach is better or more appropriate than a prescriptive approach, rather to provide information and case studies to enable decision-making around the available options. There was a strong emphasis by the group on the importance of basing the report on solid research and the results from recently executed tunnel fire tests.

The photo in this slide was taken in the 2.4km long Kirchdorf S35 Tunnel (20km north of Graz) during the fire testing of the smoke control system that we witnessed as an excursion to the conference. It passed with flying colours, as we’re still alive today after standing only 20m or so from the large fire!
To touch on the outcomes and conclusions from a number of full scale tunnel fire tests, we were able to see from the Runehamar, Memorial and Reppafjord Tunnel fire tests that uncontrolled tunnel fires (or those where no fire suppression is applied) result in poor visibility, very high temperatures and heat release rates, and significant impact on the integrity of the tunnel structure. These tests also showed that heat release rates in excess of 200MW could be generated from a fully developed non-dangerous goods fire.
By comparison, the results of the Benelux and Piota Negra Tunnel fire tests showed us that controlled tunnel fires (or fires where fire suppression is activated) result in cooler tunnel temperatures, limited visibility, lower heat release rates, and, generally, tenable conditions with the exception of visibility.

The outcomes of the fire events in both the Sydney Harbour Tunnel and Melbourne City Link Tunnel are also testament to these conclusions.
The Tugun Bypass project involved the design and construction of 7km of new motorway and a 340m long tunnel to improve interstate travel through the Gold Coast and relieve the impact of traffic congestion on the local roads at Tugun. The project was designed and constructed under the PacificLink Alliance between Queensland Main Roads, SMEC and Abigroup, where “best for project” thinking was encouraged at every level and across all aspects of the project. NDY was a sub-consultant to SMEC responsible for the design of the motorway and tunnel services.

The project was unique in that:
- the route was located across the NSW/QLD border, thereby doubling the number of stakeholder and interest groups involved
- part of it was constructed below the extension of the main runway of the Gold Coast Airport
- the posted speed limit was 100km/h, higher than most in the country
- and most classes of dangerous goods (except explosives and flammable gases) were permitted through

The project was very successful in opening 6 months ahead of the contract schedule and under budget.

The original project brief issued at the time of tender prescribed that the tunnel and services were to be designed to accommodate the effects of a maximum 100MW design fire.

However, given the unique parameters of the project, the scope of works and technical criteria issued at the time of contract award was changed to shift the responsibility for determination of the design fire size to the Alliance team. In fact the words stated “The mechanical ventilation and smoke control systems must be capable of fully functional continuous operation for the range of fire events up to and including a 50MW design fire as a minimum. The design fire must meet this minimum requirement and must address the requirements necessary for the nature of goods that will be permitted in the tunnel.”

Wow, where do we go to from here?
These statements conjured up a whole range of questions for the team:

• **What was** the nature of goods expected to pass through the tunnel?

• What impact did the specific location of the tunnel have on the range of possible fire events?

• What sort of smoke management schemes or fire systems would we need to address this seemingly limitless requirement?

• How do we quantify the amount or type of the fire’s fuel sources?

• What impact was this going to have on the Incident Management Plans to manage the range of likely events?

• Or on the reliability and the sequence of operation of the traffic management and fire protection systems?

• We had to get the buy-in from all of the project stakeholders. How were we going to do that with such an open-ended requirement?
We needed to be able to identify the full range of possible fire risks and threats, right from the minute to the unmanageable, and review their corresponding consequences in some sort of orderly fashion. We needed a process that clearly demonstrated that the team had sufficiently canvassed the issues in a logical, thorough manner, and exercised our duty of care to the stakeholders, and ultimately to the public.

Given the large number of stakeholders involved, a Risk Review Workshop Process was decided upon as the vehicle to achieve this, and we acknowledge the good work done by Risk Consultant, Risk & Reliability Consultants (or R2A) in assisting in the facilitation of these workshops. With over 20 stakeholder groups from both sides of the state border, it would be next to impossible to expect the issues to be understood and agreement sought in a single combined workshop.

Separate briefing sessions were therefore held with each of the individual stakeholder groups, including:

- Design and construction team members – who came up with a preliminary risk matrix
- Councils
- Road Authorities
- Airport Authorities
- Fire Brigades
- Environmental groups, and
- Dangerous goods departments, to name a few.

These briefings enabled each group to be given a plain English explanation of the project and its requirements, and sought specific feedback on the potential risks and fire and life safety issues important to that group. It also provided an opportunity for each group to raise issues of concern or opportunity even outside of fire and life safety. Minutes were kept for each meeting and all issues raised were fed into a central risk register, and non-fire and life safety issues (for example environmental, safety and operational issues), were passed on to the relevant design group for
A preliminary fire scenario and impact review matrix (or vulnerability matrix) was prepared for discussion with the stakeholders which listed out all of the foreseeable fire threats down one side, and the various entities which could be impacted by those threats across the top. A preliminary assessment was undertaken of the extent of consequences for each fire scenario, graded from no impact up to multiple fatalities.

Of significant concern was the impact and magnitude of potential dangerous goods fires, and the effect of operating the deluge system on some type of dangerous goods which reacted with water. A couple of detailed workshops were arranged with qualified dangerous goods experts to thoroughly review those issues.

The probability of each of the fire scenarios occurring was also assessed, (i.e. whether the fire scenario was “credible” or not), and whether or not systems or procedures could be put in place to mitigate those fire scenarios. For example, it was agreed that the tunnel structure and fire protection systems could not be designed to accommodate the effects of an aeroplane misjudging the runway, colliding with the tunnel and bursting into flames, and the likelihood of the event was extremely low.
Workshop Issues

- Impact of heavy or Dangerous Goods fires
- Focus on fire safety not environmental issues
- Illegal movements of prohibited loads and penalty procedures
- Quantification of load sizes
- Fire system types and activation times
- Tunnel system control location
- Probability assessment
- System reliability levels

Following the stakeholder briefing sessions, a full day workshop was held at the Tugun Surf Club with the external stakeholders to:

• test the credible fire scenarios identified and the proposed precautions, and
• to explore with the wider Stakeholder Group any other credible fire scenarios that should be considered by the Design and Construction team.

Each of the fire scenarios identified were systematically reviewed in detail by the stakeholders, and profiling sheets were prepared which recorded the group’s comments on the severity of each threat along with the expected precautions or controls.

As expected, the workshop discussion was lively and passionate, and covered off a whole raft of risk issues, some of which are listed in the slide. By having the individual stakeholder briefing sessions occurring earlier and by having all of the relevant experts and stakeholders in the room at the one time, each issue was discussed, factual information exchanged, and the issue was addressed on the spot.

At the conclusion of the workshop, the group was asked by the facilitator if there were any other risk issues or good practice controls that the participants were aware of but were not yet tabled. Surprisingly, none were raised.
In addition to honing in on the maximum credible fire scenarios, the outcomes from the stakeholder workshop were also used as input into the Incident Management Plans and to the Safety Integrity Levels (or SIL Levels) determination exercise for the Information, Communication & Technology systems.

Separate SIL Level workshops were conducted and attended by the design team, the technology providers, the proponent and the end users (operators) which looked at:

- the probability of occurrence of the scenario
- the control barriers inherently in place to identify or avert a major tunnel fire event before it happens (such as normal traffic management, CCTV coverage or contact from the public at the early stage of a hazard), and
- the potential sequence of events in terms of decision making, response, and fire or control system activation times

By looking at the combined effect of these items, we were able to logically establish that, to achieve the required levels of system reliability stated in the project brief, it was only the tunnel control and monitoring system which was required to be formally SIL rated, not the entire traffic management system or the fire protection system, which saved significant costs to the project.

### Safety Integrity Levels

- Separate workshops required to assess safety and reliability levels
  - Tunnel control systems
  - Fire detection systems
  - Intelligent transport systems
  - Operator controls
  - Incident management plans

- Attended by:
  - Designers
  - Technology providers
  - Proponents
  - End user (operators)
Event Scenarios

- Example of passenger vehicle fire scenario
  - Stationary vehicle causing incident with fire
  - Systems fully operational

This slide illustrates an example of one of the event scenarios we looked at in detail, and I don’t expect you to see the detail.

In this case, the fire incident was assumed to be as a result of a single stationary vehicle (perhaps from excessive heat from the brakes, or an engine fire).

The detection and control systems were assumed to be fully operational.

Starting from left to right in the diagram, the process analysed the various probabilities of the control measures to prevent consequences, including:
- Avoidance of the incident entirely by automatic traffic congestion management
- Localised fire control (i.e. the occupant using a fire extinguisher)
- Operator detection of the incident via CCTV or a vehicle detection loop alarm
- Accurate operator response
- Or, failing that, automatic fire detection, including the accuracy of the location of the fire

The next layers are:
- The probability of operation of the deluge system
- The probability of loss of control of the fire once the deluge system is activated
- The effect of emergency response and incident management procedures, and finally
- The probability of multiple fatalities or not

So, in this example, the probability of multiple fatalities occurring after all of these control barriers was $5 \times 10^{-6}$ per annum – an extremely small number.
So looking at the risk review outcomes:

The preliminary risk evaluation process initially established thirty-five (35) tunnel fire threat scenarios. Following the individual stakeholder briefings and the fire issues risk workshop involving all stakeholders, thirteen (13) credible fire scenarios were determined. Similarities within these thirteen credible fire scenarios permitted detailed fire engineering analysis of seven (7) credible fire scenarios.

Four (4) controlled tunnel fire scenarios were analysed (i.e. when the deluge system is activated) which yielded fire heat release rates in the order of 7MW.

Three (3) maximum test cases analysed the effect of a heavy goods vehicle entering the tunnel with a fully developed non-dangerous goods fire on board. These test cases yielded the maximum potential fire size of 100MW.

Other outcomes of the risk review process identified:
- It is best to activate the deluge system on the fire early (even if the vehicle contains dangerous goods) to minimise the likelihood of the fire penetrating the packaging and exposing the dangerous goods load
- The majority of fires are limited to single vehicles, and are the result of a vehicle impact
- Flammable liquid fuel fires are limited by the pool size which is dependent on the amount of fuel, the slope of the road and the capacity of the drainage system
- A high quality traffic management system and well thought out Incident Management Plans are vital to the prevention, detection and management of fire incident scenarios and minimisation of their consequences.
So why go down this path. What are the benefits?

The greatest fire and life safety risks associated with large infrastructure projects have low probability but extreme consequences if they occur.

By undertaking a risk review process, all of the project stakeholders are brought together at the initial stages to quantify and categorise the risks you are dealing with.

By harnessing the experience of the design and construction team and all of the relevant government, emergency services, environmental and specialist risk departments, it puts the expertise in dealing with these risks at the forefront.

The individual stakeholder briefings enable each group to understand the fire safety issues that may affect them, and enables their concerns to be put on the table and addressed early in the process. It is also a way of taking on board wider project issues, ideas, and suggestions which would not necessarily be captured in a wider forum because of time limitations.

The combined stakeholder workshops provide a vehicle for due diligence as each group comes to the workshop informed, and familiar with the objectives of the risk assessment process. All the necessary expertise is in the room to discuss the issues and address the concerns of others with factual responses. Ultimately, the workshops are a vehicle for joint acceptance of the range of fire risk events, and to confirm the appropriateness of the precautions proposed to be put in place to mitigate those risks.

With credible fire scenarios agreed upon, the fire engineering analysis and the design of the fire and life safety and control systems can be tailored to the unique circumstances of the project, without applying a blanket approach which can be expensive and excessive.

This results in lower cost solutions which provide the desired level of safety and which are acceptable to the stakeholders.
So, in summary, the fire and life safety risk review process removes “business as usual” thinking and enables a thorough examination of the unique circumstances of the project location and operating parameters.

It is a rigorous process that puts expertise to the forefront by engaging members of all of the stakeholder groups throughout all stages of the process.

A structured risk review allows a focused and logical approach, “leaving no stone unturned”, and enables the design and construct team to demonstrate due diligence.

By identifying the maximum credible fire scenarios, the risk analysis process enables optimisation of the tunnel services design resulting in lower cost solutions acceptable to the stakeholders.

It allows a transparent and fully developed process which is well documented and demonstrable.

By virtue of the risk assessment process becoming embedded in our current project briefs, it is the way forward.