EXPERT REPORT

For The Victorian Coroner

THE FATAL BURNLEY TUNNEL CRASHES
MELBOURNE, VICTORIA, AUSTRALIA

INCIDENT - 23 MARCH 2007

Final Report by:

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9 June 2011

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*** NOTE: DISCLOSURE OF DETAILED TECHNICAL INFORMATION – MELBOURNE CITYLINK

Melbourne CityLink is essential services infrastructure pursuant to section 28 of the Terrorism (Community Protection) Act 2003. Objects of this legislation include: to impose risk management obligations on operators on certain essential services; to protect counter-terrorism methods from disclosure in legal proceedings and to conduct terrorist related exercises annually.

Melbourne CityLink has made all requested information available in the conduct of this investigation. The detailed information provided about tunnel systems, procedures, exercises and operational limitations are not produced in this report to ensure this process does not unnecessarily compromise other safety and security performance objectives of this infrastructure.
1. ABOUT THIS REPORT

This report was prepared in 2007, with minor amendments in early 2008 and reflects the author’s views, facts and circumstances of that time. The report remains as at 9 June 2011 the subject of a suppression Order made on 4 April 2008 by the Victorian Coroner and therefore cannot be distributed.

Subsequent World events have confirmed the author’s view that the Burnley Tunnel events the subject of this report were in 2007 and still are in 2011 of great significance to our shared global learning on tunnel safety.

In particular the use of a fixed fire fighting system in the Burnley Tunnel significantly reduced the probability of fire spread and its associated risks to other tunnel users and the tunnel. Current research projects such as the SOLIT2 fire suppression testing in northern Spain and the deluge tests by LTA of Singapore can in part be traced to the interest created internationally by the performance of the Burnley Tunnel suppression systems.

The area of system performance and reliability has also become the subject of recent international interest. The importance of system performance during evolving multiple scenarios (and not merely individual sub-system operation) is revealed by the Burnley tunnel operators rapidly changing demands on the Tunnels emergency systems. Initially the event was a routine stopped vehicle in the left lane but it rapidly escalated to implementation of full emergency system activation following the multiple crashes and explosions.

The successful management of the Burnley Tunnel control systems generally and the deluge control systems specifically highlight the importance of improvisation in an emergency. The fact that the tunnel procedures contemplated improvisation and that the tunnel operators had both the confidence and technical ability to successfully improvise was a significant factor in the successful management of this event. The success of the operator’s improvisation is likely a function of many interdependent factors ranging from their training, work place culture, there sense of management’s confidence in them and, significantly, the Australian culture of informed risk taking. The importance of these subjects were discussed at considerable length during the International Tunnelling Association World Congress in Helsinki, May 2011 and again amongst French speaking tunnel operators at an inspection of the A86 duplex tunnel in Paris in June 2011.

The disconnection between actual human behaviour in an emergency and what is presumed by tunnel designers was in part revealed when evacuees declined to follow audible evacuation commands during the Burnley Tunnel incident and also rejecting opportunities to use cross passages. Full scale evacuation exercises in 2010 and scheduled again for 2011 in the Sydney Harbour Tunnel highlight the currency of the observed behaviours in the CityLink incident.

There remains considerable debate about the impact of fixed fire fighting systems on emergency exhaust capacities and other evacuation and safety systems. PIARC in 2011 is still grappling with the interrelationship between risk mitigation measures (such as fixed fire fighting systems) and their impact on other critical aspects of tunnel design such as smoke extraction, emergency egress pathway separation and tenability.

It must be noted that since the first draft of this report was written in late 2007 substantial changes have been made in both the CityLink tunnels which are said to address many of the issues and recommendations raised in this report. The impacts of these changes on tunnel safety have not been investigated by the author.

Arnold Dix
9 June 2011
2. **Summary**

On 23 March 2007 at 9:54:26 (shortly after Friday morning’s peak hours), a series of crashes occurred in the east bound Burnley Tunnel of the twin tube three lane Melbourne CityLink tunnels.

- At 9:52:30 a truck stopped in the left of three lanes in the east bound Burnley Tunnel. At 9:53:37 the tunnel operator commenced a lane closure and speed reduction plan. Initiation of that plan including its loading into the computer control systems and execution occurred between 9:53:37 and 9:54:05.

- Between 9:52:30 and 9:54:26 103 vehicles passed the stopped truck without incident. Of these 22 vehicles successfully merged from the left hand lane, including one marked police vehicle (no. 15) and four trucks. The 103 vehicles which successfully passed comprised 22 trucks, 1 motorbike and 80 cars.

- From 9:54:12 radio rebroadcast messages were transmitted in the Burnley Tunnel indicating a left lane closure and a speed reduction.

- Computer controlled lane closure and speed signs changed to reflect the left lane closure and speed reductions in the tunnel. These changes occurred between 9:54:16 and 9:54:18.

At the same time the left lane closure was being implemented and the speed reductions and radio rebroadcast messages were being played within the Burnley Tunnel a group of trucks and other vehicles approach the area of the tunnel where the truck had stopped in the left lane.

- At 9:54:22 a group of vehicles were slowing in all lanes (nearly stopped as they approach the area of the tunnel of the stopped truck.

- There was nothing exceptional about the movements of the stopping light vehicles before the incident. In all instances, each was observed to be preparing to negotiate the stopped vehicle in a responsible and courteous manner,

- The distances between all trucks and cars in the vicinity of the stopped truck before the crashes did not constitute a safe distance. All vehicles were travelling too closely.

- At approximately the same time, a truck travelling in the left lane (much more quickly than all other vehicles in this region of the tunnel) changed lanes rapidly from the left inside lane into the centre (and partially right lane) initiating a series of collisions directly impacting 5 cars and two other semi-trailers.

- Between 9:54:26 and 9:54:30 a series of collisions, explosions and fires occur in the region immediately behind the stopped truck. Eventually the truck which initiated the series of crashes hit the stopped truck and pushing it many metres forward.

- Between 9:54:26 and 9:54:33 other tunnel users, not directly involved in the crashes conducted emergency breaking manoeuvres and successfully
brought their vehicles to a stand without further collisions occurring. This group of users were travelling near or behind the crashes.

- People were observed evacuating from 9:54:42.
- Between 9:54:29 and 9:55:14 the Burnley Tunnel Controller Room Operators ("TCRO") initiated an emergency response which included the closure of the Burnley Tunnel.
- At 9:55:04 CityLink initiated an emergency call to the MFESB.
- At 9:55:14 the TCRO lodges plan to close the Burnley Tunnel.
- At 9:55:18 the TCRO initiated a full tunnel emergency response.
- At 9:55:37 the TCRO enabled emergency mode in preparation for the smoke extraction, deluge operation and evacuation.
- Between 9:55:48 and 9:55:52 the TCRO initiated a computer override updating and optimising the computer control systems to facilitate an improved response to the incident via the Burnley Tunnel’s smoke extraction, active fire suppression (deluge) and cross passage evacuation systems.
- At 9:55:54 the revised emergency response plan was initiated by the TCRO including activation of emergency smoke extraction in the crash zone.
- At 9:55:55 the deluge system was placed in standby in anticipation for activation.
- At 9:56:01 (deluge zone B19E048 commanded to activate [2nd zone])
- 9:56:30 (2nd zone B19E048 commanded to activate for the second time)
- 9:56:41 (B19E048 deluge zone commanded to activate on alternative control computer for the third time)
- 9:56:49 deluge appears in B19E048 (zone 2)
- 9:57:01 (3rd zone BFSPE049 commanded to activate)
- 9:57:03 (1st zone [FSPE047] commanded to activate) the TCRO commanded the deluge system to operate.
- 9:57:10 deluge observed zone 1.
- At 9:57:13 the third deluge zone was reported discharging.
- At 9:57:16 second zone observed to be operating via CCTV.
- At 9:57:22 evacuation mode was implemented to evacuate users via the domain tunnel. At 9:57:41 the computer control systems commenced closure of the domain tunnel in preparation for emergency evacuees and access by Emergency Services.
From 9:58:03 a mass evacuation occurred.

Few people were observed to use the specially engineered emergency safe evacuation exits despite messages and signage directing them to do so.

At 10:00:40 the first MFESB fire unit is observed at the tunnel entrance. At 10:01:00 the MFESB’s first representative arrived at the Burnley Tunnel Control Centre. At 10:04:41 MFESB personnel approach the incident site.

At 10:05:00 the first fire fighters with hoses entered the deluge zone to fight the fire. By 10:06:45 evidence of the possible effect of the emergency extraction smoke system was evident with smoke clearing downstream of the fire and longitudinal flow reversal established.

At 10:10:52 the first fireman with breathing apparatus and fire hoses enter the deluge area.

The fire involved several semi trailer vehicles and cars. The operation of the fire suppression system (deluge type) minimised fire growth and prevented fire spread. There was no spread of the fire to vehicles not involved in the crashes.

The tunnel ventilation system prevented smoke travelling naturally uphill towards the people whom were evacuating and instead was able to ensure the smoke went downhill towards the smoke extraction zone. In the area downstream of the fire the ventilation system successfully reversed the airflow and created tenable conditions except in the immediate proximity of the fire in the region of the smoke extraction system. This is a significant achievement. The longitudinal flow was substantially reduced so as to minimise accelerating fire growth at the crash site. The effectiveness of these systems working in combination is explored in detail subsequently in this report.

Damage to the tunnel was minor. There was limited spalling of the New Jersey barriers in a small area (approximately 100 mm x 150 mm) and minor heat damage to cable trays immediately above the crash zone. There was some damage to the road surface (the pavement) in the immediate vicinity of the fires. The deluge system was not harmed.

There was no breach of the structural integrity of the tunnel. The mobile telephone transmitter (leaky feeder coaxial cable system) continued to operate successfully despite minor heat damage. There was no damage to the damper control systems in the area proximate to the fires. There was no other substantial damage to the tunnel.

The three people driving the three severely damaged light vehicles lost their lives in this incident. The direct cause of their deaths is not the subject of this report.

The tunnel pavement was repaired and operationally ready within three days.

The response by the tunnel control operators to this incident was in accordance with operational procedures and displayed a high level of competence.

The computer control systems did not perform as well as would be expected. In this emergency the deficiency of performance was overcome by the competent intervention of the tunnel operator.

This high level of operator competence is reflected by the fact that the tunnel operators chose to modify the computers suggested emergency response in order to optimise the emergency response, and to initiate alternative emergency system
activation in the face of unexpected computer delays in executing potentially time
critical deluge system activations.

These actions by the operator did in fact, optimise the emergency response.

Even with the manual modifications by the TCRO of the computer system plan, the
TCRO’s response was timely and accurate. The emergency services intervention
was timely and effective.

The actions by the tunnel controller in rapidly (and correctly) activating emergency
ventilation, fire suppression and emergency evacuation systems, coupled with the
rapid response of Emergency Services, collectively contributed to the incident not
escalating into a catastrophic event.

The fact that the emergency ventilation was activated first is likely to have
contributed significantly to the safety of tunnel users because subsequent
emergency commands were delayed in there execution.

The emergency ventilation, deluge and evacuation systems were used effectively.

The CityLink controllers' actions indicate that they are competent in the effective
use of the safety systems.

The unexpected behaviour of the computer systems in this emergency raises
issues about the methodology used to verify the functionality of the safety systems
for a complex real emergency. The intervention of the operators to manage these
unexpected computer behaviours highlights the important safety critical role
human beings can play when controlling complex systems.

Conditions further down the tunnel from the crashes ("downstream") deteriorated
extremely rapidly and were likely untenable within a matter of seconds. Had there
been a series of crashes over an extended distance within the tunnel, the incident
may have injured many more people.

Analysis of the video footage clearly illustrated that there were a number of "near
misses" during the emergency stopping of other vehicles within the Burnley Tunnel
that were following the vehicles involved in the crashes. Had these near misses
been crashes they could have become sources for additional fires.

The configuration of the CityLink Tunnel allows management of multiple crash
events within the one tunnel including multiple fires. However, the current
operational procedure and observed evacuation behaviour of the road users
suggest that if such events did occur, the use of the tunnel safety systems might
not be as successful as they could be.

In particular:

(a) The current incident control system (as at 2008) did not allow the tunnel
operator to rapidly select pre-configured automated secondary crash/fire
emergency ventilation and deluge configurations. Although the operator
has the ability to manually configure the response to multiple incidents, the
enormity of successfully making correct choices in such an event must not
be underestimated.

(b) The unexpected behaviour of the computer control systems raises issues
about the adequacy of the computer control system to rapidly deal with
more complex scenarios than the essentially single fire/explosion scenario
of this investigation.
(c) The limitations on the number of deluge zones which can be used concurrently and the effect of concurrent multiple deluge zones on standpipe pressures is not well understood at an operational level.

(d) Persons evacuating the CityLink Tunnels, for the most part, chose not to avail themselves of the positively pressurised emergency cross passages to the Domain Tunnel.

In an emergency, it is highly desirable that users evacuate to a safe place other than in the incident tube.

Emergency Services response to the incident was both timely and effective. However there is an opportunity to further enhance their response by considering the prospect of the incident escalating (such as through fuel tank rupturing or volatile cargos igniting) and the challenges of working in a high noise environment.

The grades of the Burnley Tunnel are steep by world standards. Many trucks in the Australian fleet cannot easily climb such steep grades and maintain their speed. Trucks travelling down steep grades have reduced braking performance.

Accordingly, I make a series of recommendations in this report about the Melbourne CityLink tunnels. These recommendations may have application in other tunnels:

(a) Upgrading the tunnel control system so as to more readily facilitate a rapid response to single and multiple incident events.

(b) Undertaking such actions as are necessary to increase the usage of emergency cross passages and other safety related devices in an emergency.

(c) To educating the public on appropriate driving and post accident evacuations in a tunnel.

(d) MFESB reviewing its procedures for personnel entering a tunnel with a fire (e.g. breathing apparatus readiness, communications sufficiency and ‘buddy’ techniques.)

(e) Developing innovative techniques to regulate tunnel speed and vehicle separations.

The most significant risk in tunnels is vehicles travelling at different speeds. Travelling at different speeds encourages lane changing which is often (as in this case) the cause of the crash.

Drivers should be strongly encouraged not to stop in tunnels.

Measures should be taken to focus drivers attention on the traffic around (and in particular in front) of them in tunnels.

Maintaining a safe distance from the vehicle in front should become a focus of driver education in tunnels.
3. **RESEARCH**

This report relies upon material obtained from the following activities:

- Access to evidence held by the Victorian Major Collision Investigation Unit
- Attendances at the MFESB and obtaining copies of statements, reports and other relevant material
- Reviewed each of the 185 videos obtained from CityLink by the Police
- Reviewed the documents obtained from Melbourne CityLink
- Inspection of the Melbourne CityLink tunnels by way of:
  - Personal inspection during closed maintenance of all relevant safety and infrastructure facilities during August 2007 (including deluge activation and checking emergency fire cabinets and communication systems)
  - In vehicle inspections during equivalent traffic flows in both:
    - conventional vehicles
    - semi trailer(s) (HGVs)
- Meetings with attending Police and firemen to discuss matters pertinent to this inquiry
- Conducting inspections of the CityLink control room including step by step examination of the emergency systems controls
- Reviewing the thousands of lines of computer generated logs from the multiple computers which control and monitor the critical electromechanical safety systems at the tunnel
- Perusal of the autopsy results
- Perusal of witness statements
- Perusal evacuees incident surveys
- Attendances on the Sydney Harbour and Lane Cove tunnels to benchmark the Burnley Tunnel safety system. (Sydney Harbour Tunnel is Australian oldest urban road tunnel and Lane Cove is Australia’s newest)
- Attending meetings with colleagues from around the world to discuss relevant issues
- Inspecting other tunnels with fire suppression systems and/or advanced ventilation systems.
4. **THE CITYLINK TUNNELS**

The Melbourne CityLink tunnels are the only operational urban road tunnels in Victoria. They are by world standards high volume, high traffic density and proportionately high truck use tunnels. They form a critical part of Melbourne’s transport infrastructure allowing the passage of in excess of 100,000 vehicles per day.

4.1 **THE TUNNELS - INFRASTRUCTURE**

The Melbourne CityLink tunnels are complex machines akin in complexity to aircraft and other dynamic aeronautical transportation apparatus.

The Burnley Tunnel is a complex machine designed to facilitate the safe and efficient movement of vehicles and their cargos Eastbound from Melbourne. The section motorists’ drive through in the Burnley Tunnel has of the order of one thousand traffic management and mechanical and electrical devices which can be controlled from a group of master computers housed in the Tunnel Control Centre.

In addition to these devices there are many more thousands of devices ‘back of shop’ which are required to support the prime operational requirements of safe and effective movements of vehicles in normal, degraded and emergency conditions.

The development of the design to effectively manage these complex machines involves detailed analysis of air flows, fires, human behaviour and vehicles and materials. This task is ongoing and necessarily the subject of continual review and upgrading.

Like all sophisticated machines its effective operation is dependent upon the successful control of the many devices which collectively form the whole.

Maintenance, testing, upgrades and operator training all play essential roles in ensuring that in the event of an emergency the complex systems will collectively operate to deliver the desired result.

4.2 **TUNNEL FUNCTION**

The CityLink tunnels optimise traffic flows along Melbourne’s CBD east/west corridor linking the Monash Freeway to the Westgate, Tullamarine and Western Ring Road freeways.

4.2.1 **Layout of Tunnel**

The following

*Diagram 1* is a schematic diagram of the CityLink tunnels. The Burnley Tunnel is the longer of the two tunnels measuring 3.4 km long and 60 metres deep, whilst the Domain Tunnel is 1.6 km long and shallow. Each tunnel has three 3.5 metre lanes, a vertical traffic clearance of 4.9 metres and two 0.5 metre shoulders as well as an elevated 0.8 metre wide walkway.
The geology of the area required the Burnley Tunnel to go deeper than originally anticipated in order to ensure it was built in stable rock. The consequence of this is steeper slopes within the tunnel than originally expected. The impact of these slopes on safety is dealt with later in this report.

The grades in the Burnley Tunnel are summarised in the table below. Grades of 5% to 6% are extremely high for long, high volume, urban road tunnels.
To place these grades in perspective the Monaco Tunnel\(^1\) on the A500 in France is currently undergoing major refurbishment due to serious concerns about its steep grade. A new ventilation system is being installed in order to try and bring greater levels of control for emergency ventilation. Its grade is around 5.5%.

The successful control of emergency ventilation flows in a steep section of the Burnley Tunnel (around 6.2%) was a major technical achievement.

### 4.2.2 Cross Section

<table>
<thead>
<tr>
<th>Position in Tunnel (metres from western entrance)</th>
<th>Slope (Grade) %</th>
<th>Significance of Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 160</td>
<td>-0.519</td>
<td>Low</td>
</tr>
<tr>
<td>160 – 691</td>
<td>-6.242</td>
<td>Extremely high</td>
</tr>
<tr>
<td>891 – 1,275</td>
<td>-0.737</td>
<td>Low</td>
</tr>
<tr>
<td>1,335 – 1,780</td>
<td>-0.486</td>
<td>Low</td>
</tr>
<tr>
<td>2,080 – 2,910</td>
<td>+5.2</td>
<td>Extremely high</td>
</tr>
</tbody>
</table>

\(^{1}\) The use of bypass injectors and jet fans for the control of the longitudinal air velocity in case of fire. Case study: *The Monaco Tunnel on the A500*; by X Duigas, A Weatherill, F Kritter, BG Consulting Engineers Limited, Switzerland. Reported in Tunnel Safety Forum for Road and Rail, International Conference, 23 to 25 April 2007, Nice, France; p165.
4.2.3 Emergency/Normal Ventilation

In normal operating conditions tunnel air travels in the direction of traffic flow, except in the area of the exit portals where air is often extracted in accordance with strict environmental emission requirements from the Environment Protection Authority.

In an emergency the ventilation can be rapidly reconfigured to extract large volumes of potentially toxic air from above the combustion area. In addition tunnel air flow is directed from either side of a fire towards the fore so as to best ensure the safety of people at any location in the tunnel.

In the western section of the Burnley Tunnel the smoke extraction mode is driven by two sets of axial fans at two separate locations, with each fan having an extraction capacity of 110m$^3$/sec.

The cross sectional area of the tunnel is around 80m$^2$.

This extraction system is coupled to the longitudinal ventilation systems jet fans to try and achieve an air-speed near a fire of around 1.5m/sec to control the movement of smoke away from the fire against the flow of fresh air (backlayering). Such a design concept is reliant on proper operation in an emergency to work. In this instance it worked. (Refer to diagrams 2, 6 & 7).

4.2.4 Layout of Emergency Features

Both CityLink tunnels utilize an extreme range of emergency equipment.

(a) Fire hydrants and fire boxes

The fire hydrants, deluge system and fire hoses are all supplied by three multiple mains feeds.

In each fire cabinet (located every 60 metres along the tunnel) there is:

- a 36 metre 19mm fire hose
- an unequipped fire hydrant
- two dry chemical extinguishers

During tunnel inspections the functionality of these cabinets including their alarms were confirmed.
On the outside of the fire cabinets in large letters the identity of the fire cabinet is marked to assist in determining location. This number is the critical location input by the tunnel operators when responding to an incident and is also used by emergency services.

In addition there is an emergency communications intercom which contacts with the tunnel control.

**Picture 1:** In tunnel motorists’ emergency telephone. (During tunnel inspections operability of the intercom and alarms on cabinet doors were confirmed.) These devices are known within emergency services as “METS” (Motorists Emergency Telephones).

### 4.2.5 Deluge System

Melbourne CityLink uses a deluge system. This system is divided into individually operable zones of 30 metres in length and 11.5 metres in width. It is a dry system – once remotely operated quick action valves are commanded to open and an otherwise dry set of pipes is filled with water.

The use of such systems is extremely controversial internationally. In 2000 the use of such systems was – in substance – prohibited under both NFPA 502 (National Fire Protection Association of America) and PIARC standards (World Road Association). CityLink chose to embrace the approach taken in Japan and follow advice from MFESB to install the system.

In 2007 both PIARC and NFPA 502 changed their standards to recognise deluge systems as a legitimate fire life safety technology for road tunnels.

The deluge discharge rate is around 2,850 litres per minute per 30 metre zone. The tunnels are equipped with large collection sumps. In the March emergency these sumps contained the deluge water. During the 23 March 2007 emergency tankers emptied the sumps in order to ensure that if the emergency was ongoing there was sufficient capacity to collect the discharged deluge waters.

Importantly the decision to install a deluge system was coupled with detailed technical analysis of the nozzle performance. Critical factors such as droplet size distribution, trajectory modelling of
droplets through a range of longitudinal velocities and a speed of 10 metres/second was selected as the critical longitudinal velocity for achieving spread and flow performance for given water pressures.

Picture 2: Spiral nozzle in region of the tunnel fires

Picture 3: Deluge system is suspended from pipes along the roof of the tunnel

For effective deluge operation activation must be rapid and accurate. If discharged in this way fire growth rates are likely controlled, the risk of rapid fire spread minimised and thereby toxic gas and smoke generation volumes contained. The undesirable consequences of its activation such as smoke destratification, increased humidity and decreased visibility are hopefully outweighed by their other positive outcomes of fire growth rate control, containment of fire spread, and reduced temperatures.

These positive outcomes were observed to occur in the CityLink fires. The positive effects of the deluge were observed to far outweigh the negative effects of its activation in this instance.
Diagram 4: This diagram is an example of Trajectory calculations for water droplets of size Dv0.9 droplet range at a flow rate of 11.5 litres per minute at 0.5 bars of pressure.2

Detailed consideration of deluge nozzle performance is required to ensure optimal deluge performance. There is a risk that in future tunnels detailed consideration of such fundamentally important matters may be overlooked or its importance not recognised.

4.2.6 Smoke and thermal detection

(a) Linear heat detectors

A linear heat detection system is installed above traffic lanes to detect temperatures in excess of 68 degrees Celsius or a change in temperature greater than a predetermined rate. These alarms did not play a critical role in the Burnley Tunnel fires.

Smoke detectors are located in all other underground service areas.

4.2.7 Communications

(a) Radio rebroadcast

10FM and 10AM radio stations have their transmissions rebroadcast within the tunnel. This rebroadcasting enables CityLink to disrupt normal transmissions and superimpose messages over active radios whilst vehicles are in the tunnels. Usually these rebroadcasts are coupled to a tunnel public address system.

Radio rebroadcast was used in the Burnley Tunnel incident. There was a correlation between evacuation message on the rebroadcast and PA systems and observed conduct of the evacuees.

(b) Public address system

Spaced at 30 metre intervals 178 speakers can be used to make public announcements by the tunnel control operator.

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2 Spray Nozzle Engineering, Melbourne (supplier of deluge nozzles to Melbourne CityLink)
Normally the announcements are the same as those being played through the radio rebroadcast system.

There was a correlation between evacuation message on the rebroadcast and PA systems and observed conduct of the evacuees.

(c) **Emergency services radio**

A common MFESB, ambulance, Victoria Police communications rebroadcast system is provided through the tunnels. This system replicates the functionality of emergency services radios on the surface. However on the day of the incident the level of service was restricted due to scheduled maintenance.

The coverage of this system in refuge, cross passage and other non public areas was unsatisfactory at the time of finalising this report. Emergency services personnel have lost their lives in these locations in other tunnel fire events\(^3\). The provision of radio coverage is highly desirable.

The functionality of these services was not compromised by the events of 23 March 2007. It appears the combination of cable types used and deluge system protection ensured full functionality of the retransmission systems.

(d) **Fire telephone system**

A fire telephone system is installed at 120 metre intervals. This was installed especially for firemen. It has four hour battery backup and a high level of reliability.

Despite issues with communications during the 23\(^{rd}\) of March incident the fire telephone system it was not used. The reason firemen did not use the fire phone system is unclear – especially give the communications problems being experienced during the incident.

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\(^3\) Mont Blanc 1999
4.2.8 Signs

(a) Variable message signs

Variable message signs ("TIMS" Tunnel Incident Management Signs) are located at regular intervals throughout the tunnels. The tunnel control operator can display messages about lane closures, evacuations, tunnel closures etc. These were utilised during the emergency and observed to function appropriately on the CCTV images analysed.

(b) Variable speed limit signs

Variable speed limit signs allow the tunnel operator to vary the speed displayed to motorists in the tunnel. They incorporate a set of ‘wig wag’ lights which signify to motorists that the speed is being changed. These were observed to operate correctly during the emergency.

(c) Closed circuit television (CCTV)

There are 17 CCTV cameras within the Burnley Tunnel, all with pan tilt zoom capability operated by the tunnel control operator. These were used extensively and effectively during the emergency.

(d) Automatic incident detection (AID) video cameras

60 AID cameras provide images of the Burnley Tunnel. These images are constantly analysed by computers to detect incidents. It was the AID image analysis which first alerted the tunnel operators to a stopped truck in the tunnel.

The AID alarm system was instrumental to the operator being able to rapidly detect an incident and effectively respond to it.

4.2.9 Access and Egress

Access and egress by road is normally by one or other of the two tunnels. Servicing the Burnley Tunnel in addition to this are four passages linking the Burnley Tunnel to the Domain Tunnel, three safe havens where a tenable environment is sought to be maintained by active ventilation of underground caverns and a separately constructed parallel pedestrian emergency tunnel providing a safe place for pedestrians following an incident. These arrangements are depicted in the following plan.

The emergency egress pathways were not well utilized in the emergency evacuation; this was despite emergency broadcast messages directing evacuees to the egress pathways. In a range of credible scenarios failure to use these emergency egress pathways may have placed users at unnecessary risk. Measures to increase the utilisations of egress pathways should be explored. This should be addressed as a priority. CityLink’s current ‘aesthetics upgrade’ is likely to improve its performance.
4.2.10 **Rate of Hazardous Obstructions in Running Lanes**

Obstructions in running lanes are not a rare event in the CityLink tunnels. The rate of such obstructions is significantly higher in the Burnley Tunnel than the Domain Tunnel. While these tunnels are of different lengths the disproportionately high number of obstructions in the Burnley Tunnel are beyond this difference in length.

It is likely that an explanation lies in a range of factors including its degree of difficulty (due to slope) and its proximity to major vehicle entrances to Melbourne.

The following table illustrates that on average a stopped vehicle or obstruction occurs in a running lane more than once a day – on average.

This means that it is fundamental for the safe operation of CityLink that its operators are competent, its safety systems operable and its users responsible in order to ensure that a high level of operational safety is achieved and maintained. Vigilance in monitoring the ongoing trends in this data is essential.

<table>
<thead>
<tr>
<th>Incident Type</th>
<th>Burnley</th>
<th>Domain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gone on arrival</td>
<td>77</td>
<td>15</td>
<td>92</td>
</tr>
<tr>
<td>Out of Fuel</td>
<td>74</td>
<td>17</td>
<td>91</td>
</tr>
<tr>
<td>Flat Tyre</td>
<td>29</td>
<td>9</td>
<td>38</td>
</tr>
<tr>
<td>Mechanical Failure</td>
<td>133</td>
<td>26</td>
<td>159</td>
</tr>
<tr>
<td>Electrical Fault</td>
<td>33</td>
<td>8</td>
<td>41</td>
</tr>
<tr>
<td>Debris</td>
<td>23</td>
<td>20</td>
<td>43</td>
</tr>
<tr>
<td>Prohibited User</td>
<td>11</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>Accidents</td>
<td>19</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>Other</td>
<td>13</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>412</td>
<td>110</td>
<td>522</td>
</tr>
</tbody>
</table>
5. **The Incident – 23 March 2007**

In order to understand the Burnley incident an intensive analysis of the computer records, video footage and witness statements has been undertaken. The revealed ‘time line’ for the events of this incident are summarised in Appendix A. The material used to create the time line is noted in Appendix B or referred to within the time line document. Where there is a conflict in the time line the Appendix A data is authoritative over all other references in this document.

For convenience the description of the incident has been dissected into a series of phases.

5.1 **Phases**

5.1.1 **Phase 1 – 9.47AM+ - Leading to Incident**

- **Users:**
  - Vehicles – vehicles mix 28% heavy vehicles and 72% cars (as extracted from 10am data)
  - Lanes – all lanes open

- **Speed** – signs set at 80 km/h

- **Behaviour** – all vehicles travelling generally at or below speed limit.

- **Lane changes** regularly occurring without incident. All classes of vehicles, using all lanes

- **Vehicles generally congesting** as they approach bottom of steep (6.2%) decline in the Burnley Tunnel. Distances between vehicles lessening as vehicles attempt to maintain lawful speed. No obvious differentiation between speeds of vehicles in differing lanes.

Picture 5:  *Time 9:52:11*

Looking in direction of accident site prior to Truck 1 stopping. Truck 1 is seen here in middle lane prior to pulling over to a halt in the left far lane.

Vehicle Separation: non congested, uninterrupted.
• **Operations**
  - Controller – controller present and in command
  - Alarms – regular system alarms being dealt with on an as needs basis
  - Response – stopped vehicle on surface road being dealt with as a matter of course prior to stopped vehicle alarm in tunnel

• **Infrastructure**
  - Ventilation
    - operating normally with longitudinal air flow established in direction of traffic flow varying between 4 to nearly 6 metres/second
  - Communication
    - Radio rebroadcast – operating normally
    - Emergency services – the emergency services rely upon the Metropolitan Mobile Radio System. In the hour leading up to the incident routine maintenance was commenced. These activities were undertaken by a third party as part of the State’s emergency services communication program.

The routine maintenance required shifting responsibility for emergency radio from one ‘base station’ to another. These base stations are known as ‘BDA donor sites’ and each is responsible for communications with what are known as ‘remote sites’.

Responsibility for the Transurban tunnels along with other important underground remote sites was shifted to another BDA donor site which continued to be responsible for emergency communications to a range of other important Melbourne facilities.

In shifting responsibility for the underground remote sites to the other donor site the available service to all sites was generally reduced because many more remote sites were now sharing a single donor site and the capacity of the new donor site was technically less due to there being fewer channels available to share in the event of an emergency.

(Neither CityLink operations nor responding emergency services personnel were aware of these changes to emergency communication service levels in the tunnel. This led to a reduced level of service for emergency communications. Had this been known in advance an appropriate
communications risk mitigation strategy could have been in place.)

- Lane signs – all lanes were open
- Variable message signs – displaying regular messages

Surface Road

**Picture 6: Tollway Camera – Time 9:53:24**

The three trucks on the left carriageway will become involved in the collisions. They can be seen here travelling as a ‘group’ at lawful speeds towards the tunnel entrance.

5.1.2 Phase 2 – 9.52.30 to 9.52.42 – Stopped Vehicle and Alarm to Operator

- **Users**
  - Vehicles – a truck (Truck 1) observed to slow in centre lane and change into left lane and stop. Truck 1 stops at 9.52.30. Incident detection systems immediately identified stopped vehicle. This identification process superimposes a red arrow in the frame of the recorded images from the camera with the alarm. This alarm is not sent immediately to the operator. The computers assess each alarm in order to filter false alarms from real alarms.
  - Users proactively responding to stopped Truck 1 and successfully lane changing where necessary. Driver of Truck 1 puts on emergency blinkers prior to stopping during lane change and stopping manoeuvre.

**Picture 7: Time 9:52:30**

This photograph is extracted from the recorded video image of the camera nearest stopped Truck 1. It shows the first detection of the stopped Truck 1 by the computer.
- Lanes – all lanes remain open with stopped Truck 1 in left lane obstructing traffic flow
- Speed – vehicles appear to slow a little more in response to observed obstruction

**Picture 8:** Illustrates self regulation of traffic with obstructed left lane. Distances between vehicles shortened and reduced speeds through driver response to obstruction

- Vehicle Separation – vehicles travelling more closely as speeds reduced and merging commences

**Operations**
- Controller – controller not aware of Truck 1 stopping as no alarm during first few seconds of Truck 1 stopping is sent to the controller. One of the two CityLink controllers is actively responding to another stopped vehicle on the surface road. Images of this incident appear on the control room central (shared) large screen viewer.

- Alarms – no alarm
- Response – none at this time

**Infrastructure**
- Ventilation – as per Phase 1 (normal)
- Communication
  - Radio rebroadcast – as per Phase 1
  - Emergency services - as per Phase 1
  - Lane signs – as per Phase 1
  - Variable message signs – as per Phase 1

5.1.3 PHASE 3 – 9:52:42 UNTIL 9:53:37 – OPERATOR RECEIVES AND RESPONDS TO ALARM FOR STOPPED TRUCK 1

**Users**
- Vehicles – same as in Phase 1
- Lanes – same as Phase 2
- Speed – same as Phase 2
- Vehicle Separation – same as Phase 2
- User Behaviour – same as Phase 2

![Picture](image)

**Picture 9: Camera 51 – Time 9:53:36**

Traffic moves to centre and right lanes to avoid stopped truck. Vehicles slowing without speed signs being altered. Traffic self regulating.

- **Operations**
  - Controller – computer systems indicate first stopped vehicle alarm for Truck 1 at 9:52:42 followed by another stopped vehicle alarm at 9:52:45.

  At 9:52:58 the operator manually selects a video camera to inspect the alarmed area and visually confirms the stopped Truck 1.

  The Operator contacts incident response officers of CityLink to respond to stopped Truck 1 and go to the truck and render assistance. (Source: witness statements – not on computer logs or video footage)

- **Alarms**
  - 9:52:42: stopped vehicle alarm
  - 9:52:45: stopped vehicle alarm x 2
  - 9:53:11: operator physically acknowledges 3 stopped vehicle alarms on the computer control system

- **Response**
  - Video camera confirmation of stopped Truck 1 alarms commences at 9:52:58 and results in dispatch of two incident response officers, acknowledgement of stopped vehicle alarms and commencement of lane closure computer plan at 9:53:37.
• **Infrastructure**
  - Ventilation – same as Phase 1
  - Communication
    - Radio rebroadcast – same as Phase 1
    - Emergency services - same as Phase 1
    - Lane signs – same as Phase 1
    - Variable message signs – same as Phase 1

5.1.4 **Phase 4 – 9:53:37 to 9:54:26 – Lane Closure Initiation**

• **Users**
  - Vehicles – same as in Phase 1
  - Lanes – left lane closure initiated and commenced
  - Speed – vehicles slowing
  - Vehicle Separation – space between vehicles decreasing
  - User Behaviour – changes to tunnel signage via variable message and speed signs coupled with messages over the radio rebroadcast system concurrent with observed changes to speed and position of vehicles. Driver of Truck 1 returns to his cab at 9:54:00 after 71 second inspection of trailer.
  - Variable speed signs change at 9:54:16
  - Truck 2 changes from centre lane to left lane before variable message changes reducing the speed limit

**Picture 10: Time 9:54:22 +**

Vehicles in all lanes observed to be nearly stopped in proximity of Truck 1 stopped in left lane. Evidence of heavy braking by vehicles in this area e.g. Truck 4 in lane 3 skidding.
This photograph is taken only moments before the collisions commence. The truck in the left lane ("Twigg") is braking behind two stopping vehicles being obstructed by the stopped truck (Truck 1). The truck in the right lane’s trailer is skidding under brakes. The truck which crashes into all of these vehicles is not yet in the frame. It is approaching at a greater speed than these slowing vehicles from behind in the left lane.

- **Operations**
  - Controller – tunnel controller initiates and facilitates response to stopped vehicle (Truck 1) in left lane. This process includes reconfirmation of the vehicles position via operator selected video cameras.

    A new incident report is created on the control computers which requires information such as where the incident is, where lane closures are required from in order for the computer to compile the necessary response

    - Response
      - 9:53:37 to 9:54:04: new plan for incident initiated and operator completes incident details in control computer. Details must be entered into the computer by the
operator before an incident response proceeds.

- 9:54:04: completed incident plan loaded
- 9:54:05: incident plan started
- 9:54:12: operator confirms plan to proceed
- 9:54:12: radio rebroadcast message for lane closure commences (~ +2 seconds in computer log differences between computers) (ID148)\(^4\)

**Infrastructure**

- Ventilation – remains unchanged
- Communication
  - Radio rebroadcast – lane closure message at 9:54:12
  - Emergency services - not required
  - Lane signs – lane closed signs activated in left lane
  - Variable message signs – variable message signs alter to reflect lane closure and reduced speeds.

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**Picture 12:** Camera 51 – Time 9:54:18

(Note truck stopped ahead in left lane)

**Picture 13:** Camera 51 – Time 9:54:19

(Note truck “McCains” travelling more quickly than other vehicles up left lane)

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\(^4\) PARRB message 148: “Attention all drivers. This is the CityLink Control Room. Traffic restrictions now apply within the tunnel. The left lane is closed due to an incident approximately 2 kilometres from the tunnel entrance. Please observe all overhead lane signs and a reduced speed limit of 60 kilometres per hour from the tunnel entrance to Fire Box B33. CityLink thanks you for your cooperation.”
5.1.5 Phase 5 – 9:54:26 to 9:55:14 – Major Collisions

**Picture 14:**
*Camera 53*
*Time 9:54:24*

(Note: Smoke from rear wheels of truck in right lane BEFORE any of the truck lane changing and crashes occur.

**Picture 15:**
*Camera 53*
*Time 9:54:26*

(Note: Truck in centre lane crashing into truck in right lane) – over a two second period the Twigg truck moves only a few metres, and likewise the truck in the right lane. During this period the McCain truck attempts to pass the Twigg truck, and crashes into the truck in the right lane of the tunnel.

**Picture 16:**
*Camera 54*
*Time 9:54:27*

Controllers alarms at time of collision (Red arrows are the computer generated “alarm” signatures).

**Picture 17:**
*Camera 55*
*Time 9:54:32*

(Note: Truck with steel rolls narrowly avoids a major collision. Captured here with smoke from crashes and fires.

- **Users**
  - Vehicles – Several vehicles involved in major collisions involving immediate and obvious explosions, vehicle damage and likely death. Vehicles immediately behind incident manage to stop without further crashes than those caused by the initial collisions.
  - Lanes – Left lane closed – all lanes blocked
  - Speed – Traffic stopped as a result of collisions – all lanes blocked

**Picture 18:**  
*Time 9:55:13*

Cars in all lanes stopped. No drivers have left vehicles or begun self rescue. Several vehicles nearly crash during emergency braking in the seconds following the series of crashes.
- Vehicle Separation – Many vehicles narrowly avoid subsequent collisions as they come to a halt. Some vehicles try and reverse away from incident and/or leave tunnel but are stopped.

- User Behaviour
  
  - Those people involved or otherwise close to the initial major collisions rapidly leave their vehicles and/or render assistance to others involved in the collisions.
  
  - Immediate ignition and explosions make the seriousness of the incident apparent to those people close enough to see incident. People proximate to this region, whom are able to do so, leave.

Picture 19:  **Time - 9:54:42**

13 seconds after initial impact showing truck driver rushing to assist the driver in the car which has been struck by the truck in the right lane.

Picture 20:  **Time - 9:55:29**

Showing truck drivers evacuating using the elevated walkway.

- **Operations**
  
- Controller
  
  - The controller was already monitoring this area of the tunnel because he is implementing a left lane closure for the stopped vehicle (Truck 1)
It appears the controller witnessed the crashes because they appear on a recording of the video cameras he manually selected at the time of managing the Truck 1 incident.

9:54:26: the crashes begin

9:54:29: the tunnel controller physically acknowledges completion of the left lane closure plan that he started at 9:54:05

9:55:04: the break glass alarm is activated in the control room

- Alarms
  - 9:54:29: first new incident alarm (Camera 53)
  - 9:54:32: incident alarm (Camera 53)
  - 9:54:35: incident alarm (Camera 53)
  - 9:54:49: stopped vehicle alarm (AID)
  - 9:54:50: stopped vehicle alarms (AID)
  - 9:55:02: stopped vehicle alarm (AID)
  - 9:55:07: 3 stopped vehicle alarms (AID)

- Response
  - Computer logs show multiple activities as result of operator input.

- **Infrastructure**
  - Ventilation – no change
  - Communication
    - Radio rebroadcast – 9:54:40 left lane closure message playing in Burnley Tunnel (from earlier lane closure)
    - Lane signs – no change (from previous state)
    - Variable message signs – 9:54:33 overhead variable message signs changing to reflect left lane closure plan

- **Users**
  - Vehicles – some trying to reverse out
  - Lanes – all stationary
    - Speed – all vehicles stopped
    - Vehicle Separation – congested
    - User Behaviour – self rescue commenced

- **Operations**
  - Controller
    - 9:55:37: tunnel controller enables emergency mode
  - Alarms – multiple alarms
  - Response
    - 9:55:15: emergency response plan
      - Implementation of tunnel plan 990758 (Burnley Tunnel closed) begins several hundred commands to electromechanical systems to change messages and signs to close the Burnley Tunnel
    - 9:55:37: the controller enables emergency mode. This initiates a full escalation of emergency systems. In this mode such functions as smoke extraction, deluge and tunnel evacuation become options available via the computer controls to the tunnel operator.

- **Infrastructure**
  - Ventilation – unchanged
  - Communication
    - Radio rebroadcast – nil
    - Emergency services - on their way …
    - Lane signs – all changing to effect Burnley Tunnel closure
5.1.7 PHASE 7 – 9:55:38 TO 9:56:01 – ENGAGING EMERGENCY MODE

**Users**

- Vehicles – stopped
- Lanes – blocked
- Vehicle Separation – congested
- User Behaviour – evacuation commencing

**Operations**

- Controller
  - 9:55:38: computer system confirms Burnley Tunnel is closed
  - 9:55:48: Burnley Tunnel emergency mode disabled by tunnel controller

- Response – the tunnel controller must assess the incident and determine the most appropriate response. The initial incident response was for the area known as B18 but the operator determined that a better response would be achieved by using B19 in the emergency mode. The operator disabled the original emergency mode – reprogram the location – and then re-implement the emergency mode at 9:55:52. At:
  - 9:55:52: the operator confirmed he wished to proceed with the emergency response
  - 9:55:54: the operator commands for emergency smoke extraction sent by computer
  - 9:55:55: Deluge system enabled and ready to discharge in correct zone


Truck driver escaping fire. This truck driver is running past the flames – he is seen calling emergency services on his mobile telephone.
• **Infrastructure**
  
  - **Ventilation**
    
    - **9:55:54** to **9:55:58** over 100 commands are sent by the computer control systems to the tunnel’s ventilation equipment to implement an emergency ventilation regime. This requires:
      
      - fresh air to be provided to evacuees in the tunnel

  ![Picture 22: Camera 54 – Time 9:57:02 View upstream of fire](image)

  ![Picture 23: Camera 60 – Time 9:57:02 View downstream of fire](image)

  These two photographs graphically illustrate the effects of ventilation at exactly the same time in the Burnley Tunnel around 100 metres apart. The area upstream of the fire is provided with large volumes of fresh air to allow people to breath and keep toxic smoke and gasses away. In the area immediately downstream of the incident these toxic smoke and gasses are moving towards the exit portal. Emergency ventilation will attempt to contain and extract this toxic mix. The process of containing them in this way takes several minutes to implement.

  - air speed to be closely regulated at the incident
  - smoke to be extracted:
    - away from evacuating people; and
    - into overhead exhaust ducts;
  - air quality to be optimised between the area of emergency smoke extraction and the exit.

  The following sequence of still photographs is extracted from the video footage from Camera 60. They are showing a region of approximately 300 metres downstream of the fire. These photographs illustrate the total loss of tenability downstream of the fires and the subsequent intervention of the
emergency ventilation system to establish access for emergency services personnel.

It should be noted that an escalation in the fire intensity and/or a failure of elements of the emergency ventilation systems would rapidly return the area shown into untenable conditions. Accordingly this area, even with only comparatively light smoke, is a high danger zone for emergency workers.

The MFESB personnel in the truck seen in Picture 27. Camera 60 – Time 10:07:09 would have no way of knowing that only shortly before they arrived at this location conditions were most likely untenable. (Statements from MFESB indicate that breathing apparatus were not activated prior to entering the tunnel. It is acknowledged that such equipment has a limited operational time.)

Picture 24: Camera 60 – Time 9:55:01

Image downstream of crashes
35 seconds after initial impact

Picture 25: Camera 60 – Time 9:56:00

Image 94 seconds after impact
- Communication

- Radio rebroadcast – 9:55:39 emergency message playing on radio rebroadcast system in tunnel (ID 220)\(^5\)

- Variable message signs – 9:55:39 message ‘turn on radio’ and ‘turn engines off’ being displayed.

\(^5\) PARRB message 220: “Attention all drivers: This is the CityLink Control Room. Traffic restrictions now apply within the tunnel due to an incident. The tunnel has been closed approximately 1 kilometre from the entrance. It is not safe for traffic to proceed past the incident until it is cleared. If possible vehicles in the left lane are requested to move into the centre lane. Please observe the overhead signs. If instructed to, stop, switch off your vehicle’s engine, leave your radio on and remain in your vehicle. Emergency services are working to clear the accident. As soon as the incident is cleared you will be able to proceed. CityLink thanks you for your cooperation.”
5.1.8 Phase 8 – 9:56:01 to 9:57:21 – Activation of Emergency Systems

- **Users**
  - Vehicles – stopped
  - Lanes – all lanes closed to users
  - Speed – stopped
  - Vehicle Separation – congested
  - User Behaviour
    - 9:56:18: drivers of vehicles near incident attempt to reverse or otherwise establish gaps between themselves and the fires
    - 9:56:19: people involved in crashes within crash zone evacuate the crash zone

- **Operations**
  - Controller –
    - 9:56:01: tunnel controller commands deluge zone B19 E048 to open. [Deluge appears on the live CCTV footage at 9:56:49 – Camera 54]
    - 9:56:03: tunnel controller requests message (deluge warning) ID241 to play.
    - 9:56:30: tunnel controller again requests deluge zone B19 E048 to open (he has not seen it operate on the CCTV) [Deluge appears on the live CCTV footage at 9:56:49 – Camera 54]
    - 9:56:41: Traffic Operations Manager uses alternative computer to attempt (for the third time) to activate B19E048.
    - 9:57:01: tunnel controller requests second deluge zone FSPE049 to open (9:57:10 second deluge zone is seen to activate on the CCTV)

---

**PARRB message 241:** “Attention all drivers: This is the CityLink Control Room. An incident has occurred in the tunnel. The tunnel sprinkler system is about to be activated at the incident site. Drivers near the incident site are requested to stop. For your safety please observe all overhead lane signs and await further instructions.” (An alternative ending “… and await further directions. CityLink thanks you for your cooperation.” Has been suggested but not confirmed by the author.)
• 9:57:03: Traffic Operations Manager requests deluge B19E047 to open.

5.1.8.1 Deluge

The following sequence of photographs depicts the deluge system operation as recorded by tunnel CCTV.

Picture 28
Camera 54 – Time 9:56:49
Deluge Zone B19E048 seen activating

Picture 29
Camera 54 – Time 9:57:12
Deluge Zone B19E047 seen activating

Picture 30
Camera 54 – Time 9:57:28

Picture 31: Camera 54 - Time 9:56:49
Shows first zone of deluge fire suppression in zone B19, shortly before the next zone commences.

Picture 32: Camera 54 – Time 9:57:12
Showing commencement of deluge activation for zone B19 E047 (FSPEO49)
Camera 54 – Time 9:57:28

Fully developed deluge activation zone B19 EO47
(Note: No vehicles stopped in congested mode in this region.)

Camera 60 – Time 9:56:49

Cameras downstream from the crash site record zero visibility (at its height) and poor tenability soon after the crash. The activation of the deluge system does not appear to worsen the extremely degraded conditions which already existed.

Camera 65 – Time 9:56:49

Visibility at this section is worsening as each second passes and the air in the section is becoming less tenable as a plug of smoke and toxic fumes travels down the tunnel tube from the crash site.

- Alarms – although the alarms appear in the computer log they do not interfere with the emergency mode activation on the main computer. Multiple alarms populate the computer logs from the time of the crash.

- Infrastructure

- Ventilation – emergency mode ventilation implemented. Analysis of video footage and instrumentation from air flow detectors indicates emergency ventilation is effectively managing emergency ventilation requirements by:

  - Maintaining sufficient air flow towards the accident and thereby providing fresh air to people evacuating
• Reversing the air flow between the Burnley Tunnel exit portal and the extraction point near the crash thereby improving tenability for emergency services

• Extracting air from near the fire to maintain in tunnel tenability

• Positively pressurising cross passages to ensure safety of evacuating people

• Isolating the air in the Domain Tunnel from contaminated air from the Burnley Tunnel

**Camera 60 – Stop C**

The following sequence of photographs are extracted from a video camera located downstream of the emergency ventilation extraction zone. This sequence documents the rapid degeneration in tunnel tenability immediately following the crashes while also recording the improved tenability obtained as the emergency tunnel ventilation system gains control of the toxic smoke and gas from the fires.

**Picture 36:** Camera 60 – Time 9:55:01

The rear of a truck involved in the incident as it stopped (after the other vehicles were involved in the major collisions behind it) is just visible in the top left of the frame.

**Picture 37:** Camera 60 – Time 9:56:01

Over the next 60 seconds tunnel tenability rapidly degrades. The truck driver rightly chooses to flee the tunnel in his truck.
In tunnel tenability poor. Emergency ventilation system has been activated but has not yet gained control of toxic gases and smoke in area downstream of the fires.

Visibility starts to return and smoke begins to clear.

Over a few minutes the emergency ventilation system reverses the air flow back towards the emergency extraction point. If the tunnel was congested this process would provide some protection for occupants of stopped vehicles and establishes tenable conditions.

Fire truck comes into view.
- Communication
  - Radio rebroadcast
    - 9:56:04: emergency warning regarding deluge activation plays over car radios (ID 241)
    - 9:56:32: emergency warning regarding deluge activation plays over PA
    - 9:56:59: emergency warning regarding deluge activation play over car radios

5.1.9 PHASE 9 – 9:57:22 TO 10:00.39 – FORMAL EVACUATION

- Users
  - Vehicles
    - stopped in Burnley Tunnel,
    - still leaving Domain Tunnel
  - Lanes
    - Domain Tunnel is closed progressively from the right lane to the left lane to protect evacuees from the Burnley Tunnel accidentally being ran over or causing a crash should they emerge into the Domain Tunnel before vehicles in the Domain Tunnel have cleared. This is clearly depicted in the video footage and reflected in the computer logs.
    - Burnley Tunnel – all lanes closed and stationary
  - Speed
    - Domain Tunnel speed limits are reduced to 40 km/hr

Picture 42: Camera 60 – Time 10:08:01

Smoke continues to clear
- Burnley Tunnel is closed

- Vehicle Separation

- Traffic in the Domain Tunnel becomes congested as lanes are progressively closed from right to left and speed limits reduced.

- Traffic in Burnley Tunnel stationary – tunnel closed.

Picture 43: Camera 60 – Time 9:59:36

Traffic responsibly merging left at reduced speed in the Domain Tunnel as lanes are progressively closed from right to left to make safe emergency evacuees from the Burnley Tunnel as they arrive via cross passages.

Picture 44: Camera 60 – Time 10.05.31

The last cars leave Domain Tunnel as the first evacuees from the Burnley Tunnel arrive via emergency cross passages. They can be seen here walking along the elevated walkway towards the sun light at the portal. There are no signs telling the evacuees which way to evacuate in the Domain tunnel.

- User Behaviour

- (evacuation messages over tunnel PA and radio rebroadcast begin 9:57:42)

- Burnley Tunnel deluge warning over the PA and radio rebroadcast

- Drivers in the Domain Tunnel respect the changed speed and lane closure changes.

- 9:58:03: general evacuation commences in the Burnley Tunnel.

- 9:58:05: in area near Camera 52 evacuation is lead by a disabled person’s wheelchair assembly and self rescue (inference that disabled more sensitive to risk of staying in car and need to self rescue than able bodied people)
- **Operations**
  - **Controller**
    - 9:57:22: evacuation mode selected for evacuation via Domain Tunnel
    - 9:57:26: started evacuation plan (this initiated a series of computer controlled changes to both the Burnley and Domain Tunnels to facilitate an evacuation from the Burnley Tunnel with an incident proximate to fire boxes B16 to B19
    - 9:57:30: computer begins implementing Burnley Tunnel evacuation plan
    - 9:59:44: computer requires operator to confirm back layering of smoke is not an issue
  - **Alarms**
    - During this period there are multiple alarms ranging from low air flow alarms at the portal, stopped vehicle, loss of video (AID 722S & AID 720S), various ventilation system alarms, lighting alarms, debris detected in lane alarms, slow vehicle alarms, degraded visibility alarms, over-height vehicle alarm
      - 9:58:20: technical shelter door alarm (TS10)
      - 9:57:24: fire telephone system major fault alarm – acknowledged at 9:58:04
- **Infrastructure**
  - **Ventilation**
    - 9:55:52: emergency ventilation implemented. During the following 4 minute period the emergency ventilation systems reverse the flow of air downstream of the crash site, from approximately 5 to 6
metres/second towards the exit portal to approximately 1 metre/second towards the incident and smoke extraction systems. The speed of air moving downhill towards the accident is decreased from around 4 metres/second to in the order of 1 to 2 metres/second.

- This process of establishing emergency ventilation air flows takes around 4 minutes and is critical to balancing the needs of establishing and maintaining tenable environments with the risks of increasing fire size through forced ventilation.

- Communication

- Radio rebroadcast
  - 9:57:40: pre-recorded message (ID136) over the PA system in zones 1 and 2
  - 9:57:41: pre-recorded message (ID227)
  - 9:57:41: pre-recorded message (ID 136) over PA in Domain Tunnel
  - 9:57:42: Burnley Tunnel evacuation message playing on radio rebroadcast and Public Address systems (ID227)

  [Note: Emergency cross passage lighting observed to come on around 9:57:53]

  - 9:58:37: immediate evacuation message (ID227) on Burnley Tunnel Public Address system
  - 9:59:33: evacuation message (ID227) via ‘internal’ in Burnley Tunnel
  - 10.00.17: evacuation message (ID227) over radio rebroadcast

- Emergency services -

PARRB message 227: "Attention: This is the CityLink Control Room. Due to an incident, the tunnel needs to be evacuated – I repeat – the tunnel needs to be evacuated. Please ensure your vehicle’s engine is switched off. Please exit your vehicle. Walkway lights will be turned on, along with exit signs indicating the closest and safest exit point. Please use the walkway on the right side of the tunnel and walk back along the tunnel towards the West Gate Freeway. There are flashing lights above the exit doors to indicate a safe exit point. Please keep the left lane clear for access by the emergency services. Please remain calm. If you have difficulty leaving your vehicle or if you are disabled please turn on your hazard lights or flash your vehicle’s headlights to alert emergency services and other motorists that you need assistance. CityLink thanks you for your cooperation.” It has been suggested that the end of message does not say “CityLink thanks you for your cooperation” this could not be confirmed.
- Lane signs – in Domain Tunnel lane closures and speed reductions continue to facilitate Domain Tunnel closure and safe access for evacuees from Burnley Tunnel.

- Variable message signs

  . Electronic signs in tunnel advised people to either, ‘evacuate now’, and in some locations ‘walk back to tunnel entry’ depending on location in tunnel. ‘Turn off engines’, ‘no smoking’ signs appear in some locations. These signs are coming on between 9:57:40 and 9:57:43

  . In Domain Tunnel speed signs reducing to 40 km/h and lane closures occurring from 9:57:43 (as seen on Domain Tunnel cameras) (Note: I have not been supplied any portal video footage and so am unable to comment on the timeliness and effectiveness of the initial Domain Tunnel closure.)

- Cross passages

  . 9:57:53: emergency cross passages lighting is seen to come on (Camera 48 Stop F)

5.1.10  PHASE 10 – 10:00.40 TO 10:05.00 – ARRIVAL OF FIRE SERVICES

- Users

  - Vehicles – Domain Tunnel closed and free of vehicles. Burnley Tunnel stopped and congested from entrance to crash scene and clear from crash scene to exit

    - Lanes – all stationary

    - Speed – all vehicles stopped

    - Vehicle Separation – congested

- User Behaviour

  . Fire cabinet door at B15 opened (possibly an evacuee from an incident truck 10:01:51)

  . Users enter cross passage 10:02:10

  . People observed returning to vehicles after previously evacuating 10:02:37

  . Groups of people observed to form and make collective evacuation decisions 10:03:02

  . Some people observed looking at fire cabinets but not utilising 10:03:30
First evacuees enter Domain Tunnel 10:04:07
Tunnel users proceeding to crash scene to take photographs 10:04:59

**Operations**
- Controller
  - Monitoring the evacuation of Burnley Tunnel, system status for ventilation, deluge and other safety critical operations. Operator switching between cameras. As MFESB representative has arrived at the control room liaison has begun
- Alarms – multiple but monitored by controller
- Response – continuation of previous response

**Infrastructure**
- Ventilation – emergency mode continuing with emergency control of ventilation being established. See Diagram 5
- Communication
  - Radio rebroadcast
    - 10:01:14: Burnley Tunnel closed and immediate evacuation messages – ongoing every 30 seconds
  - Emergency services
    - 10:00:40: first MFESB fire truck unit arrives Tunnel portal
  - Lane signs – no change
  - Variable message signs – no change

5.1.11 Phase 11 – 10:05AM TO 11:15AM – FIRE FIGHTING

**Users**
- Vehicles – same as above
- Lanes – same as above
- Speed – all vehicles stopped
- Vehicle Separation – congested
- User Behaviour
  - 10:05:07: groups of people helping the less able. For example a group form to help lift an
apparently disabled person in a wheelchair onto the walkway

- Evacuation continuing with people accumulating in the region of the city side portal of the Burnley Tunnel

- Evacuees in the Domain Tunnel (from the Burnley Tunnel vehicles) choose to walk on the elevated walkway

- **Operations**
  - Controller
    - Same as above.
    - Alarms – as above

- **Infrastructure**
  - Ventilation – emergency mode continuing with emergency control of ventilation established.
  - Communication
    - Radio rebroadcast – ongoing
    - Emergency Services Customer Services become aware of a potential telecommunications issue with emergency services radios in the tunnel
      - 10:30:00 to 11:00:00: telecommunications system modified to give CityLink sole access to the available telecommunications capacity
      - 10:48:04: Deluge system shut down on all three zones to reveal crashed vehicles and fire damage

- **Emergency services**
  - 10:06:37: fire fighters observed making their way to crash scene on foot through stopped vehicles in Burnley Tunnel
  - 10:07:29: fire brigade in fire truck approach crash site downstream (approaching into smoke)
  - 10:08:01: fire engine stops near accident scene
  - 10:08:40: three MFESB personnel and two police observed approaching crash
site on foot through stopped traffic in incident tunnel

. 10:09:01: person arrived on foot at accident site and by 10:09:25 has entered the deluge zone without BA or a fire hose

. 10:10:52: first fire fighter with breathing apparatus and fire hose enters the deluge zone

. 10:12:36: first Police car enters Domain Tunnel

. 10:48: MFESB commands deluge to be turned off

. 11:15: MFESB declares fire under control
  ▪ Lane signs – no change
  ▪ Variable message signs – no change

5.1.12 Phase 11 – 11:15am to 2.30pm on 23.3.07 – Preliminary Inspections and Opening Non-Incident Tunnel

• Users
  - Vehicles – same as above
  - Lanes – same as above
  - Speed – all vehicles stopped
  - Vehicle Separation – congested but vehicles now being removed
  - User Behaviour
    ▪ Registered and interviewed systematically
    ▪ Assisting with removal of their vehicles

• Operations
  - Controller
    ▪ Systems checking and reopening of Domain Tunnel at 2:30pm

• Infrastructure
- Ventilation – normal ventilation re-established in Domain tunnel. Inspections and preparation for repairs in Burnley Tunnel (see separate schedule on repairs)

- **Communication**
  - Radio rebroadcast – testing of systems and confirmation of functionality for Domain Tunnel and Burnley Tunnel
  - Emergency services

- **Post incident investigations**
  - Lane signs – not applicable
  - Variable message signs – not applicable

- **Users**
  - Vehicles – all removed from tunnel
  - Lanes – remain closed
  - Speed – not applicable
  - Vehicle Separation – not applicable
  - User Behaviour
    - As above

- **Operations**
  - Controller
    - Incident recovery
    - Alarms – as above

- **Infrastructure**
  - Ventilation – emergency mode deactivated
  - Communication
    - Radio rebroadcast – not applicable
    - Emergency services
      - 11:15am MFESB declares fire under control
      - Conducting investigations
    - Lane signs – not applicable
    - Variable message signs – not applicable
5.1.13  PHASE 12 – 2:30PM ON 23.3.07 TO 27.3.07 – REPAIR AND REOPENING OF INCIDENT TUNNEL

Burnley Tunnel is inspected, repaired and systems are recommissioned. Opening is delayed for administrative reasons. The nature and extent of the repairs are discussed in section 5.5 on pages 61 and 62 of this report.

The detailed time line of events appears in Appendix A to this report.
6. INCIDENT ANALYSIS

6.1 BRIEF OBSERVATIONS OF ACTUAL INCIDENT

Through the analysis of the video footage it was possible to clearly identify and trace the journey of all vehicles in the tunnel including the trucks and cars involved in the collisions on 23 March 2007.

From that analysis, the following observations can be made:

(a) None of the vehicles observed in the sequence of videos analysed appears to have been exceeding the speed limit prior to the left hand lane being closed within the tunnel. Between the truck stopping in the left hand lane and the left hand lane closure being implemented, 22 trucks, 80 cars and one motorbike were observed to identify the road obstruction and to successfully make the merging manoeuvre from the left land to the centre and right lanes in the tunnel.

(b) That there were a group of trucks proceeding along the road from the Westgate Bridge who maintained similar relative positions from outside to inside the tunnel, as this group of trucks rounded the right hand bend preceding the steep (6.2%) decline towards the area where the truck crash occurred, the only exceptional phenomenon was a group of vehicles obstructing the left lane.

(c) That all vehicles (except one truck) within the group of trucks and cars coming through the tunnel at this time slowed and were responsive to the changed traffic conditions which were occurring within the tunnel as a result of the truck stopped in the left hand lane.

(d) That one of the group of trucks which was ahead of the others, having likely observed the stopped truck in the left lane slowed and likewise, stopped as it was unable to safely merge from the left to the centre or right lanes.

(e) That this second truck which had stopped in preparation for safely manoeuvring to the centre or right lanes behind the first truck stopped in the left lane, and did so behind two other vehicles which had likewise, been unable to select a safe diversion opportunity within the tunnel.

(f) That the drivers of all stopped vehicles had done and were not observed to do any manoeuvres which were dangerous or in anyway contributory to the crashes.

(g) That the drivers of all vehicles near the series of collisions were able to all stop their vehicles in time without further crash despite the emergency nature of the stopping manoeuvres required.

(h) That the drivers of all following vehicles were able to stop some distance away from the crashed vehicles and thereby minimised the likelihood of fire spread and minimised the likelihood of asphyxiation due to proximity to the crash sites.
6.2 **VENTILATION**

6.2.1 **NORMAL VENTILATION MODE**

The CityLink tunnels are longitudinally ventilated during normal conditions with air extraction near the portals to ensure air containing vehicle emissions meets strict environmental air quality requirements.

Typically the air flow along the tunnels is at around 20 km/hr (6 metres/second). Mostly the movement of vehicles through the tunnels keeps the air moving in the direction of traffic flow. This phenomenon is known as ‘the piston effect’.

On the day of the incident the emergency ventilation system was activated, rapidly changing the ventilation flow to enhance tunnel safety.

6.2.2 **EMERGENCY VENTILATION MODE**

The emergency ventilation mode utilises smoke extraction capability in the roof of the tunnel (known as ‘smoke dampers’) coupled with controlling the speed of air travelling towards the fire in the direction of the traffic flow (the upstream air flow) and reversing the flow of air from the fire towards the exit portal to towards the fire from the exit portal.

In other words the ventilation system tries to bring clean fresh air into both sides of the fire and extract the toxic gas and smoke from above the fire. This is a very complicated task to achieve. In this emergency this operational objective was achieved.

The reason for developing such a complex emergency response is to both protect any tunnel users whom may be caught in congested traffic beyond the crash/fire scene and also to provide a reasonable environment for emergency services to enter the tunnel to fight the fire.

![Diagram 5 - Schematic representation of the emergency ventilation system in the roof of the Burnley Tunnel including information on tunnel slope.](image)
Diagram 6 - Schematic representation of smoke plume in extraction zone with reduced (controlled) fresh air supply in the direction of vehicle travel and reversed flow back towards the fire from the eastern end of the tunnel.

Diagram 7 depicts the actual recorded changes in the direction of air flow at different locations in the tunnel. Importantly it shows how quickly the longitudinal air flow was reduced upstream of the fire (green and purple lines) and how air flow was reversed downstream of the fire (red line).

The following series of photographs illustrates what this airflow reversal looked like inside the tunnel some 300 metres further along the tunnel from the scene of the fires.
<table>
<thead>
<tr>
<th>Time</th>
<th>Camera 65 – Chainage 12082</th>
<th>Camera 70 – Chainage 12382</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:56:00</td>
<td><img src="image1.jpg" alt="Image" /></td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td>9:57:00</td>
<td><img src="image3.jpg" alt="Image" /></td>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>last truck leaving the tunnel just visible</td>
<td></td>
</tr>
<tr>
<td>9:58:00</td>
<td><img src="image5.jpg" alt="Image" /></td>
<td><img src="image6.jpg" alt="Image" /></td>
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<tr>
<td>9:59:00</td>
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<td><img src="image8.jpg" alt="Image" /></td>
</tr>
<tr>
<td>10:00:00</td>
<td><img src="image9.jpg" alt="Image" /></td>
<td><img src="image10.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Time</td>
<td>Camera 65 – Chainage 12082</td>
<td>Camera 70 – Chainage 12382</td>
</tr>
<tr>
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<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>10:03:00</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
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<tr>
<td>10:04:00</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>10:05:00</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>

The above sequence of photographs clearly depicts the impact of the emergency ventilation system on stopping – and then reversing smoke movement down the tunnel. At this time the fire was still burning in the...
tunnel and the emergency smoke extraction system was successfully extracting most of the toxic smoke and gases.

This type of emergency performance is what is sought.

**Ventilation in context**

The ventilation design concept in Melbourne CityLink, despite being developed in the latter decade of last century, is consistent with the latest European directive and specific country legislative changes (e.g., France). As noted by R Buchmann Poyry Limited in Switzerland:

> “In recent years many countries have changed their requirements for ventilating road tunnels in an emergency. Traditional linear exhaust systems are no longer permitted; the smoke has to be exhausted from the tunnel close to the fire. The design of this new ventilation system requires a completely different treatment. Aspects like exhausted flow rate, leakages, high exhaust duct under pressure, and escape way ventilation as well as controllability become important.

...  

The ventilation system was and still is a major part of the road tunnel safety system but the design case for the system has completely changed. The principle aim of the ventilation was to maintain the required air quality during normal operation, whereas today it is the emergency case, extracting the smoke at the fire site so as to prevent its further spreading.

...

The new approach is to concentrate the exhaust flow at or near the fire location and create air flows in the tunnel so that the smoke propagation over the stationary vehicles can be minimised or even prevented. In the Swiss designed guidelines the requirements are a minimum exhaust flow of 3 to 4 times tunnel cross section and a longitudinal air flow in the tunnel towards the fire ... [of] 3 metres a second from one side [in the traffic direction] for unidirectional traffic tunnels. ...”

6.3 **FIRE IN PERSPECTIVE**

The Burnley Tunnel fires were remarkable in three important respects:

(a) The fires began instantaneously through the initial series of collisions. Analysis of video footage clearly documents almost immediate fire growth from around 10MW to what is estimated at somewhere around 30 MW, in two minutes (this is a comparatively large fire over such a short period of time by international standards);

(b) Despite the availability of flammable material fire growth was limited; and

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8 Estimating the power required to effectively ventilate a tunnel in an emergency — R Buchmann, Poyry Limited in Switzerland, Tunnel Safety Forum for Road and Rail, International Conference, 23 to 25 April 2007, Nice, France.
Despite the availability of fuel (vehicles) in the tunnel, fire spread was limited.

- **Instant Fire**

The immediate fire had an almost immediate heat release rate of 10MW. This was caused by the initial crashes between the truck and other vehicles.

The seriousness of this as a triggering event is highlighted by a series of tests which have been conducted around the world on typical fire heat release growth rates. The following **Diagram 8** summarises this information.

**Diagram 8**

**HRR from large vehicles**

The vertical axis indicates the heat release rate and the horizontal axis indicates the time from initial ignition. Of importance is the steep and steady curve from approximately five minutes after ignition to peak heat release rates, typically in the order of 75 to 200 MW.

Fires of these magnitudes are extremely dangerous in tunnels. People within the tunnel are at great risk from the enormous volumes of toxic gas and smoke generated coupled with the very high rates of heat transfer in the tunnel air. Furthermore, at such high heat release rates fires "jump" hundreds of metres along tunnels between vehicles. (This is the subject of further discussion below).

In the Burnley Tunnel incident, having a vigorous and multi-seated series of fires (several fires) which each had an ample supply of fuel, and air (with
other vehicles comparatively close by) made this incident – in world terms – extremely dangerous.

<table>
<thead>
<tr>
<th>ACCIDENT, YEAR</th>
<th>ROAD TUNNELS</th>
<th>VEHICLE TYPE</th>
<th>ESTIMATED PEAK HRR (MW)</th>
<th>ESTIMATED FIRE DURATION</th>
<th>NUMBER OF FATALITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Mont Blanc</td>
<td>15 trucks, 9 cars *</td>
<td>300-380</td>
<td>9-13 h</td>
<td>39</td>
</tr>
<tr>
<td>1999</td>
<td>Tauern</td>
<td>16 trucks, 24 cars</td>
<td>300-400</td>
<td>7-10 h</td>
<td>12</td>
</tr>
<tr>
<td>2001</td>
<td>St Gotthard</td>
<td>13 trucks, 10 cars</td>
<td>&gt;200</td>
<td>3-4</td>
<td>11</td>
</tr>
<tr>
<td>2005</td>
<td>Frejus tunnel</td>
<td>4 trucks, 3 fire fighting vehicles</td>
<td>&gt;200</td>
<td>&lt;6</td>
<td>2</td>
</tr>
<tr>
<td>2007</td>
<td>Burnley tunnel</td>
<td>2 trucks, 3 cars</td>
<td>10 - 20</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

The above table summarises a series of other road tunnel fires from around the world. In each of these foreign cases, the number of vehicles initially involved in the fires was less than in the Burnley Tunnel fire. In the Burnley Tunnel crashes the fire neither grew appreciably nor spread to involve other vehicles. In all instances of car crash induced fires some fatalities are attributable to the vehicle crashes.

As illustrated by the table, the number of vehicles ultimately involved in the tunnel fires overseas became greater than the Burnley Tunnel fire. In the Burnley Tunnel incident, the spread of the fire was contained and limited to those vehicles involved in the initial series of collisions.

Limiting the fire growth and stopping the spread of the fire within the Burnley Tunnel was a major technical achievement. The only other country which has achieved such results is Japan. Japan and Australia share one technology in common – the deluge system for fire fighting.

Diagram 9

Diagram 9 above is an extract of Diagram 8 with a simplified heat release rate curve superimposed upon the curves for heat release rate growth obtained in testing from around the world.
Diagram 9 illustrates that although the heat release rate in the Burnley Tunnel fire was greater than in the initial period for these tests, the expected rapid increase in a release rate did not occur.

This is also evident in the draft modelling analysis of the incident by Connell Wagner in the following figure. The diagram illustrates both the steep rate of fire growth and the dramatic impact on heat release rates of the deluge system. This modelling was limited to two deluge zones. In the real event three zones were used.

![Total HRR](image)

**Figure 7: HRR time history**

There were only two differences in the way these incidents were managed in the Burnley Tunnel than those experienced during these tests and in other catastrophic road tunnel fires around the world. It was the combination of smoke extraction and rapidly deployed deluge system operation which most likely ensured that the heat release rate did not increase as expected and remained comparatively constant thereby allowing the intervention of fire fighting personnel to put the fires out.

This is an unusual outcome and without parallel in major tunnel fires in Europe or the United States.

- **Fire Spread**

Actual road tunnel fires from around the world graphically document the ability of tunnel fires to travel long distances between vehicles. The distances travelled are typically in the order of 100 or more metres. This is illustrated in the following Photograph 1 from the Tauern fire of 1999. This...
photograph illustrates how the fire was able to travel long distances within the Tauern tunnel destroying all flammable material as it passed.

Picture 45

**Tauern Fire 1999**

*Prof. Haukur Ingason 2007, SP Fire Technology, Malardalen University, SP Technical Research Institute of Sweden*

In the Burnley Tunnel rapid and effective activation of the emergency ventilation system to control the longitudinal velocities in the tunnel was critical to create tenable conditions for emergency access downstream of the fire and tenable conditions for evacuation upstream of the fire for evacuees. This was coupled with rapid and effective activation of the deluge system. These two factors link to explain why the Burnley Tunnel fires remain comparatively small, could be extinguished readily, did minimal damage to the tunnel infrastructure and allowed CityLink to re-open so rapidly.

The positive impact of these systems on the health and wellbeing of people evacuating the tunnel and Emergency Services’ personnel fighting the fires was very high.

- **A Comparative Recent Fire?**

On 12 October 2007 several trucks were involved in a series of crashes in the Newhall Pass Tunnel California. The Newhall Pass Tunnel has no ventilation system nor active suppression system. The number of vehicles involved is similar to the Burnley Tunnel fires.

Picture 46 following shows the series of trucks burning without any effective emergency fire fighting intervention.
Picture 46

The resulting structural damage to the tunnel is highlighted in the following Picture 48.

By comparison, the Burnley Tunnel fire which involved a similar number of vehicles but had the active fire suppression and ventilation system resulted in damage as depicted in the following Picture 49.
The minimal extent of the damage to the tunnel is illustrated in the following Picture 50. The spalling of the non-structural road barrier was to an area approximately 100 mm x 150 mm.

It can be clearly seen from these photographs that for a similar number of vehicles the damage is very different.

The best explanation of these differences is the active suppression system and the emergency ventilation system. Perhaps more importantly is the fact these systems were operated in a timely and effective manner in CityLink and that MFESB were able to rapidly respond.

6.4 Ventilation Discussion

It is well known and documented that near the seat of a fire in a tunnel the toxic smoke and gasses tend to remain buoyant. This phenomenon of a layer of hot buoyant smoke and gas underlies the safety concept for emergency evacuation in many tunnels throughout the world.

However it is also well known that as this smoke and gas cools it falls from its stratified state on the ceiling rapidly degrading tunnel tenability. The distance over which this phenomenon occurs is often debated but its effect is dramatic. In the Burnley Tunnel incident this phenomenon is documented by the video footage downstream of the incident.
The following picture shows a truck driver fleeing the scene of the crashes while the intense fire burns. The sharpness of the shadow he casts on the elevated walkway illustrates the intensity of the blaze. The bright orange colour of the light, and rapidly swirling clouds of fiery gas and embers is also consistent with the intensity of the blaze.

**Picture 51: Camera 55 Time 9:55:59**

![Area of stratifying smoke](image)

**Picture 52: Camera 60 Time 9:55:59**

![Destratified smoke downstream of fires](image)

At the same time as the picture above only around 100 metres further downstream Camera 60 records the development of dark toxic smoke in a matter of seconds following an escaping vehicle which had stopped after the crashes.

**Camera 56**

![Sequence of photographs](image)

This sequence of photographs documents the rapid degeneration of conditions downstream of the incidents and within the extraction zone. This area remains degraded during the entire fire fighting phase for over an hour.
Diagram 10 - The area shown with the smoke plume is the area of smoke extraction that Camera 56 is located within and photographing. It remained severely degraded for the duration of the incident.

The potential of this event to have escalated to a catastrophic event must not be discounted. Had CityLink not been so well prepared ‘on the day’ through the continuation and improvement of:

- design,
- training,
- maintenance
- expert operator intervention.

And/or had emergency services not been able to intervene in a timely manner and/or had there been the sudden and unexpected rupture of a fuel vessel and/or had there been a second incident as cars came to an emergency stop, the situation may well have led to catastrophic fires, loss of life and extensive tunnel damage.

The rapid reduction in longitudinal ventilation (through appropriate use of the emergency ventilation system), coupled with smoke extraction (at the correct location) resulted in the controlled movement of buoyant combustion products DOWN HILL which thereby provided protection to evacuating motorists and emergency services personnel.

The ventilation system was also able to reverse the flow of air in the unoccupied section of the tunnel – thereby allowing emergency services access to a point near the incident. This is also a major achievement and essential because there was no access in this region via cross passages from the Domain Tunnel because in this region the tunnels are not connected by emergency passages.

The fact that the emergency ventilation, extraction and fire suppression systems worked in a complementary way, coupled with the expert operation of the control systems by the operator is the most important factor responsible for restricting the consequences of the crashes to the injury and damage levels in the event.
6.5 **Damage**

There was only minor damage caused to the Burnley Tunnel by the crashes and subsequent fires.

6.5.1 **Civil Infrastructure**

(a) **Pavement:**

Some damage from the gouging effects of the motor vehicles as they crashed and some heat damage to the road surface at the seat of the fire.

(b) **Overhead Steel Works:**

Steel framing supporting signs, cable trays and deluge system all in good condition. No structural issues.

(c) **Tunnel Wall:**

No spalling. No structural damage.

(d) **New Jersey Barrier:**

Localised spalling on new jersey barrier.

(e) **Smoke Duct:**

No structural damage.

(f) **Ventilation System:**

Two smoke dampers near incident were not physically damaged but in order to ensure ongoing operational reliability cabling was replaced. No damage to seals between adjoining duct segments above fire site. No damage to dampers in rest of ventilation system.

(g) **Fire Detection and Suppression:**

Fibro laser cable burnt and broken at accident site.

(h) **Deluge System:**

No damage to deluge system.

6.5.2 **Mechanical and Electrical**

(a) **Cable Trays:**

Approximately 20 metres of cable tray damaged by heat to the north side of the incident. (This was the side of the...
fires). There was no damage to the south side, only meters away on the other side of the tunnel.

(b) **Roadway Lighting:**

Five light fittings and two controller boxes were destroyed by the fire. Power and control cabling in the heat affected area required replacement.

(c) **Electrical Cabling:**

Cabling for roadway lighting, two dampers (not the damper were not specifically damaged) and two tunnel incident management signs were heat damaged and required replacement.

(d) **Leaky Coaxial (FM) and Public Address Cables:**

The FM and Emergency Services communications’ cables suffered no structural damage apart that there was some heat damage to the insulation in the area near the accident. It remained fully functional.

(e) **CCTV Cameras:**

No damage identified and all cameras operational. Cleaning required for two downstream cameras.

(f) **Lane Usage Sign:**

No damage identified.

(g) **Tunnel Incident Management Signs:**

No damage.

(h) **Motorist Emergency Telephone:**

One METS phone had fire damage to a cable that required replacement.

6.5.3 **Repair Schedule**

A review of the repair logs indicates that all works were completed and commissioning finalised within three days. This included obtaining the necessary permits to conduct the works, conducting such inspections as were necessary and ensuring there was a high level of confidence in the systems, prior to their commencing operation.
6.6 Detailed Analysis from Differing Perspectives

6.6.1 The Operator

The actions of the operator on 23 March 2007 are considered in the context of the systems available at the operator's control, the training, practice and procedure for their operation and how they were activated during the incident on 23 March 2007.

An event such as a fire is recognised as a Category III event – being the most serious type of safety event the tunnel can experience.

6.6.2 Exercises and Upgrades

CityLink regularly conducts exercises. Conducting exercises is of little value unless lessons learned are incorporated into revised procedures and control systems.

The full scale field exercise in 2004 in the Burnley Tunnel demonstrated weaknesses in the control systems. Subsequently the control systems which were responsible for the emergency response on 23 March 2007 were upgraded.

The upgrades relating to control system conflicts observed in 2004 were not apparent in this review of all computer logs and witness statements on hand. CityLink has changed its control system since its 2004 exercise. Had these changes not been made they would have been detected in the computer logs and witness statements.

6.6.3 The Incident – Operators Perspective

Analysis of the detailed computer logs, extracted video footage from the operator controlled CCTV cameras, the preserved CCTV video, CCCS Operator Guide, CCCS Operator Reference Manual, and comparison with witness statements leads me to make the following observations:

- 9:52:00: the tunnel control operator was dealing with a routine broken down vehicles on a surface road
- 9:52:42: the first of a series of stopped vehicle alarms began appearing on the tunnel controllers computer control system
- 9:52:58: the tunnel control operator physically selected a camera to display live images of the stopped truck
- 9:53:11: the tunnel control operator physically acknowledged the stopped vehicle alarm
• 9:53:37: the tunnel control operator opened a computer plan to facilitate closing the left lane and subsequently takes the necessary steps to initiate the left lane closure at 9:54:05

• 9:54:12: the tunnel control operator initiated a radio rebroadcast message advising drivers of the lane closures

• 9:54.12: a series of changes occur within the tunnel to variable speed message signs and lane closure and general messaging signs (these changes can be observed on the video footage)

• Displayed during this period on the tunnel control operators selected screen is an image showing cars and trucks successfully changing from the left lane to the centre and right lanes both before and after the lane closure procedure is initiated

• 9:54:26: and for a period of in the order of 2 to 3 seconds displayed on the tunnel control operator’s screen is a series of crashes and explosions with fire

• 9:54:29: the tunnel control operator acknowledges on the computer the completion of the left lane closure plan

• 9:54:29 to 9:55:14: a tunnel incident management plan is formulated by assessing the information being displayed on video cameras and alarms. The plan is implemented at 9:55:14. This plan closed the Burnley Tunnel from upstream of firebox B18. Analysis of tunnel control operator’s video shows the controller was actively viewing the incident and surrounding tunnel areas in order to make appropriate selection for tunnel closure response

• 9:55.04: (during preceding period of plan formulation above) the break glass alarm to the MFESB is activated and a telephone call made to the MFESB to confirm that it is a real alarm, and provide first details of the incident to the MFESB

• 9:55:18: the tunnel control operator makes a critical decision to implement an emergency plan

• 9:55:37: the tunnel control operator enables the emergency mode on the computer control system which provides him access to the smoke extraction deluge and evacuate tunnel options (this is occurring while the computer
9:55:48: the tunnel control operator intervenes with respect to the critical identification of the incident location altering it from fireboxes B18 to B19. This action requires the operator to have consciously decided that a superior outcome would occur if the incident location in the computer is changed. During this period review of the video material demonstrates that the operator was switching video footage in order to apprise himself of the situation.

9:55:52: the emergency mode was re-enabled using the updated incident location of B19.

9:55:54: the tunnel control operator selected smoke extraction as his first emergency mode response. The operator has a choice of what to do first. The selection of the smoke extraction initiated a cascade of several hundred commands to the electromechanically ventilation systems as well as other safety systems. Such choices were part of the standard operating procedures.


9:56:01: the tunnel control operator requested the zone (B19EO48) furtherest from his CCTV vision to open.

9:56:03: the tunnel control operator commanded the deluge warning message to be broadcast on the radio rebroadcast and PA systems in the Burnley Tunnel.

During this period the tunnel control operator continues to switch between CCTV cameras which show what is occurring in various parts of the tunnel.

9:56:30: the tunnel control operator requests for a second time the furtherest deluge zone (B19EO48) to operate.

9:56:41: traffic operations manager requests deluge zone (B19EO48) to open (this third request has been separately verified in another computer log [PMCS computer log] which I have perused).

9:56:49: the tunnel control operator observes the deluge operating in zone B19 EO48 – this constitutes a delay of 48 seconds between the initial request for deluge and its actual activation.

9:57:01: the second deluge zone (FSPEO49) is requested to open.
• 9:57:03: the traffic operations manager requests deluge zone (B19EO47) to open

• 9:57:10: the deluge zone (B19EO47) is seen to operate

• 9:57:13: the computer system reports that deluge zone (B19EO49) is open – although this is not visible on the CCTV systems. The deluge system having now been successfully activated and separately confirmed the tunnel control operator now chooses to enable evacuation mode.

• 9:57:22: the tunnel control operator decides the evacuation should occur through 'safe tunnel' (Domain) and makes appropriate selection on th4e CCCS.

• 9:57:26: the tunnel control operator initiates evacuation of the Burnley Tunnel into the Domain Tunnel and starts the evacuations plan. This plan initiates the systematic closure of the Domain Tunnel. The tunnel control operator maintains surveillance using the CCTV cameras over both Burnley and Domain Tunnels during this period. From this footage the progress of systematic tunnel closure, emergency evacuation, emergency ventilation and deluge can be monitored by the controller.

• 9:59:44: the computer requests the operator to confirm that back layering is not an issue. This request relates to the risk that the emergency ventilation system might be unable to control the smoke and illustrates the need for operator input to manage the emergency on an ongoing basis. The alarm is acknowledged by the tunnel control operator at 9:59:57.

• 10:01: MFESB representatives arrive at the control room.

The operator plays no major role in management of the incident from this point other than to monitor system performance and await instructions from emergency services.

Picture 53: Camera 58 – Time 10:07:25

Fire truck pulls into position and parks in the thick smoke
6.6.4 DISCUSSION

The time line and facts noted above arise from the computer logs and video images and relate to the most critical period of the incident.

Prior to the crashes the operator's attention had been drawn to the stopped truck in the left lane of the Burnley Tunnel. The routine selection of the left lane closure plan to protect tunnel users and the truck and its driver required the operator to enter the location of the incident. During this period, dozens of vehicles, both cars and trucks successfully observed the obstruction and merged into the centre and right lanes.

These traffic movements were displayed to the operator because he had selected this location to observe as he prepared the left lane closure plan.

The procedure followed by the operator was timely and in accordance with both the Operators Guide and Tunnel Incident Management Subsystem Operator Reference Manual.

The effectiveness of the alarms and CityLink responses to them must be placed in perspective. As noted by Lyberg:

"... a … fire in a typical road tunnel will in 95% of the situations be detected within 64 seconds and that an alarm will be sent within 168 seconds after detection. The most time demanding phase after detection is verification".

In this instance detection was almost immediate and verification extremely quick.

Having implemented the initial lane closure plan for the stopped truck, the tunnel operator likely witnessed the multiple vehicle collisions, explosion and fires. Analysis of the video footage captured directly from the tunnel operator's activated CCTV screen depicts a graphic series of events which are without parallel in any other known recorded tunnel incident in the World.

The tunnel operator having witnessed these events processed what he had seen, acknowledged alarms and set about immediately following the procedure for implementing an emergency response in addition to a regular traffic plan. Because the systems are not automated a failure to respond by the operator at this point would have had potentially catastrophic consequences. Having reviewed the video footage it is likely the operator was well aware of this fact.

The operator followed the procedures, systematically and in a timely way not only closing the Burnley Tunnel, initiating emergency ventilation, systematically firing the deluge system (from furtherest to closest), and initiated an emergency evacuation (including closure of the Domain Tunnel). The operator also altered the location of the incident from B18 to B19, fired the deluge and recognised that there was an unanticipated delay. Having

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identified the unanticipated delay, sought and received assistance from the traffic operations manager, confirmed visually its activation and proceeded with the emergency event management.

Each of the steps taken to effectively respond to this emergency were made in accordance with the Operator Reference Manual and the Operator Guide. The fact that the operators were able to optimise the systems response through proactive thinking should be specifically acknowledged. These actions suggest emergency training had been effective.

Issues arising - there are two issues which arise from this event from the operators’ perspective deserving of attention (in addition to my other recommendations) being:

(a) The control systems inability to automatically deal with more than one incident

(b) The consequences of deploying multiple deluge zones on water pressure, and volume available to the shared deluge/hydrant systems)

Neither of these issues raise criticisms of the operators. Both matters are worthy of consideration as part of the lessons learned process from the incident.
6.7 MFESB PERSPECTIVE

6.7.1 MFESB – FIRE BRIGADE RESPONSE

The following timeline depicts the fire brigade response in relation to the incident.

- 9:55:04: brake glass alarm fired in the tunnel control room requesting MFESB response to Burnley Tunnel (inferred from MFESB time logs)
- 9:55:04: the TCRO in the CityLink Control Room rings MFESB to confirm alarm and provide further details of the incident
- 9:55:07: Emergency Services Telecommunications Authority receives an automated fire alarm call for an incident in the Burnley Tunnel (inferred from MFESB time logs)
- 2 pumpers are despatched to Burnley Tunnel
- 10:00:40: MFESB truck arrives at the Burnley Tunnel portal (Camera 41)
- 10:01:00: MFESB representative arrives tunnel control room
- 10:01:51: Fire cabinet door B15 opened
- 10:02:37: Emergency Services arrive up entrance from Kings Way (Camera 41)
- 10:04:41: MFESB arrive downstream from B19
- 10:04:43: MFESB entering Burnley Tunnel in truck at eastern end (exit end)
- 10:05:00: first fire fighter with fire hose enters the deluge scene (Camera 54) – only attends the fire for 40 seconds and then departs
- 10:06:37: fire fighters seen passing stopped cars (Camera 48)
- 10:07:29: fire brigade stop downstream approaching into smoke (Camera 58)
- 10:08:01: fire engine stops in view of Camera 58
- 10:08:40: 3 MFESB personnel and 2 Police seen on foot heading to incident (Camera 52)
- 10:09:01: fire brigade arriving on foot at incident site (no BA)
• 10:09:21: Police on foot approaching incident site

• 10:09:25: Fireman without hose enters deluge zone (Camera 54)

• 10:10:52: First fire fighter with breathing apparatus and fire hose enters fire zone (Camera 54)

• 10:12:36: Police car seen arriving contra flow King Street exit to Domain Tunnel (Camera 123)

• 10:30:00: Bureau of Emergency Services telecommunications become aware of telecommunications issues in Burnley Tunnel (time provided by Emergency Services)

• 10:30:00 to 11:00:00 customers other than Domain and Burnley Tunnels transferred to alternative communications tower to provide increased capacity to emergency effort

• 10:48:00: MFESB command deluge be turned off

• 11:15:00: MFESB declares fire under control

6.7.2 Fire Fighting

Fire fighters approach the fire from both ends of the tunnel. They were timely and well able to locate the fire.

Picture 54: Camera 52 - Stop F
Time 10:08:44

Fire fighters approaching the incident scene on foot

Picture 55: Camera 54
Time 10:05:00

Fire fighter? with hydrant powered hose
It is immediately apparent that the response was rapid and while directed with emergency services’ vehicles at both ends of the incident tunnel within five to seven minutes and a Metropolitan Fire and Emergency Services Brigade representative arriving in the tunnel control room in less than six minutes.

Perusal of the timeline also clearly demonstrates that in under nine minutes (i.e. 10:05), the first fire fighter with fire hose is observed to enter the deluge zone and begin attacking the fire.

There can be no doubt that the rapid and effective arrival of the MFESB positively contributed to this incident being managed as effectively as it was.

The tunnel safety system coupled with the active intervention of the fire brigade is likely to have been the principle reason that the fires remained comparatively small, there was no flashover, and there were no deaths other than those other people involved in the actual motor vehicle crashes.

However, there are several aspects of the MFESB’s response which could – in other circumstances – have led to the death or injury of MFESB personnel. These factors are:

(a) The MFESB personnel entered the incident tube downstream of the incident (that is towards and into the smoke) without first putting on breathing apparatus.

(b) The MFESB personnel having entered the incident tunnel with the smoke proceeded for a period of approximately eight minutes (as determined from the video footage) and then into the extremely dense smoke section immediately downstream of the incident before retreating back beyond
the smoke extraction zone into a comparatively less smoky location.

(c) That in taking this action, the MFESB exposed their members to a higher level of risk of harm than needed in the event that:

- There was an escalation in the fire (such as for the involvement of a fuel tank, cargo etc)

- A failure in the emergency ventilation system to extract the toxic gases and smoke

In some sections of the incident tunnel air quality was comparatively good. This air quality was only being maintained by the emergency ventilation system.
The following sequence of photographs illustrates the rapidly changing conditions in the tunnel closer to the crashes in the minutes before the MFESB arrived.

Camera 60 – Stop C

9:55:01 9:56:01 9:57:01

10:06:01 10:07:01

10:07:09

10:08:01

(d) The MFESB personnel had difficulties establishing and maintaining communications:

- The normal two-way radios proved problematic; and

- Reliance was placed on remote mobile phones.

- No use was made of the specially provided “fire phones” within the tunnel

(e) Some MFESB officers entered the Deluge zone without breathing apparatus and/or individually without ‘buddies’.

While each of the above actions did not result in any injury to any fire officer, they are of concern because they suggest a lack of knowledge of the emergency ventilation system (its strengths and weaknesses) and that officers whom were quite properly acting in the course of their duty, perhaps unknowingly, exposed themselves to undue risk by entering the Deluge zone without a companion and/or entering the zone without appropriate breathing apparatus.
• **Mobile Phones**

The use of mobile phones as a primary means of communication in an emergency is extremely undesirable. Experience from the London bombings, Twin Towers attack and other major catastrophic events around the world indicate that where there are masses of people involved (such as with the case of CityLink), there is a real and immediate likelihood that the mobile phone provider will either:

- Turn off the mobile tower in order to protect the service from an unscheduled collapse due to excessive use;
- Turn off the service in response to concern that the event maybe a terrorist attack and that bombs initiated with mobile phones maybe engaged;

There is also a risk that the leaky feeder telephone aerial system in the underground will be compromised by the fire. Personnel reported difficulties with the emergency capacity of the emergency network.

Furthermore, in addition to these complications with respect to the way in which communications were handled (i.e. the use of mobile telephones), the fire brigade (and emergency services) were unaware of the operational level that the emergency communications had been downgraded to that caused the emergency channel availability in the CityLink tunnels to be of a lower level of services than normal.

Collectively, these factors could have seriously compromised MFESB’s personnel safety in the event that there was a decrease in tenability within the tunnel through any one of combination of factors including:

- Rapid expansion of the fires
- Explosions
- The failure of electro mechanical emergency ventilation systems
- The failure or malfunction of emergency suppression systems

The type of radio used by MFESB personnel relies upon the operator hearing an audible tone which signifies either the availability or unavailability of channels for emergency communication.

• **Coverage**

The emergency services radios do not work in all cross passages, refuges and other emergency evacuation areas of the tunnel. This should be remedied to protect users and emergency services personnel in an emergency.

• **Noise**
In a tunnel emergency, it is likely that the audio environment will be extremely compromised by the noise of the emergency ventilation system. Therefore, the use of two-way radios which rely upon the user hearing an audible signal to establish whether a channel is or is not available for emergency communications may not be appropriate.

PIARC has recognised the potential noise impact of jet fans during an emergency. They note:

"Jet fans operating in a tunnel can generate high noise levels, and can have adverse effects on speech transmission between people in the tunnel. This may become a safety issue when the noise level prevents the tunnel users from understanding what they were asked to do or when it makes it difficult for the firemen to communicate with each other …"10

It is recommended that an appropriate mitigation strategy for this limitation on the technology currently used by MFESB personnel in their combative role, be considered as a matter of some urgency.

The combination of high noise environment, decreased availability of channels due to maintenance and the use of mobile phones by MFESB personnel does – in my opinion – raise fundamental issues with respect to the ongoing and effective management of emergency communication systems within the CityLink tunnels and the appropriateness of the issued MFESB two-way radios and their associated procedures in a noisy tunnel incident. The wisdom of using conventional and mobile phones as an emergency communications device needs further consideration.

It should be noted that conventional and mobile telephones can – if a fee is paid – be linked to a special protected bandwidth by the telecommunications’ providers which is protected in the event of a telecommunications’ collapse or a directed shutdown of communications for security reasons.

I am not aware if this feature is available in Victoria.

6.7.3 Fire Hose Pressure

A number of attending officers raised queries with respect to water pressure in and around the incident scene from the hydrant system. Subsequent analysis indicated there was no problem with the pressure and flow rate with two deluge zones operating.

Analysis of the computer logs indicates that three deluge zones were operating (not two). The impact on hydrant pressure and volume of three or more deluge zones operating should be investigated to better understand the fire fighters experience in this

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incident and to assist preparing response plans to multiple incident (multiple deluge) events.

6.8 **HUMAN BEHAVIOUR**

6.8.1 **SPEED**

The incidences of 23 March 2007 occurred in a downhill section of the tunnel.

It is well known by tunnel users that speed cameras operate at all times within the CityLink tunnels and that speed limits are rigorously enforced.

It is difficult for drivers to determine a vehicles speed in the tunnels because of factors including:

- It is an unfamiliar driving environment (e.g. no lamp posts)
- The walls are close
- The ceiling is close
- There is artificial lighting
- The slope is steep
- The road surface makes a different noise from tyres

During the inspection of the video footage provided, numerous tunnel drive throughs and interviews with professional drivers (truck, hire car and taxi), it is clear that many drivers in the CityLink tunnels choose to travel well below the 80 km/h speed limit.

The decision to drive slower than the 80 km/h speed limit increases the likelihood of there being a differential speed between vehicles in the tunnels. As noted elsewhere in this report, the differential speed of vehicles in the tunnel has been identified and is thought to be a significant risk factor for the passage of vehicles through the tunnels as it increases the likelihood of lane changing and increases the likelihood that vehicle separation would be minimised.

The driver task of travelling well below the posted 80 km/h speed limit is complicated on the downhill sections of the CityLink Tunnel by two important factors:

(a) The comparatively steep downhill slope of >6%; and

(b) The significant and direct tailwind of in the order of typically 20 km/h.

In other words, the combination of slope and tail wind coupled with the presence of and rigorous enforcement of speed restrictions means that many drivers focus much of their driving attention on ensuring that their vehicles travel lower than the posted speed limit of normally 80 km/h. It appears from the computer logs that commands are sent to the speed cameras immediately the tunnel
speed limits are altered. From this I have inferred that speed cameras are also adjusted almost instantly speed limits are decreased. It is of little surprise that many Melbourne motorists travel too slowly – well below the speed limits.

In the incidences on 23 March 2007 the driving task down this downhill section of tailwind tunnel was complicated by the stopped truck in the left lane. Analysis of the video footage prior to the incidences in question showed a group of vehicles – including both trucks and cars – engaged in consistent braking and ‘bunched’ as they approached the site of the subsequent crashes.

Indeed, careful analysis of the video footage of these vehicles indicated that at least one of the trucks had smoke coming off the rear trailer wheels before any crash had occurred. This appeared to be the combination of speed, proximity to other vehicles and traffic disturbance caused by the stopped vehicle in the left lane.

It is recommended that the impact of the way in which speed is regulated in the tunnels upon driver behaviour (and in particular consistency of speed and driver distraction), be examined with a view to – if necessary – developing an alternative means for regulating speed in the tunnels which optimises the consistency of vehicle speed.

The current practice of linking the speed camera to a reduced speed limit in the tunnel reinforces the public’s fear of speeding in the tunnels. This fear of speeding is itself a driver distraction and undermines the tunnels performance through reduced speeds and driver focus on speedometers as opposed to the vehicles around them.

In Austria a lighting system has been developed and installed which ‘runs’ lights along the wall at the speed limit. Drivers can adjust their speed by reference to the moving light.

It should be noted that it is not uncommon for there to be adverse safety impacts of an overwhelmingly positive safety initiative. It maybe that the use of speed cameras in the way that they are currently used within the Melbourne CityLink Tunnel could be improved so as to promote more consistent driver speed, less driver distraction and therefore, greater safety.

6.8.2 Speed Limits

Reducing Speed Limits

There is a direct relationship between the vehicle speed, impact and injury. This relationship underlies the reduction in speed limits on normal surface roads in built up areas to 50 kph and the introduction of speed limits on the open road recently in the Northern Territory. Overseas this has been reflected in Europe by the recent speed limit enforcement programs in countries such as France and Germany and even the introduction of speed limits on some German autobahns.

However, tunnels:
• Are designed for specific speeds
• Accommodate a range of vehicle classes
• Do not have polls, posts or other vertical obstructions (other than at exit ramps where the diverging tunnel wall meets the tunnel wall of the main tunnel)

In these circumstances where traffic densities are sufficiently light vehicle separations can be achieved and maintained. The safety benefits of reduced travel times (and thereby exposure to crash risk) and the separation of traffic such that it is all moving in the one direction at or near the same speed coupled with the statistical evidence that tunnels provide a safer travelling environment than typical surface roads, means that the benefits of a reduced speed limit during normal uncongested flow conditions does not outweigh the disbenefits of a reduced speed limit such as increased speed differential between trucks and cars, longer journey times and increased risk of crashes through congestion.

I have carefully considered the question of speed limits generally and for heavy goods vehicles in the Burnley Tunnel.

From my review of the literature, extensive observation and investigations of tunnels throughout the world and careful consideration of the “normal” modes for tunnel accidents it is my view that the consistency of the speed of vehicles within a tunnel is the single most important factor in minimising the probability of crashes. My reasoning is as follows:

(a) If all vehicles are travelling at or about the same speed the need to perform overtaking manoeuvres is minimised.

(b) The probability of “congestion” occurring as a result of interruption to flow by slower vehicles is minimised.

(c) The throughput of traffic through the system is optimised.

The effects of altering speed limits for all vehicles are evident from the videos examined in the course of this investigation. The video footage of the surface road which (was at the time) 100 kilometres per hour as compared with the 80 kilometres per hour speed limit within the tunnel, clearly illustrates the difference in traffic vehicle spacing caused as a direct result of a change in vehicle speed. The vehicles become much more congested when the speed limit changes and this appears to correspond with more lane changing as vehicles decelerate at different rates.

In such circumstances I do not recommend that there be a reduced speed limit for trucks in the CityLink Tunnel, nor a reduced speed limit for all vehicles.
6.8.3 **SPEED CAMERAS AND SLOPE**

The design characteristics for the tunnel which increase the likelihood of there being differential speeds within tunnels should be carefully addressed during the design phase of tunnels.

In the Burnley Tunnel the steep (by world standards) slope both entering and exiting the tunnel contributes to the risk of there being an accident. On the downhill section of the tunnel great attention must be paid by drivers to not exceed the 80 kilometres an hour speed limit.

It is widely known that speed cameras operate within the tunnel.

Analysis of the computer log records strongly suggests that these speed cameras are immediately altered to reflect changed speed signage.

Accordingly motorists are (rightly) concerned about exceeding the speed limit and many motorists choose to travel well under the speed limit.

This creates a series of obstructions to traffic flow as motorists pay great attention to their speed often travelling substantially less than the 80 kilometres an hour speed limit.

6.8.4 **SLOPE AND EXIT SPEED**

The steep (5.2%) slope of the Burnley Tunnel exits is a significant impediment to trucks maintaining a constant, or even reasonable speed.

These problems are highlighted by the following graph of modelling prepared by Dr Blanksby at the ARRB Group Ltd on vehicle performance and slope.

![Graph showing speed vs distance for a semi-trailer](Image)

This graph not only shows the performance disparity between trucks and cars but highlights the consequences of approaching a long steep grade at lower speeds.
If the tunnel speed limit is reduced for trucks, it would reasonably be expected that many would be travelling at less than 35kph before they left the tunnel. The slope has no effect on cars.

This means that not only would lower speed limits more severely affect traffic flows through the tunnel, there would also be a significant increase in the amount of vehicle pollution caused by the trucks.

6.8.5 **Evacuation**

Detailed examination of the video footage reveals that the predominant means of evacuation was via the incident tunnel back in the reverse direction of travel.

As has been experienced in experiments and in other instances overseas, users were observed to take some time to make a decision to leave their vehicles.

Once evacuating, those whom were near the incident scene were observed to evacuate more quickly than those who were at a greater distance. Those closest to the incident were seen to run, while those further way whom did not appreciate the seriousness of the crashes walked, and in some cases at best, strolled.

**Human Behaviour**

**Picture 60**
*Camera 53 – Time 10:02:28*
Truck driver gets personal things out of truck

**Picture 61**
*Camera 52 – Time 10:03:36*
Person emerges from right hand side of tunnel running towards incident

**Picture 62**
*Camera 52 – Time 10:03:43*
Person running back towards incident

**Picture 63**
*Camera 52 – Time 10:03:53*
Goes around front of truck

**Picture 64**
*Camera 53 – Time 10:04:39*
Re-emerges from beside truck

**Picture 65**
*Camera 53 – Time 10:04:59*
Person taking photos
Furthermore, behaviour which has been associated with fatalities in other tunnel instances was readily observed. Fatal behaviour includes:

- Returning to a vehicle after having initially evacuated
- Travelling to the scene of the fire to “take a picture”
- Delaying leaving their vehicle
- Leaving evacuation until it is too late (despite time enough to evacuate)

The further people are from the crash the less likely they will evacuate promptly.

6.8.6 DISABLED

There were disabled people within the tunnel at the time of the evacuation. Their evacuation behaviour is interesting to note.

The analysis of the video footage clearly identified at least one adult disabled person fairly near the scene of the crashes. Importantly, the person driving the disabled person reacted most quickly of all drivers under surveillance within the region of the CCTV camera.

It is clearly discernable from the video footage that the boot region of the disabled person’s car was opened before other people began to evacuate and that the assembly of their wheelchair and evacuation proceeded rapidly.

Wheelchair

Picture 66  Camera 52 – Stop F
Time 9:58:05
Vehicles stopped, boot already open

Picture 67  Camera 52 – Stop F
Time 9:58:27
Driver has assembled the wheelchair and is assisting the passenger to get into the chair
Other road users readily offered assistance to other tunnel users at a point of embarking upon the evacuation journey and again, when the wheelchair was raised up to the elevated walkway, entering the cross passages and then returning and being assisted from the elevated walkway back onto the road.

There were also numerous examples of people with young children whom had to be put in pushers (effectively disabled) for the evacuation on foot to a place of safety in the tunnel and hundreds of others (around 275) whom evacuated out of the portal.

Inspection of the tunnel confirmed that some of the cross passages (through which access to a place of comparative safety would normally be attained) included a journey up a large staircase. These stairs pose a
formidable physical challenge for evacuees – it is not surprising evacuees were observed returning to the incident tunnel to evacuate after entering the cross passages. It is likely this occurred after apprising themselves of the extent of the stairs.

Although it could not be ascertained from the video footage, it is considered likely that the reason the disabled person returned to the roadway after entering the cross passage was that they could see the staircase which would have to be climbed in order to access the safe domain tunnel.

It was also apparent from observations of the video material that many people walked past emergency cross passages notwithstanding the flashing lights and signs inviting them to enter in order to access a place of safety.

In these circumstances, the cross passages – despite the effort to mark, alarm and provide them as means of emergency egress to access a safe place, were not well used. Of the 275 evacuees, only around a few dozen actually used these emergency pathways.

Many people chose to use the elevated walkways but – walked past the cross passages and chose not to use them. This observation is consistent with observed behaviour in other incidents around the world. Unfortunately this has led to a number of deaths in the Mont Blanc, Tauern, Gotthard and Frejus fires. The CityLink ‘aesthetics’ upgrade program will likely improve the performance of the evacuation systems.

6.9 IMPLICATIONS

In an emergency, the incident tunnel is the least desirable place to be. Incidents in other tunnels have resulted in serious and rapid degradation in tenability great distances from the incident. Deaths have and can occur kilometres from the incident itself. In a fire such as this, the entire Burnley Tunnel is a danger zone. In an emergency such as this, every effort should be made to have people leave the tunnel and, unless they are very near the portal (say, within 100 or 200 metres), access the other tube as a safe place.

There are two aspects to encouraging such behaviour:

(a) Education about the special risks of an incident in a tunnel; and
(b) Making the emergency cross passages and havens more attractive to access.

**International Context**

Of the emergency egress arrangements I have observed around the world those currently being adopted in the latest Japanese tunnels by the Metropolitan Expressway Company are worthy of special note.

In a recent Tunnel inspection in Tokyo (March 2008) I noted some new features for deep road tunnels. While the geological conditions of each tunnel may not allow each of the following features to be incorporated in a road tunnel they do provide examples of alternative arrangements for emergencies.

The first area entered is the reception gallery.

This reception gallery runs parallel to the operating road tunnels (in this section of the tunnel) – this is where people first enter after exiting the incident tunnel.

Note in particular the disabled persons assembly point, emergency phone and directional signage in this refuge area.

After leaving the reception gallery the long route to the surface is via multiple – short – flights of stairs.

Only 10 stairs (maximum) between horizontal landings.
Intermediate galleries on assent for people to gather or rest (with excellent directional and location signage).

This picture illustrated the dimensions of the landing areas in between short flights of stairs.

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<table>
<thead>
<tr>
<th>Photo</th>
<th>Description</th>
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<tbody>
<tr>
<td><img src="image1.jpg" alt="Image" /></td>
<td>Intermediate galleries on assent for people to gather or rest (with excellent directional and location signage).</td>
</tr>
<tr>
<td><img src="image2.jpg" alt="Image" /></td>
<td>This picture illustrated the dimensions of the landing areas in between short flights of stairs.</td>
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<tr>
<td><img src="image3.jpg" alt="Image" /></td>
<td>Signage well describes the exit route and the location of the evacuee.</td>
</tr>
<tr>
<td><img src="image4.jpg" alt="Image" /></td>
<td>A large refuge area just below the surface which can be used as a safe place well away from the incident (such as for triage).</td>
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Accordingly, as a result of my analysis of the behaviour of regressing passengers of the Burnley incident, I recommend that:
(a) CityLink take such steps as are necessary to make the emergency cross passages more attractive for emergency evacuation in the event of an emergency; and

(b) That an advertising campaign take place to educate tunnel users on the importance of promptly exiting the incident tunnel in the event of an emergency.

It should be noted that the importance of leaving the tunnel in an emergency will also serve to remind the MFESB and other emergency services’ personnel about the importance of safety procedure for attending emergency incidents.

With respect to future projects I recommend that more attention be given to creating user friendly evacuation pathways.

6.10 **DRIVER BEHAVIOUR**

Vehicles should not stop in tunnels, on bridges or on any other confined roadway. To so stop, offends one of the principal elements of good road craft – don’t stop on the roadway.

Truck drivers are trained not to stop on Freeways, bridges, and by implication tunnels. The risks to road users of crashing into the rear of a stopped truck are well known and understood. This was one of the reasons anti-intrusion bars are now fitted to the rear of modern truck trays.

Truck drivers know that an explosion from the rear trailer of their truck normally signifies a blown tyre. Furthermore even in the event of a tyre fire they are trained to keep their vehicle moving either until the fire subsides or they find a safe place to park their truck.

For most heavy vehicles it is not sufficient that there is space on the side of a conventional road to ‘pull over’ as their mass limits often exceed the stability of the road shoulder and there is a real risk that their vehicle will rollover.

However there is currently a need to reinforce the importance of clearing an active roadway of a broken down vehicle – be it a truck or a car.

An education campaign stressing the importance of not stopping vehicles so as to cause a lane obstruction would be well placed. In the case of a tunnel the need for such driver modification is highlighted by the events of 23 March 2007.

6.10.1 **OBSTRUCTING LANES**

Obstructing lanes is known to be potentially dangerous. So too are the risks associated with congestion in tunnels.

While emergency lanes are an option to manage lane obstructions, so too are lane closures in the event of a broken down vehicle. This option is used by CityLink and allows the benefits of optimising traffic flow and the ability to stop traffic.
CityLink would be less safe if it were two lanes and one emergency lane than three lanes with the ability to rapidly close a lane.

6.10.2 DRIVER ERROR

Analysis of the extensive video footage of this incident has allowed me to trace the passage of the vehicles involved in this series of crashes.

Up until a few seconds before the crash there is nothing unusual about the behaviour of any of the vehicles moving into or through the tunnel. However the truck which ultimately collides into each vehicle distinguishes itself by its comparatively high speed (but not speeding) and its late lane change to avoid a line of stationary traffic.

Unlike all other vehicles its speed remains relatively constant while the vehicles in front and to its side slow down. This vehicle’s movement – and most importantly its speed – does not appreciably alter until the series of collisions occur.

6.10.3 DRIVER EDUCATION

There is very little effective driver information for tunnel users in Victoria. PIARC\textsuperscript{11,12}, The European Union Directive on Minimum Safety Requirements for Tunnels\textsuperscript{13} and NFPA 502\textsuperscript{14}, directly or by implication recognise the importance of drivers responding appropriately when there is an emergency in a tunnel.

There have been and no doubt will continue to be a raft of suggestions with respect to driver education, however it is the effectiveness with respect to the following core safety objectives which must be always considered.

(a) Will the driver education reduce the likelihood of a crash occurring?


\textsuperscript{14} NFPA 502 Standard for Road Tunnels, Bridges and Other Limited Access Highways, 2008 Edition – National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471 – An International Codes and Standards Organisation, USA – Copyright 2007
(b) In the event of a crash will the education increase the likelihood of behaviours which will minimise the likelihood of subsequent harm?

There are currently opportunities for better driver education on tunnel safety in Victoria. While it is acknowledged that the CityLink website hosts tunnel safety information its usefulness is extremely restricted as most drivers do not study the CityLink website. Potential future education themes include:

(a) stressing the importance of not stopping in a road tunnel
(b) obeying all directions when travelling in a tunnel including:
   (i) not exceeding speed limits (nor driving too slow)
   (ii) keeping a safe distance from the vehicle in front (safe distance to be determined by the tunnel operator)
   (iii) minimising the number of lane changes within the road tunnel
   (iv) respecting the needs of heavy vehicles for increased stopping distances (leaving a space for heavy vehicles)
   (v) heavy vehicles selecting the appropriate lane for passage through the tunnel on the basis of their exit speed (uphill) and not their entry speed thereby respecting the space needs of conventional vehicles and not blocking lanes by remaining in fast moving lanes
   (vi) respecting lane closures
   (vii) stopping from entering a tunnel or within a tunnel when requested
   (viii) turning off the vehicles engine when requested
   (ix) leaving vehicles and evacuating immediately when requested
   (x) using the emergency escape passages when requested (using escape paths as directed)
   (xi) not returning to an evacuated vehicle

6.10.4 HUMAN BEHAVIOUR

Analysis of human behaviour in actual tunnel emergencies coupled with detailed research (led mostly by the Netherlands) and reflected in PIARC Working Group 3 Human Behaviour Publications indicates that very strong and clear messages must be given to tunnel users to warn and guide them of what to do in an emergency. PIARC 2007 at page 141:
“...people usually have difficulty changing their course of action when suddenly placed in a situation quite different from the norm.”


Importantly PIARC also recommends that wherever possible two different kinds of warning sides be given; for example a visible and an audio alarm. This is important for a range of reasons which include the fact that not all people respond to all sensory inputs (for example the visually or hearing impaired) or that there may be a particular reason that a mode of system fails (for example a jet fan may be more noisy than expected in emergency mode thereby obscuring audible signal, or an incident may have occurred which compromises the effectiveness of visual signals).

Timely instructions should be given to leave the tunnel space. The more time people have to actually escape from the tunnel, the safer they will be.

Currently the signage within CityLink is not sufficiently clear and visible during normal operating situations that most road users would learn about the presence and location of the emergency exits during normal usage.

The 'aesthetics' upgrade being undertaken by CityLink is designed to address these issues. An analysis of the effectiveness of the upgrade is beyond the scope of this report.

Incident in Context

6.11 A SYSTEMS RESPONSE

It is collective functionality of the many components of a tunnel which combine to deliver safety and security performance.

“System safety and security is the systematic application of engineering, technology, and management tools to identify, analyse and control hazards and threats within operational, budget and time constraints. Systems encompass all of the integral factors that make up a tunnel, including people, operating procedures, engineering and technology systems and controls, and the physical aspects of the tunnel structure. Each of these elements independently provides some degree of safety and security. However when combined, they significantly improve safety and security.”

16 Making Transport Tunnels Safe and Secure, Transportation research board of the National Academies (Advisers to the Nation [USA] on Science, Engineering and Medicine) Washington DC 2006
6.12 **Infrastructure**

The most critical influence on the safety performance of underground road tunnels over its lifetime is the basic physical design.

The physical design will establish the basis for its safety performance.

The basic design of the tunnel will likely remain unaltered for in the order of 100 years. All other elements of operational safety must be built, refined, refurbished, upgraded and regulated.

In the road tunnel context these fundamental critical design elements are the:

- Road network tunnel interfaces
- Vertical alignment (slope)
- Horizontal alignment (curves)
- Merges and diverges
- Internal dimensions (width, height and therefore lane widths, numbers, emergency lanes, lay-bys and vehicle clearances)
- Emergency egress provisions – cross passages and escape paths
- Normal and emergency ventilation – shafts and ducts
- Provisions for maintenance and upgrading of systems (e.g., Accessible service ducts, trays and room for future equipment)

These elements collectively constrain the safety performance of the tunnel through its design life because in the vast majority of circumstances the as
built infrastructure will never be able to be closed for substantial remodelling or building due to the enormous disruption this would cause to the communities they are built to serve and the disproportionate cost of attempting such alterations once built.

In Europe concern over tunnel safety and capacity has led to many tunnel duplication projects (such as the Plabutsch Tunnel in Austria, the Elbe Tunnel in Hamburg, Germany).

In every instance the basic fabric at the existing tunnel has remained substantially unaltered.

6.13 SAFETY ‘STANDARDS’

There is a popular misconception that meeting the ‘standard’ constitutes World’s best practice – and in some way ensures an appropriate level of safety.

Standards are, and can never be, more than an agreed position with respect to safety. Each standard contains the basis of the social, intellectual, historical and organisational context under which it is formed. In every instance they are a form of consensus about a combination of agreed ‘truths’ and objectives.

In the tunnel safety context the two most popular standards to cite in Australia are those from PIARC and those from NFPA 502. These are but two of the most authoritative international standards on tunnel safety.

Had CityLink been built ‘to the standards’ the deluge fire response system coupled to longitudinal ventilation with smoke extraction could not have been included in the tunnel. Deluge systems had long been identified as not only unwarranted – but dangerous.

By way of example the PIARC 1999 document ‘Fires by Control in Road Tunnels’ PIARC states:

“Sprinklers (Fixed Fire Fighting System) are generally not considered as cost effective and are not recommended in a usual road tunnels.”

In NFPA 502 (2004):

“... Use of sprinklers (Fixed Fire Fighting System) in road tunnels generally is not recommended.”

Yet, by 2007 the most recent publications of both PIARC and NFPA recognise sprinklers as an option for fire and human life protection in tunnels.

The CityLink tunnels were built with deluge systems despite the fact that neither PIARC nor NFPA endorsed their use at the time of design and construction.

This highlights the importance of sound design analysis during tunnel design – and not simply following a standard.
Standards provide a useful basis or considered analysis of how best to deliver an appropriate level of safety – but are not a declaration or crystallisation of the ultimate safety truth.

Sound engineering analysis – considering – the interdependence of engineering, operation, infrastructure and users in the context of standards is the superior methodology for ensuring safety. This report is not a review of standard compliance.

6.14 SAFETY DEVICES

There is a popular misconception that the provision of safety devices in road tunnels defines the level of safety of that tunnel. This misconception is promoted by the vendors of safety devices and has been legitimised by practices of associations such as the European Automotive Users Association (the equivalent of the RACV) which for some years compared the safety of road tunnels in Europe on the basis of which devices they had.

If this test was applied to Australian road tunnels they would each be ranked amongst the safest tunnels in the world. However the actual level of safety experienced by users is a function of how a range of factors combined (including the use of the devices) behave as a safety system.

There is a real risk that the Australian approach to including so many safety devices in tunnels will, with the passage of time, lower the level of safety if budget constraints and complacency occur.

Tunnel owners and/or operators must monitor, test, refine and upgrade their systems as they age so as to ensure the tunnel safety systems are in a state of operational readiness to minimise the likelihood of an incident and minimise the consequences of an incident should it occur.

6.15 DESIGN

6.15.1 ROAD NETWORK TUNNEL INTERFACES

The interface between the surrounding road network and a tunnel plays a critical role in the risk profile for road users of the tunnel. Historical data on crashes has identified the portal area (both entrance and exit) as a high risk zone. Strategies to minimise these risks from the design perspective include managing sight lines for drivers both to the tunnel portal and extending into the tunnel so as to maximise the opportunities for drivers to see that which lies ahead while at the same time minimising any input they must make to their vehicle such as changing speed or changing direction (corners) and/or lane. Such a focus minimises the risks of collision with other vehicles and tunnel structures.

Devices within the tunnel may also contribute to higher levels of safety through specialised lighting, road surfaces, tunnel wall treatments, and other visual clues to assist the driver in exercising due skill and diligence in the transition.

The entrances to the Domain Tunnel played a critical role in stopping traffic during the Burnley Tunnel emergency. New
technologies, such as the recently developed ‘virtual’ stop barrier as installed in the Sydney Harbour Tunnel are significantly improving this area of tunnel performance. No virtual barriers are installed in the CityLink tunnels.

The Sydney Harbour Tunnel has utilised this new technology for over 12 months and the results are extremely impressive with all emergency incidents (over 34) resulting in immediate and effective tunnel closure once the virtual portal barrier is activated.

In an emergency such rapid portal closure is fundamental to minimising the number of people exposed to harm.

6.15.2 VERTICAL ALIGNMENT (SLOPE)

The slope of the tunnel affects the overall safety in three main ways:

- Vehicle performance
- Visibility
- Gas behaviour

6.15.2.1 Impacting upon the prospect that vehicles will travel at same speed regardless of class (trucks, cars, motor bikes)

Slope converts part of a vehicle weight into a force which pushes vehicles down a hill, or restrains them from going up it. The heavier the vehicle, the greater the forces involved.

In heavy vehicles (such as semitrailers or HGV’s) advanced engine and conventional braking system combinations still deliver vastly differing downhill braked, and uphill climb performance to conventional cars.

On uphill sections the combinations of engine type, drive train and load will result in varying heavy
vehicle uphill performance which would differ not only between trucks but also very significantly with the same truck, different loads and different drivers.

On the other hand most conventional light vehicles climbing the slope will pose no obstruction to maintaining vehicle speed at all.

Minimising the differences between the speeds of vehicles thereby directly increases safety in tunnels. In the Burnley Tunnel the steep grades make running traffic at a constant speed impossible on the exit grade.

![Graph illustrating vehicle performance on slopes](image)

**Speed on a 4% grade** – This graph illustrates the limits on vehicle performance on slopes. Trucks cannot generally maintain the speed limit, even on a 4% slope, (Burnley Tunnel exit is even greater at 5.2%) whereas cars can easily accelerate to any lawful speed.

6.15.2.2 **Impacting forward and rear visibility of the driver**

The transitions in grade (slope or vertical geometry) of a tunnel directly affect the ability of the driver to observe vehicles in front and behind while also impacting their ability to read signage within the tunnel. Managing these transitions to maximise driver sight lines positively contributes to tunnel safety.

In the Burnley Tunnel the area of the crash and the broken down truck would not be visible to drivers until they had come down the first section of tunnel and were rounding the right hand bend before the crash area. This is not to suggest that the
standards for sight distances are not met within these tunnels.

6.15.2.3 Interfering with the flow of buoyant (both positive and negative) toxic gases and smoke directions of travel

In a range of credible scenarios positively buoyant (hot and/or light) gases and/or smoke, and/or negatively buoyant (cold and/or heavy) gases and/or smoke, will naturally move up or down slope respectively. The amount of intervention required by a tunnels emergency ventilation system to counter these natural phenomenon will be directly related and its likely effectiveness inversely proportional to tunnel slope.

The Burnley Tunnel’s emergency ventilation system was able to overcome this natural tendency and draw hot gasses downhill.

6.15.3 Horizontal alignment (curves)

As is the case with changes in slope curves obstruct drivers forward and rear vision and thereby reduce the inherent safety of the tunnel. The presence of curves also requires drivers to stay within their lanes while changing the direction of their vehicles. Curves are associated with same direction collisions. However in long tunnels (such as >5km) they are often included to stop driver boredom.

6.15.4 Merges and diverges

Merges and diverges are two vehicle movements which are associated with vehicle collisions.

When vehicles merge they must occupy the exact location at only slightly different times. The merging process requires the drivers of all vehicles to adjust their speed and location to facilitate the lane changing. Lane changing increases the likelihood of crashes. Minimising lane changing increases the inherent safety of a tunnel.

Diverging also requires lane changing. In some configurations it can have a cascading effect as vehicles change lanes several times in order to be in a position to diverge. Diversions also create a risk to tunnel traffic where the diverging traffic ‘backs up’ blocking the diversion egress route and in the worst case obstructing flows in the tunnel. Minimising diverging increases the inherent safety of a tunnel.

The Burnley Tunnel crash was directly related to a failed merging manoeuvre to avoid queued traffic.

6.15.5 Internal dimensions (width, height and therefore lane widths and vehicle clearances)
Lane dimensions create a buffer between traffic travelling at the same time in the tunnel between the vehicles laterally. The wider the lanes (within reason) the lower the probability of vehicles inadvertently crashing into each other through driver error. Squeezing extra lanes into tunnels while theoretically increasing tunnel throughput can compromise safety.

The height of the tunnel when coupled with the width defines the volume of the tunnel. In many emergencies this is a fundamental parameter for the tunnel safety as it provides a reservoir of tenable air and an opportunity for buoyant toxic gas and smoke to accumulate above evacuating road users.

These dimensions also provide ongoing opportunities to upgrade, renovate and refurbish tunnels by allowing sufficient space for new signage, facilities and other safety critical devices.

Both CityLink tunnels are large in international terms. The provision of three full width lanes and provision for normal height trucks establishing a high degree of inherent safety.

The use of three full width lanes is not typically, even within Australia. For example Australia’s first urban tunnel (Sydney Harbour) and most recent (Lane Cove) both being restricted to two lanes.

Unlike on surface roads or even freeways, the opportunity for vehicles to diverge from the active laneways in the event of an emergency is limited. Tunnel engineers in CityLink utilise a barrier system known as “The New Jersey Barrier” which is designed to reflect energy in a way which minimises the likelihood of harm to vehicles and redirects them in the direction of traffic flow. However, as illustrated in this incident, where a vehicle is pushed between a truck and the wall of the tunnel severe distortion of the vehicle will occur as the tunnel wall is unyielding.

Furthermore, even large vehicles such as trucks should they hit the New Jersey Barrier and/or climb the barrier and be deflected from the wall, their energy will be directed along the tunnel within the tunnel lanes. This is and will remain one of the challenges for tunnel engineers within the tunnel environment. Although leaving a carriageway on the surface road may result in crashing into a poll or a tree (which is often fatal) there is, as yet, no technology known to be used within tunnels which safely absorbs the impact of vehicles.

6.15.6 EMERGENCY STOPPING LANES

There are no emergency stopping lanes or emergency stopping niches within the CityLink Tunnel.

Many tunnels, even within Australia, have emergency stopping niches which provide a sanctuary for vehicles able to enter them.

Niches provide an immediate refuge for vehicles which are, for whatever reason, stopped in a tunnel.
Niches provide real and tangible safety benefits in tunnels however, they do come at a safety cost. Experience in other tunnels (such as the Sydney Harbour, M5 East and Lane Cove Tunnels in New South Wales) demonstrates that the transitions of vehicles both into and in particular, out of niches create safety hazards. Nonetheless, these can be managed by visual alarms which advise an operator when a vehicle is entering a niche and appropriate traffic management to facilitate the re-entry of vehicles into the active traffic lanes within a tunnel.

However, superior in overall safety performance to a tunnel with either an emergency stopping lane or safety niches is a wider tunnel with an extra lane. An extra lane provides a higher level of safety to either a narrower tunnel with safety niches or a narrower tunnel with an emergency lane because:

- The higher vehicle capacity of the wider tunnel produces a lower probability of accidents
- The capacity of the tunnel to transmit vehicles is equal to or exceeds the network capacity
- The wider tunnel provides more opportunities to create emergency lanes as and where needed should the need arise.

Where active intervention through lane closures and speed reductions cannot be achieved rapidly safety lanes or niches provide a superior outcome to extra lanes.

In my opinion the use of the third lane as a safety lane would – overall – be less safe for CityLink than the current three lane option.

6.15.7 Conversion of an Existing Lane into an Emergency Stopping Lane

Some sections of the CityLink Tunnels could readily have the left lane closed and reserved for emergency stopping. Those sections which could not be managed in this way are in areas where there are left lanes merging within the tunnel. Currently, the CityLink tunnels are managed with their left lane closed during periods of high congestion in order to both reduce the probability of traffic jams (the reduction in tunnel through capacity mimics the capacity on the congested surrounding road network and thereby reduces the probability of a traffic jam caused by the tunnel’s high capacity to move vehicles in the surrounding road network) while also preserving a lane for emergency response vehicles.

The CityLink practice is prudent tunnel management as it both reduces the probability of crashes occurring and facilitates emergency vehicle intervention in the event that they do occur.

It does not follow that in normal free flowing traffic conditions there would be a safety benefit in permanently closing the left hand lane to accommodate vehicles which stop. Closing the left hand lane in this way would substantially reduce the capacity of the tunnel to carry vehicles and thereby contribute to greater traffic densities within those lanes operating and create a negative traffic capacity
differential between the tunnel and the surrounding road network. Such a situation is extremely undesirable.

An example of an Australian tunnel which operates in this way is the M5 East Tunnel in Sydney. The road network feeding the M5 East Tunnel exceeds the capacity of the tunnel. The resultant traffic jams in the entrances to the tunnel and within the tunnel are extremely undesirable and pose a real and continuing risk to road users. Where there is a choice between tunnel capacity through lane usage to avoid congestion and the provision of an emergency lane for the sake of providing an emergency lane, the higher capacity tunnel provides the superior safety outcome.

6.15.8 EMERGENCY EGRESS PROVISIONS

Emergency egress provisions are normally in the form of alternative emergency egress pathways or safe places. Subsequent provisions of such pathways while possible are often difficult for both geological (and geotechnical) reasons as well as the disruption such construction would cause to the operational infrastructure. Appropriate emergency egress is fundamental to safe tunnel operation.

Because CityLink’s two tunnels are at different depths cross passages between tunnels involve large flights of stairs. These are a constraint on movement between tunnels but are preferable to refuges in an emergency. These cross passages are provided with emergency ventilation – making them safe places during most emergencies.

6.15.9 EMERGENCY LANES AND SAFETY NICHES

These features provide ‘refuges’ for vehicles when they have unscheduled stops (such as a breakdown). Unfortunately they also encourage people to stop in tunnels, and in the case of emergency lanes are often used for upgrading tunnel capacity subsequent to their installation.

On balance the provision of safety ‘niches’ is often considered a better option as it provides a refuge for vehicles which is outside the normal flow of traffic without the opportunity of converting them to extra lanes – either by conscious decision or errant act.

The management of vehicles entering and exiting refuges becomes a high priority for safe tunnel operation as the merging vehicles must re-enter the traffic flow from a virtually stopped state. Nonetheless niches are normally desirable where the geotechnical conditions do not make their provision impossible or prohibitively expensive.

The underlying geological conditions also play a major role in determining whether the CityLink Tunnel could have safety niches retrospectively installed. The CityLink Tunnels are, for the most part – geotechnically speaking – under water. In addition, the
pressures from groundwater are significant geotechnically and will continue through the entire design life of the structure.

The curved vault form of the majority of the CityLink structures is the engineering response to these pressures. Retrospectively breaching the tunnel walls to excavate emergency niches in these circumstances would be extremely problematic. This is quite unlike the geological conditions typically experienced in places such as Sydney where the Hawkesbury Sandstone provides comparatively excellent tunnelling conditions which facilitate the opportunities to carve structures such as niches comparatively simply.

Combining niches with cross passages big enough for vehicles to change between tunnels is also often a desirable option. The cross passage option for emergency vehicles is favoured in many tunnels overseas.

In CityLink any lane can be an emergency lane as the control room has the ability (and does) close lanes when a vehicle stops. This mode of managing the risks caused by stopped vehicles demands rapid intervention by the tunnel operator and appropriate responses by tunnel users.

Examination of video footage coupled with tunnel inspections suggests there remain a minority of tunnel users whom do not respect lane closures when they are implemented. As graphically illustrated in this incident the process of closing lanes provides a residual risk of serious collisions. This risk is less than in a two lane tunnel with a stopping lane because of the overall safety benefits of having 3 lanes for traffic flow.

6.15.10 NORMAL AND EMERGENCY VENTILATION

Normal and emergency ventilation demand significant portions of an underground space for ducting and equipment. The emergency mode requirements can change as knowledge of actual fires and changes to the number, type and cargos of vehicles change through the life of the tunnel.

The adequacy of the Burnley Tunnel design was reflected in the excellent emergency ventilation response.

6.15.11 PROVISIONS FOR MAINTENANCE AND UPGRADING OF SYSTEMS

(E.G. ACCESSIBLE SERVICE DUCTS, TRAYS AND ROOM FOR FUTURE EQUIPMENT)

The implications of maintenance and accessibility of service ducts and other equipment facilities are easily overlooked in the design phase of a tunnel. Complications with ongoing maintenance, upgrades and refurbishment caused by these aspects of the design can seriously compromise the ability of the owner and operator of the tunnel to maintain and enhance operational safety over the tunnels design life.

The rapid repair of the Burnley Tunnel suggests its open roads design for cabling is adequately protected by safety systems.
6.16 TUNNEL RISKS IN CONTEXT

6.16.1 SAFETY AND RISKS IN ROAD TUNNELS

Although percentages vary it is generally recognised that incorrect behaviour of road users is the main cause of all road crashes. Reports such as that by the Organisation for Economic Cooperation & Development (OECD)\(^\text{17}\) suggest this may be as high as 95% of all crashes.

6.16.2 RISK IN CONTEXT

Internationally it is generally accepted that for road tunnels:

- Accident rates appear to be slightly lower in tunnels than for uncovered roads\(^\text{18}\)
- The approach zones to a tunnel are more dangerous than the central section of a tunnel
- Non fire incidents are more numerous than those involving fire\(^\text{19}\)

Dr Beard noted recently at a select inquiry for the European Parliamentary Inquiry that because most deaths in tunnels result from common traffic accidents it is essential to address this as well as fire related incidents which are more likely to result in multiple fatalities:


\(^{18}\) Recommended Behaviour for Road Tunnel Users Michel Egger, Conference of European Directors of Roads, France. (Ch 16 The Handbook of Tunnel Fire Safety 2005)

\(^{19}\) Dr A Beard background paper for European Parliamentary Enquiry ‘Assessment of the Safety of Tunnels’ Parliamentary Workshop – 16 May 2007 European Parliament, Brussels
“In particular measures to avoid collisions need to be very seriously examined; for example, with barriers and measures to control vehicle speeds and enter vehicular distances. Such measures would also help to avoid fires. Creative thinking is called for. For example, the use of a large laser – projected ‘STOP’ sign onto a water curtain which is being tested at a portal to Sydney Harbour Tunnel; to effectively stop vehicles entering the tunnel during an incident … simple measures may also help, such as having a white road surface instead of black to improve visibility; as is the case in a Swiss tunnel”

Dr Beard’s views that minimising the likelihood of crashes are fundamental to delivering ongoing tunnel safety, and managing the unique consequences and risks in a tunnel are shared by the author.

6.17 THE DYNAMICS OF FIRES IN TUNNELS

To understand the significance of the Burnley Tunnel incident an introduction to the science and history of tunnel fires is essential.

The behaviour of fires in road tunnels is not intuitive. The reason for this can be summarised as follows:

- Heat from burning vehicles tends to be reflected back to the fire source making the tunnel fire burn more intensely and grow more rapidly than if the fire were on a surface road
- The confined space within the tunnel may lead to the air available to the fire being insufficient to support the combustion or which in turn can create large volumes of toxic fumes and the products of incomplete combustion.

Furthermore the behaviour of air within tunnels becomes highly complex and disturbed when there is a fire. This can lead to severe changes in normal ventilation airflow characteristics including reverse airflow along the surface of the roof, and other unexpected behaviours. These complications are the subject of numerous papers and are summarised in the work of Haukur Ingason. SP, Sweden Fire Dynamics in Tunnels, Chapter 11, The Handbook of Tunnel Fire Safety 2005. As noted by Mr Ingason:

“Such effects on the ventilation not only complicate fire fighting procedures but also present extreme hazards by propagating toxic fumes and gases far away from the fire.”

Another effect which although is not intuitive is central to modern ventilation design and operation is heated smoke and gases propensity to travel towards oncoming fresh air near the roof of a tunnel. This phenomenon is known as ‘backlayering’.

This effect has been responsible for injuries and deaths through asphyxiation when buoyant toxic mixes of smoke and gas travel over evacuating tunnel users (or even emergency services personnel) cool and then descend into the escape route of people.
Managing this phenomenon is complicated by tunnel grade and the rate of heat loss in the ceiling of the tunnel. In the CityLink control system, tunnel controllers are prompted to check for backlayering by the computer system when emergency ventilation has been implemented.

In the 23 March 2007 incident a review of all video footage and ventilation data clearly establishes that back layering was effectively controlled, even though there was a steep grade in the area of the fire. This is a major technical achievement and contributed to the safety of all tunnel users after he crashes.

6.18 Historical Context

It is important to place the events of 23 March 2007 into a historical context. The most significant road tunnel fires from an historical perspective are the Mont Blanc Tunnel fire of 24 March 1999, the Tauern Tunnel fire 29 May 1999 and the St Gotthard Tunnel fire 24 October 2001.

In each of these three fires all of the people trapped in the smoke died from gas toxicity rather than elevated temperature. It should be noted that in the Gotthard Tunnel fire:

“... an explosion caused by the rupture of one of the HDV,S [semi-trailer] tanks filled with diesel oil vapours occurred 30 minutes after the fires beginning.”

There are also important lessons with respect to the human behaviour which can be learnt from the prior three incidents and which are reflected in the human behaviour observed in the Burnley Tunnel accident. As noted by PIARC at page 85:

“[of] The 12 victims of the Tauern Tunnel fire, eight died as a result of the initial motor vehicle accident. Three other victims were found in a vehicle that was nearly 100 metres north of the ignition point. Police incident investigation showed that the vehicle belonged to two of the people, who for some reason did not attempt to flee despite the many other people around them doing just that. The third person had apparently fled from his own vehicle, and then attempted to return in search of some documents. This person had last took refuge with the other two, and died with them. The last victim was found 800 metres away from the fire towards the south (the interior of the tunnel). He apparently was asphyxiated as he tried to flee out of an emergency [shelter].”

In the case of the St Gotthard Tunnel fire, there also some interesting observations which are pertinent to the Burnley incident.

“It seems the other 10 victims of the St Gotthard fire were people whose vehicles were at such a distance from the fire that they could not see it (300 to 800 metres away). By the time they saw the smoke, the time free act was very short. All of these victims were on the northern side of the fire. Five victims were found in their vehicles. Three victims walked more than 200 metres, which is greater than the theoretical maximum distance to reach an emergency exit. One victim was found next to an emergency exit, either not having seen the door or not being able to open it.” (page 85)

It is useful to place the burning tunnel fire into context. In relation to the Mont Blanc, Tauern and St Gotthard fires PIARC notes at page 87:
"The total number of deaths in the Mont Blanc Tunnel was 39, including one fire fighter. Twelve people died in the Tauern Tunnel fire. The St Gotthard fire caused the death of 11 people. Eight more people were hospitalised for smoke exposure.

Each of these three fires led to very significant material losses. Severe damage significantly to the tunnel vaults were observed (over 900 metres for the Mt Blanc Tunnel, and 500 metres for the Tauern Tunnel), as well as to the roadway pavements and slabs. In the Tauern Tunnel, the immediate ceiling was damaged over a length of nearly 300 metres. The tunnel equipment and secondary lining was also destroyed or severely damaged by high temperatures and fire by-products over considerable distances in both tunnel fires. In the St Gotthard Tunnel, the intermediate ceiling collapsed over a length of about 250 metres in the fire zone. It was noted that the radiant cable located in the fresh air duct at the St Gotthard Tunnel worked properly over the whole tunnel length during the fire, whereas all equipment located in the traffic space had to be replaced.

The Mont Blanc Tunnel reopened to traffic in March 2002, almost three years after the catastrophe. It was significantly renovated after about one year of negotiation between France and Italy on the new standards that would apply. The cost of repairing and renovating the Mont Blanc Tunnel was 350,000,000 Euros.

The Tauern Tunnel was cleaned and repaired within three months, including important improvements to the exhaust ventilation system that now make it possible to concentrate the whole exhaust capacity above the region of fire.

The St Gotthard Tunnel was closed to traffic for two months. The direct cost associated with repairs and traffic interruption was 1.2 million Euros. It was reopened with alternate traffic HGVs. The legal enquiry concluded that the only party responsible for the fire and its consequence was the HGV driver who caused the accident. As he died in the incident, no further action was taken."

As a result of the analysis of the three fires PIARC produced a lessons learned table from the three incidents. Following the examination of the actual Burnley incident this report will use these lessons learned from the PIARC analysis as a platform to review the performance of the Burnley Tunnel at Chapter 6 of this report.

6.19 RISKS TO TUNNEL USERS

6.19.1 ROAD USERS AND EMERGENCY SERVICES

All people who may be in a tunnel are tunnel users, this includes emergency services, road users and technicians. Due to differences in their tasks and expertise each is dealt with separately in terms of their safety.

5.19.1.1 Road Users

Tunnel users are merely road users who are travelling through a tunnel. Research from around the world has clearly identified errors by drivers as being responsible for in the order of 95% of all crashes.
Analysis of crashes and fatalities on road networks in France and Italy suggests that the rate of such incidents occurring in road tunnels is less than the average for the road network generally.

However the consequences of such an event occurring within a road tunnel can be different to events on other types of road structures because of:

(a) the physical enclosure of the road which creates an unforgiving barrier to the lateral or vertical movement of a vehicle from the carriageway; and

(b) the confined space which necessarily:

- alters the movement and distribution of toxic gas and smoke in the event they are released
- alters the nature, volume and rate of toxic gas and smoke generation through the regulation of oxygen supply
- alters the dynamics of combustion by confining and reflecting back energy released during combustion

This means that as a matter of fact in a tunnel:

- a vehicle may experience a different type of collision exposing its occupants to differing harm for the same speed in a tunnel
- a vehicle which catches on fire in a tunnel will burn differently to the same vehicle burning on a surface road
- that the combustion products of such a fire including toxic gas, smoke and heat will behave or can behave unexpectedly in terms of its speed of movement, its buoyancy and its adverse health effects

These facts are the reason so much attention is rightly directed to tunnel design from a safety perspective.

These facts underlie the imperative that tunnel users modify their behaviour when driving in tunnels so as to minimise the likelihood of a crash and should an incident occur (whether they are directly involved or not) take immediate action to self rescue to a place of comparative safety.

The Burnley incident clearly illustrates that road users could (and should) drive more appropriately in tunnels and in the event of an accident evacuate in a more timely and effective manner.

6.19.2 EMERGENCY SERVICES

In Victoria each of the emergency services has a statutory responsibility to respond to a tunnel incident. Appropriate user behaviour also applies to emergency services. Because
emergency services may enter the tunnel environment during an incident several critical factors must be effectively woven into their emergency response.

Each tunnel has a unique configuration of layout, emergency system and devices, operational procedures, operational performance and operational vulnerabilities. During an emergency these must be understood for safe and effective emergency response.

Each of these idiosyncrasies should not be underestimated when formulating emergency response plans.

For example all modern road tunnels including both CityLink tunnels and the EastLink Tunnel use differing emergency ventilation concepts. The differing ventilation concepts can alter the risk environment in differing parts of the tunnel in the event of a system ventilation failure and in emergency mode.

Because the nature of an incident can change as a fire alters in type, number and intensity with the passage of time there will always be a real risk of a punctuated change to the effectiveness of the emergency devices in controlling the tenability of the post incident tunnel environment. This means that an event such as the rupturing of fuel tanks could (and has) result in a rapid degeneration of conditions for emergency services personnel in tunnels.

Even in road tunnels where dangerous goods are not permitted (such as CityLink) goods being transported lawfully may become dangerous in a tunnel context. This problem was identified as underlying several fatal tunnel fires in Europe with innocuous cargos like margarine and flour, tyres and plastic behaving as dangerous goods inside a tunnel.

Even simple matters such as the use of ventilation systems in an emergency can have unforeseen implications for the safety of emergency services personnel and road users. For example the high noise levels generated by jet fans in an emergency can make any form of communication relying upon hearing difficult.

The response by emergency services to the Burnley Tunnel fires suggests there are opportunities to better prepare their personnel and equipment should an incident occur in the future.

6.19.3 TECHNICIANS

It is almost inevitable that people with a special relationship to the tunnel will either be called upon to respond to a tunnel incident or will be working in the tunnel on one of the many thousands of monitoring, control or response systems when an incident occurs. Like all other users they must make themselves safe.

The only additional challenge for these people is that they may be in non public areas and getting information to them about appropriate self rescue (and ensuring they take such action) more problematic. Such matters are readily addressed through inductions and appropriate on site personnel management.
In this incident analysis of the computer logs identified a technician was working within the tunnels and evacuated without incident.

6.20 VEHICLES

6.20.1 THE DYNAMIC PERFORMANCE OF LIGHT VEHICLES (CARS) AND HEAVY VEHICLES (TRUCKS)

Cars and trucks share the same speed limits within the Burnley Tunnel and upon open roads despite the fact that their dynamic (moving) performances are vastly different.

This simple fact partly explains why the death toll for truck/car collisions is approximately one truck driver death for every seven motor vehicle deaths.

6.20.2 ACCELERATION AND GRADEABILITY

The ability of a truck to climb grades when laden is dramatically different to that of a passenger car. These factors are important to safety because they affect the interaction between trucks and other traffic. On a 1% grade, for instance, a semi-trailer should be able to maintain a speed of 80 km/h (a B-double may only achieve 70 km/h), whereas a passenger car would barely notice this grade and could travel considerably faster. On steeper grades, the speed differential is more severe.

For example, on a 4% grade, a semi-trailer is likely to be able to maintain a speed of around 35 km/h, compared to a car, which can easily travel at 100 km/h, creating a very large speed differential. Diagram 12 provides a comparison of the performance of a typical car and semi-trailer on a 4% grade highlighting this differential.

Diagram 12 also illustrates the importance of approach speed. It shows that if the truck enters the 4% grade at 80 km/h, it takes over 500 m to drop to 60 km, and nearly 2 km to reach the steady speed of around 35 km/h. Most 4% grades are less than 2 km in length.

The exit grade on the Burnley Tunnel is 5.2% (1.2% worse than the graph below) over a distance of 830 metres. Numerous tunnel inspections reveal many trucks struggle to maintain a reasonable exit speed even when they approach the uphill section at 80 km/h, after exiting at very low speeds. If the truck speed limit was reduced to 50 kph, many trucks would have exit speeds of less than 35kph due to the grade.
Having a lower acceleration capability than cars, trucks also take much longer to overtake other vehicles. In the tunnel context this is one of the reasons consideration should be given to minimising sections of steep grades and incorporating truck exclusive lanes.

6.20.3 Braking

The Australian Design Rules specify that, heavy vehicles are required to be able to brake at 4.17 m/s² in an emergency stop. A passenger car must be able to brake at 6.43 m/s². Mechanically, it takes longer for a truck’s brakes to actuate because of the movement of pressure along the air lines (this problem is eliminated by Electronic Brake Systems). This delay can be around 0.5 s on a semi-trailer, increasing with length, and is part of the reason for the difference in braking requirements for different vehicle types.

In terms of stopping distance, the difference can be quite dramatic, as shown in Table 1, with a truck taking about one and a half times the distance of a car to stop.

Table 1: Stopping distances for different vehicles

<table>
<thead>
<tr>
<th>Speed</th>
<th>Truck</th>
<th>Car</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 km/h</td>
<td>59 m</td>
<td>38 m</td>
</tr>
<tr>
<td>60 km/h</td>
<td>33 m</td>
<td>22 m</td>
</tr>
</tbody>
</table>

“This is the performance that can be expected for well maintained equipment. If brakes are not appropriately maintained, braking
performance can degrade considerably and trucks are far more sensitive to this than cars. A poorly maintained truck could easily have twice the stopping distance of a poorly maintained car.” Dr Chris Blanksby, Australian Road Research Board Personal Communication 2007

6.20.4 CRASH AGGRESSIVITY

Because of the high mass (and thus energy) of a truck relative to a car, trucks are far more aggressive than cars in multi-vehicle crashes and thus are more likely to cause injury to the occupants of other vehicles.

For these reasons, and on balance, truck speed should not be reduced in the Burnley Tunnel – to do so would significantly increase the need for lane changing and passing manoeuvres on the exits and thereby greatly increase the risk of collisions.

Reducing the overall speed limit for both the freeways and tunnel would reduce this speed differential, however the problem with the steep grades would remain as trucks entering the steep climb out of the tunnel would be even less able to maintain speed than they are today with an 80 kph speed limit.

If the speed for both the open road and the tunnel was reduced this would adversely impact upon the capacity of the network and lead to greater risks of congestion. (Congested traffic is less safe than free flowing traffic). If only the tunnel had a reduced speed this would lead to a highly undesirable traffic restriction.

However I strongly endorse the operational practice of reducing tunnel speeds to maintain safety when traffic flows are disrupted or there is another good cause to do so.

There are a range of “underrun” devices which can be fitted to trucks which reduce the likelihood of trucks driving over cars and crushing them and their occupants. Mandating the use of such devices would have its benefit on all roads – including tunnels.

6.20.5 VEHICLE COMBUSTION

In the tunnel environment the combustion potential of cars and trucks is likewise disproportionate the fuel loads in cars are not typically more than 5 to 10 megawatts whereas recent research suggests a truck may be in the order of 100 to 200 megawatts when fully involved. Even unloaded vehicles may carry upwards of 50 litres of fuel if they are a car or in the order of 1,000 litres of fuel if they are a truck.

The combination of these scientific facts results in the following general propositions:

- Where trucks and cars share the same road, with the same speed limit, separated by the same distances and generally travelling at the same speed the probability of a truck
crashing into cars is significantly higher than the probability of cars crashing into trucks.

- That the likelihood of fatalities when trucks and cars collide will be higher for car occupants than truck occupants

Modern vehicles increasingly rely upon new light compounds. Many of these are advanced plastics with special structural and weight properties.

Unfortunately the trend to these modern materials has greatly increased the rate at which vehicles burn and the toxicity of the combustion products.

The Burnley Tunnel crashes demonstrate how the combination of ruptured fuel tanks and modern materials combine to create rapidly burning, highly toxic fires. The fires also demonstrate how such fires in a combined space have potentially lethal consequences.

This issue further compounded by the potential for large flammable loads being carried by commercial vehicles.

The value of rapidly activated fire suppression and emergency ventilation systems is demonstrated by the Burnley Tunnel fires.

Without such systems the consequences would have likely been for more severe in terms of injuries, damage to infrastructure and recovery times.

6.20.6 VEHICLES IN TUNNELS

These fundamental differences in the performance of trucks and cars necessarily lead to careful consideration of the risks associated of placing vehicles underground in tunnels. Internationally the response varies from almost a ban on cars in the Dublin Port Tunnel (a toll imposed in the order of AUS$80 for cars – but free ($0) for trucks) to the A86 in Paris which bans trucks and is restricted to low height vehicles.

Melbourne CityLink falls partway between this spectrum allowing a high proportion of trucks but banning placarded dangerous goods.

The result of this car and truck mix, with restricted dangerous goods usage, is a tunnel which must provide an appropriate level of safety to its mixed users.

Because both truck and car users share the same road it is necessary to manage fairly the wide differences in performances between these two classes of vehicles. Failure to manage these differences inevitably leads to a higher risk of injury and death.

There are no vehicles routinely travelling on Victorian roads which are especially designed to operate underground or in a confined space. All modern road tunnels are designed to provide an appropriate environment for vehicle engines to operate effectively underground and to ensure the health of road users is protected from the combustion products.
6.20.7 Fuels

All petrol, diesel, LNG and LPG vehicles burn fossil fuels and emit combustion products. The fuels these vehicles burn are carried in tanks. These tanks can either be ruptured during a crash or be compromised as a result of a subsequent fire.

It is expected that within the next decade or so vehicles using hydrogen as a fuel may also routinely use our roads. The extremely high heat release rate of hydrogen coupled with its extremely high propagation rate and oxygen demands will pose challenges for both vehicle design and incident response in tunnels in the future.

6.20.8 Materials

Modern vehicles increasingly rely on light weight plastic compounds. These compounds are extensively used in an effort to minimise the weight of vehicles and therefore their fuel consumption.

Most manufacturers of motor vehicles (both cars and trucks) pay little or no regard to the combustibility of these materials when combined in their vehicles.

On the open road the effect of these materials can be seen in the increase over the last two decades in the number of single vehicle, short duration, high intensity, vehicle fires.

Although the use of seat belt pretensioners, air bags and other trauma reducing devices has increased the level of safety for some road users from injury directly resulting from a crash, the author apprehends the risk of being trapped in a burning car and injured by the fire has in fact increased.

Because of the special factors in a tunnel with respect to confined spaces and energy reflection the need to leave the cabin of a burning vehicle is greater in a tunnel and the risk to other people within the tunnel from the burning vehicle is also greater than on a surface road.

Modern plastics produce a range of toxic gases which when burnt include a range of neurotoxins which inhibit a human beings ability to think (and therefore their ability to self rescue). Furthermore they burn vigorously, and potentially more vigorously in a confined space. The influence of ventilation on the availability of oxygen also affects their combustion and thereby the volume and nature of the toxic gases and smoke produced in a tunnel.

In most instances of deaths in tunnels those not killed by the crashes themselves are killed by the smoke and gases. There have been few reports of people killed by the heat of a fire. Deaths from smoke and gases have occurred up to kilometres away from the combustion point (e.g., Kaprun Tunnel (ski tunnel) fire killing 170 people, some as far as 2.5 kilometres from the combustion point).
These facts reinforce the importance of crash avoidance and rapid response following a crash in a tunnel.

6.20.9 MANAGING RISKS TO NEIGHBOURS FROM COMBUSTION PRODUCTS

As noted elsewhere within this report, during an emergency, tunnel ventilation responds by altering the flows of air in the area of the incident, enhancing where possible the in-tunnel air quality and extracting and transferring the combustion products to points outside the tunnel.

In the emergency mode, the tunnel ventilation systems’ performance is significantly different than during normal operation. These significant differences relate to both the volume of air being discharged and the velocity of the air as it is being discharged.

In addition, unlike the normal operation environmental air quality, the concentrations of combustion products are comparatively high and usually contain toxic components. The exact quantity of these toxic components and their concentration are dependent upon the incident being managed. Although CityLink prohibits dangerous goods from transport through the tunnels, the combustion of vehicles produces potentially dangerous emissions. Within the tunnel, it is these combustion products which pose the most serious risk to human health. There is a popular misconception that the heat generated from incidents such as fires are the greatest risks within tunnels when in fact, it is the contaminates produced by the combustion which have been shown historically to be the main cause of injury and death.

It is also reasonable to presume that dangerous goods will be carried through the tunnels and that the prohibition on the transport of dangerous goods will merely reduce the frequency that they are transported. The exact nature and volume of dangerous goods within the tunnels is a matter of speculation. Vic Roads conducts random audits on heavy vehicles to determine the goods they are transporting but the sample size is comparatively small from a statistical perspective.

Interestingly, there is a strong argument that from a community’s point of view it is safer to transport dangerous goods through tunnels because the overall risk to the community is reduced due to the shorter travel time, shorter distances and lower probability of an accident occurring within the tunnels. Furthermore, there is some experience internationally which indicates that if an accident does occur within a tunnel it will cause less harm generally to the community and result in less injuries than if it was to occur on a surface road.

Leaving this debate to one side, the issue at hand for this urban road tunnels is whether the risks to neighbours generated by the discharge of combustion products from a tunnel subsequent to an emergency warrants special mitigation strategies to manage those risks.

In my opinion, they do. In the CityLink case, it is my view that the mitigation strategies required directly relate to the use by CityLink
of elevated ventilation stacks in spatial proximity to high-rise buildings.

In a range of incident-atmospheric scenarios, it is foreseeable that a plume of toxic material would intercept adjoining high-rise buildings.

This does not mean that the risk of such an event is high, nor that such risks are inappropriate within an urban environment. Fires within cities produce toxic clouds and these are managed in an emergency.

The distinguishing feature with CityLink is that its ventilation system makes the point of emission of such toxic material known in advance of the event and the ventilation system which facilities such emissions is specifically designed to do so. In addition, adjoining neighbours know, and ought to reasonably expect that in an emergency combustion products will be emitted from the ventilation towers from CityLink.

There is no known technology used to mitigate these risks from fires used in any tunnel known to the author. In practice utilising an elevated discharge (stack) emergency ventilation stations and tunnel portals is the common practice. There have been no known injuries caused by emergency emissions from road tunnel fires. There has, however, been fatalities caused by emissions from a funicular ski tunnel fire so this risk should not be dismissed as fanciful.

In such circumstances, I recommend that for all tunnels an assessment be made of the potential neighbourhood impact of emergency ventilation emissions following an incident and appropriate measures be put in place to mitigate any risks which warrant mitigation treatment.

In the case of CityLink, establishing an emergency ventilation protocol with adjoining neighbours would be prudent and appropriate. Such a protocol need likely be no more than a means to rapidly advise adjoining buildings to close their windows and switch off air intake devices.

There has been no instance known to the author of a fire incident in a road tunnel’s discharge from its ventilation towers causing injury or harm to adjoining building occupants. It does not follow that a mitigation strategy is not required for such events should they occur as the occurrence of such events is quite rare.

Likewise, mitigation strategies such as special emergency air cleaning technologies have not been employed in any tunnel anywhere in the world known to the author. Unless the likelihood of such events was higher and/or the consequences of such events were documented to be more severe than anticipated installation of such technologies (if they exist) would not be appropriate. The author is unaware of any technologies suited to such an application.

If the risks posed by the emission of combustion products were determined to be unacceptably high to adjoining neighbours, other
options, including, raising the height of the ventilation towers, could be considered.

It should be noted that the performance of the ventilation towers in an emergency is fundamentally different to the performance of the ventilation towers in distributing tunnel air during normal operation. These comments in relation to the impact of combustion products on neighbours are not applicable to the operational dynamics of normal tunnel air ventilation systems. Such systems operate under a range of significantly different conditions.

6.21 The Deluge System

On 23 March 2007 the deluge system was operated by the tunnel operator. The installation and use of a deluge system during a period of evacuation in a fire is extremely controversial internationally. PIARC – until September 2007 this year did not recommend that sprinklers be used in road tunnels. Indeed up until this point not only were sprinklers not recommended by PIARC they were identified as being dangerous.

Reasons stated by PIARC for this danger included:

- difficulties in manual operation,
- low efficiency for fires inside vehicles,
- water causing explosions with petrol and other chemical substances if not combined with appropriate additives,
- vaporised steam hurting people,
- reduced visibility; and
- the smoke layer being cooled down and de-stratified.

Accordingly CityLink’s decision to put sprinklers in the road tunnels was highly controversial internationally and against international trend. The only other country which routinely uses a similar deluge type sprinkler system is Japan.

In CityLink the deluge zones are 30 metres long and 11.5 metres wide and discharge at a rate of 2850 litres per minute, per zone. The deluge is activated from the city’s main water supply.

The CityLink waste water tanks hold 250,000 litres. There are arrangements to remove water from the tanks for reprocessing. This occurred during the fires so as to ensure the deluge water collected did not exceed the emergency storage capacity of the tunnel. During the fires these emergency storages had collected water removed while the incident was in progress.

During meetings in Japan in June 2007 discussions were undertaken with senior road officials from the Japanese Tunnel Safety Authority. They confirmed that the results of the Burnley Tunnel fire in Australia were entirely consistent with the Japanese experience where deluge systems were operated.
Similar events in Europe have resulted in multiple fatalities and major infrastructure loss. The comments of the Japanese are consistent with the Australian approach and experience.

6.21.1 Fire Size

The fires which occurred has a direct and immediate consequence of the motor vehicle collisions were essentially instantaneous and according to the investigations of the MFESB as a result of breached fuel vessels within the cars which were involved. These fires immediately engaged the flammable material each of the cars were constructed with and contained and extended to the vehicles outside the vehicle cavities.

Neither the large fuel tanks on the trucks nor the freight loads within the trucks became engaged in the fires. This is likely to have occurred because of a combination of critical factors including:

- The early and effective application of the deluge suppression system;
- The timely and effective intervention of the fire brigade.

Much of the smoke and toxic gas produced during the initial period of the fire was likely generated from within the vehicles themselves. Although with time, this extended to the tyres and other components are parts external to the vehicles.

6.21.2 Effect of the Deluge

The impacts of the crashes were so severe that they caused immediate fires within and external to the crash vehicles.

No system for externally applied fire suppression in road tunnels has been observed to suppress or extinguish fires within vehicles. This is because externally operated fire suppression systems cannot penetrate within vehicle cavities.

Similar systems to deluge such as sprinkler, mist and foam fire suppression systems are routinely fitted within vehicle cavities in military and civilian vehicles where internal fire suppression has been identified as critical.

Examples of such systems include within the engine compartments of large diesel engine vehicles such as ships, rail locomotives, tanks and to a limited extent, the engine compartments of some trucks.

Within the tunnel safety sector there has only been one technology which has been promoted as able to suppress or extinguish vehicle fires within the cavity of a vehicle other than a fireman directing a hose directly into the cavity of a vehicle.

This system is known as hypoxic air.

The hypoxic air treatment system is intended to use large volumes of oxygen depleted air to dilute the naturally occurring concentration of oxygen as a means of reducing and/or extinguishing any fire within the tunnel including those within vehicles. This technique is based upon the recognition that to survive, human beings need a lower partial pressure of oxygen than fires require to burn.
This system is used in confined space environments such as orbiting space stations where the consequences of fire maybe catastrophic and the importance of maintaining a tenable human environment during a fire paramount.

To date, the costs associated with the technical and engineering challenges of storing a sufficient volume of oxygen depleted gas to effectively flood a tunnel environment in an emergency have outweighed the perceived benefits of utilising such technologies in emergencies. Conceptually, such a system has emerged because it avoids the need to ventilate an incident tunnel with large volumes of oxygen rich air in order to protect the well being of tunnel occupants. Avoiding the injection of large volumes of oxygen rich air into a fire zone may be desirable as to do so can increase the intensity and fire growth rates. (In Australia and Japan the deluge system, coupled with low longitudinal air velocities and smoke extraction mitigates this risk.)

It is within this context that the deluge system (or other fire suppression systems) which reduce the heat release rate, the fire intensity and fire growth rates are so important in managing fire incidents. Without such fire suppression systems the ventilation systems which are essential in providing and maintaining a tenable environment for people within the tunnels would also be likely to intensify fires and accelerate fire spread.

The draft computer analysis of the CityLink fires by Connell Wagner (commissioned by the MMFB) illustrates the positive effect of deluge. The positive effects of deluge on temperatures are illustrated by the results depicted in these graphs.

Figure 0: Temperature (at surface) of vehicles – With deluge suppression (Burnby39)
The very rapid fire growth would have likely made tenability within the vehicles extremely poor very quickly. Analysis of the video footage illustrates an immediate fire of considerable intensity (approx. 10 megawatts) and it is observed to grow rapidly until the deluge system operates. This is consistent with the draft modelling results on fire intensity from Connell Wagner (commissioned by the MFESB). This modelling was limited to two deluge zones. In the real event three zones were used.

Figure 6: Temperature (at surface) of vehicles – With out deluge suppression (Burney27)

Figure 7 suggests that the application of the deluge system rapidly decreased the heat release rate of the fires. This modelled result is consistent with what was observed in the video footage and from witness accounts.

Figure 7: HRR time history
7. **BURNLEY FIRE – A PIARC PERSPECTIVE**

PIARC produced a table of lessons learned from the Mont Blanc, Gotthard and Taurean tunnel fires. An extract of the most relevant lessons learned from the PIARC report is modified below by the inclusion of a Burnley fire column:

<table>
<thead>
<tr>
<th><strong>EUROPEAN EVENTS</strong></th>
<th><strong>CONSEQUENCES</strong></th>
<th><strong>LESSONS LEARNED (PIARC)</strong></th>
<th><strong>BURNLEY FIRE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The fire itself</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The fire grew rapidly, even if the lorry load was not considered as dangerous goods.</td>
<td>-- • Difficult to reach the fire because of smoke and heat. • Tunnel users could not extinguish the fire with an extinguisher.</td>
<td>• HGV serious fires can happen even with “non-dangerous” goods. Redefine the notion of “dangerous goods” for road tunnels.</td>
<td>The fire grew very rapidly with a series of “explosive” ignitions. Without active intervention by the deluge system it is reasonable to expect the fire would have escalated into a very large fire rapidly.</td>
</tr>
<tr>
<td><strong>Safety facilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast and precise fire location detection.</td>
<td>++ Optimisation of the ventilation operation.</td>
<td>Need of fire detection systems able to locate rapidly the fire.</td>
<td>Fast and precise fire location detection achieved.</td>
</tr>
<tr>
<td>First alarm given by opacimeters and smoke detectors.</td>
<td>+ Fast alarm.</td>
<td>Fire detection systems should include smoke detection in addition to temperature elevation detection.</td>
<td>Burnley Tunnel has CCTV with automatic incident detection. This automated incident detection does not include specialised smoke detection systems although lane obscuration by smoke may set off an alarm. This can be contrasted with the upgraded Sydney Harbour Tunnel which does have computer based image analysis smoke detection.</td>
</tr>
<tr>
<td>Two people died in a pressurised shelter because of heat.</td>
<td>-- Two victims.</td>
<td>Pressurised shelters must be related to an evacuation route that is not the tunnel itself.</td>
<td>Some of the pressurised shelters in the Burnley Tunnel are related directly to the tunnel and not the evacuation route. This is undesirable according to PIARC. The suppression system in the Burnley Tunnel alters the risk profile assumed in the PIARC documents.</td>
</tr>
<tr>
<td>The rating cable placed in the fresh air duct worked properly during the whole fire whereas other equipment in the traffic space were destroyed.</td>
<td>++ Communication was possible during the entire rescue operation.</td>
<td>Place heat sensitive equipment in a fresh air duct whenever possible.</td>
<td>Communication was possible during the entire rescue operation. Damage to communication systems cabling was comparatively minor. The use of the deluge system has been identified as the most significant reason why the cabling was protected.</td>
</tr>
</tbody>
</table>
### Response by rescue forces

<table>
<thead>
<tr>
<th>Events</th>
<th>Consequences</th>
<th>Lessons Learned (PIARC)</th>
<th>Burnley fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>First fire fighters arrived from the most smoked tunnel side.</td>
<td>Could not reach the fire.</td>
<td>Need to inform the fire fighters of the extent of the smoke plug in the tunnel.</td>
<td>In the Burnley incident the first fire fighters arrived from the smoke tunnel side. They could reach the fire but had to withdraw. The fire fighters were unaware of the extent of the smoke plug. It appears from this investigation that they were unaware in detail of the functional effect of a smoke extraction system within the tunnel. Had the extraction system been unsuccessful (such as where the intensity of the fire escalated beyond the capability of the deluge system to suppress it). The fire fighters would have been at extreme risk. The fact that the fire fighters entered the tunnel without their BA equipment on and operational highlights this risk. The fact that they stopped near the area where the plug of dense smoke was situated to put on their BA equipment also highlights this risk.</td>
</tr>
<tr>
<td>Misunderstanding about the fire place.</td>
<td>Arrived at the tunnel late.</td>
<td>Need to train the fire fighters.</td>
<td>No misunderstanding about the fire place. Arrived at the tunnel in an extremely timely way. Fire fighting response in terms of timeliness was excellent.</td>
</tr>
<tr>
<td>Fire fighters entered the tunnel with inappropriate equipment.</td>
<td>Fire fighters were trapped in the tunnel. One died, and the evacuation of the others needed several hours.</td>
<td>Need to train the fire fighters – cooperation needed between the tunnel operators and the fire fighters to inform them on the situation inside the tunnel.</td>
<td>Not an issue during this incident but would have become such an incident had the fire escalated. Possible modes of escalation include breaching of diesel fuel tanks, heavy goods vehicle, illegal dangerous goods that become engaged in the fire etc. Training of fire fighters is routinely conducted.</td>
</tr>
<tr>
<td>European Events</td>
<td>Consequences</td>
<td>Lessons Learned (PIARC)</td>
<td>Burnley fire</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Fire fighters reach the fire in the shortest time technically possible.</td>
<td>+</td>
<td>Even with their short reaction time, the fire was already very large and difficult to fight.</td>
<td>In the event of a large fire, users have to self evacuate in a very short time period.</td>
</tr>
<tr>
<td>Car drivers entered the tunnel in spite of the red signal and siren.</td>
<td>--</td>
<td>More victims.</td>
<td>Need to inform the users on the behaviour expected from them.</td>
</tr>
<tr>
<td>Users use the emergency exits.</td>
<td>++</td>
<td>Fewer victims.</td>
<td>Need to inform users on the behaviour expected in case of a fire.</td>
</tr>
<tr>
<td>The victims were drivers who stopped in the tunnel 300 to 600 metres away from the fire, apparently because they could not see the fire.</td>
<td>--</td>
<td>As these tunnel users saw the smoke their action time to reach the emergency exits was very short.</td>
<td>The tunnel users should be told that in case of a traffic stop in a tunnel with no information on what is happening, they must leave their vehicles to reach the emergency exits or shelters.</td>
</tr>
</tbody>
</table>
### Tunnel operation

**Fresh air supplied for capacity (from the bottom).**

- Accelerated the smoke velocity towards the portals.
- Longer smoke plug.

**Lessons Learned** (PIARC)

- Reduce fresh air supply if the longitudinal velocity is not controlled.
- Ventilation procedures have to be checked periodically in the light of available recommendations.

**Burnley fire**

Fresh air supply was reduced. Extraction implemented and reverse air flow established downstream of fire. This is a major technical achievement and positively contributed to the safety in the tunnel.

### Fresh air supply from the ceiling stopped after the fire alarm.

++ Permitted smoke stratification in the minutes following the fire.

**Lessons Learned**

- Fresh air supply must be reduced in the fire zone to favour a smoke stratification.

**Burnley fire**

Fresh air supply reduced in fire zone and coupled with smoke extraction. De-stratification occurs with use of deluge system. Providing fresh air at the lower velocities to the fire zone coupled with reducing the fire growth rate and risk of flash over maintained such tenability as to allow emergency services to intervene in deluge zone. This is a major technical achievement.

### Ventilation procedures were not followed (blowing instead of extraction).

- No smoke extraction in the fire zone.
- Blowing from the ceiling contributed to the smoke de-stratification.

**Lessons Learned**

Need to train the tunnel operations to react to emergency situations.

**Burnley fire**

Tunnel operators reacted according to training and in response to actual emergency situation.

### A vehicle queue built up at the back side of the fire.

-- A large number of people in the dangerous zone.

- The fire transmitted to other vehicles.

**Lessons Learned**

- Fire safety distance must be respected when vehicles have to stop in tunnel. Need of information for the user.
- Barriers should be installed in long tunnels to avoid the accumulation of vehicles in danger zones.

**Burnley fire**

Fire safety distance when viewed in the context of the deluge fire suppression system were respected in this incident. Non-congested conditions allowed drivers to stop some distance back from the crash zone. However in the event that there were multiple incidents the drivers stopped behind the main crash zone were “bumper to bumper”. This is extremely undesirable. There is currently no information for drivers in tunnels as to an appropriate safe distance to stop. “The most dangerous vehicle in a tunnel is the vehicle in front of you.” is a suggested type of campaign message.

---

**Legend**

- ++ Very positive consequences
- + Positive consequences
- - Negative consequences
- -- Very negative consequences
This comparative table clearly identifies that although the Burnley Tunnel performed extremely well on aspects of incident detection, fire suppression and intervention, lessons can be learnt and improvements made in areas such as:

- Emergency services access and personal protection
- User evacuation both willingness to flee and willingness to use cross passages and refuges
- Users propensity to stop vehicles too closely to each other

As noted by PIARC which report at page 95:

“The need to precisely locate the fire in the tunnel is essential for operating the ventilation system in the most efficient way. The time response of public fire rescue forces was on the order of 15 minutes for both the Mont Blanc and Tauern fires. In the St Gotthard fire, the time response was even shorter, but not sufficiently so to rescue all the victims trapped in the smoke. This means that the safety of users depends mainly on their ability to self evacuate in the few minutes after the fire breaks out, during the first stages of the emergency ventilation operation.

This demonstrates the importance of educating tunnel users on optimising their ability to self-evacuate (i.e. flee). It also shows the importance of proper ventilation system operation to:

(a) the initial evacuation of tunnel users as well as the progression of fire rescue forces into the tunnel.”

In the case of the Burnley incident detailed analysis of the video footage made available during this investigation indicates that most users chose to walk along either the elevated walkway or tunnel bed to the portals to evacuate. In the event of a sudden and anticipated failure of the tunnel control systems to manage the smoke and toxic gases within the fire such decisions could be fatal. Accordingly it is recommended that more effort be made to educate tunnel users on the importance of evacuating from a tunnel incident via the emergency cross passages or such other facilities as are available. In circumstances where the tunnel portal is visible and readily accessible exit through the tunnel portal may be appropriate. Nonetheless the speed at which tunnel conditions can deteriorate should not be underestimated.

The series of images extracted documenting the rapid and complete degradation of tunnel tenability downstream of the fire. The image becomes completely obscured over a 30 second period.

Camera 56

7.1 Emergency Exits

Emergency exits must not only be provided, they must be used. There are a series of design principles which have been developed following emergency incidents around the world with respect to increasing the likelihood that emergency exits will be used. These design principles are captured at page 135 of the PIARC report - *Systems and Equipment for Fire and Smoke Control in Tunnels “Design Principles”*.

<table>
<thead>
<tr>
<th>AS BUILT</th>
<th>RESPONSE CITYLINK</th>
<th>PROPOSED CHANGES TO CITYLINK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency exits should be clearly signed as such to distinguish them from equipment room access. The recommended colour of the doors (very often the “emergency exit” colour green) must be considered in combination with the type of tunnel lighting.</td>
<td>The current CityLink design while better than many other tunnels within Australia does not meet world’s best practice for clear signage to distinguish them from equipment room access etc.</td>
<td>Update emergency exits treatment</td>
</tr>
<tr>
<td>Doors and openings should be sized to handle a large number of people in a short time as well as the passage of rescue workers with equipment or stretchers.</td>
<td>The doors and openings in the current CityLink Tunnel were observed to be sufficient for the volumes of people using them in the subject incident however it is likely that there will be queuing if larger volumes of people try to use the exit. In their current dimensions they cater for what is in substance a single or perhaps two a breast flow of pedestrians.</td>
<td>Review adequacy of doorway for emergency egress</td>
</tr>
<tr>
<td>Emergency exits should be visible either directly or by visible and recognisable signs from any position in the tunnel.</td>
<td>Emergency exits are visible within the tunnel however they are not at world’s best practice levels of visibility.</td>
<td>Update emergency exit treatments</td>
</tr>
<tr>
<td>Illuminates of the access floors, doorsteps, etc and the room just behind the emergency exit should be “inviting” and be designed to prevent people from falling or stumbling.</td>
<td>The CityLink exits are not “inviting”.</td>
<td>Update treatment</td>
</tr>
<tr>
<td>Kerb lighting/markers should not be obstacles for walking people.</td>
<td>The use of elevated walkways for accessing the emergency exits constitutes an obstacle. The analysis of the video footage shows that this obstacle was readily overcome by users of the tunnel. Even users in a wheelchair were observed to be able to use the elevated walkway by the generous and courteous assistance of other people evacuating. Likewise children in</td>
<td>No changes recommended, but consideration of non elevated walkways for future tunnels recommended.</td>
</tr>
</tbody>
</table>

By Arnold Dix 125 : 174 9 June 2011
<table>
<thead>
<tr>
<th><strong>AS BUILT</strong></th>
<th><strong>RESPONSE CITYLINK</strong></th>
<th><strong>PROPOSED CHANGES TO CITYLINK</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>pushers etc were able to access the walkway. However use of an elevated walkway does constitute an obstruction and it would be desirable for the walkway not to be elevated.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency exit doors should not be locked.</td>
<td>Although emergency exit doors are not locked within CityLink there was at least one reported instance of a person seeking to evacuate who found a door locked. Having reviewed the video material and detailed computer alarms during the event it is likely that the reason for this apparent locked door was insufficient differentiation between emergency exit routes and utilities doors. Addressing the requirement of clearly signed emergency exits more thoroughly you would likely address the apparent locked exit door phenomenon.</td>
<td>Update treatment of emergency and non emergency doors</td>
</tr>
</tbody>
</table>

Discussions with CityLink indicate that they were designing significant upgrades of this aspect of the tunnel design prior to 23 March 2007. A briefing on the proposed changes suggests significant improvements to these aspects of the tunnel design will shortly be implemented as part of the aesthetics upgrade.
8. Monitoring of Events in the Course of Operation

The passage of time without serious incident must never be interpreted as the risk of a serious incident occurring decreasing. In normal circumstances there will be events which occur in a tunnel which although not obviously serious, are when viewed statistically and probabilistically are significant.

Recording all incidents provides a useful database on the performance of the tunnel. Because the tunnel’s performance requires an interaction between users, their vehicles and tunnel systems the collection of such data can – through the passage of time – create a database which can reveal trends which on a day to day basis are not obvious.

For example the probability of a stopped vehicle in the CityLink tunnels may in fact increase with the price of petrol. In other words as the economic pressures on motor vehicle users increase so too does the probability of cars travelling within the tunnel with insufficient fuel to complete the journey. As demonstrated by the incident of 23 March the probability of an accident occurring where there is a stopped vehicle is greater than where there is no stopped vehicle. Collection of data in this way allows the tunnel operator to identify trends and then develop strategies to mitigate them. In the case of running out of fuel the mitigation strategy might be as simple as a public awareness campaign about the importance of having sufficient fuel in your vehicle when travelling on freeways, bridges and tunnels.

It is also essential to identify relevant changes in the risk profile. A change to hydrogen powered vehicles, a plastics factory in Richmond, a new type of plastic vehicle – are all examples of changes which may require a considered response manage changes to the risk profile.

Creating a State or even National database which records accidents and allows analysis of events to discover emerging safety trends is highly desirable. Standardising it for all Victorian tunnels, or ideally all Australian tunnels

Augmenting this database with an ‘emerging risks’ category – e.g. Hydrogen cars; would be prudent.
9. **The Role of the Operator – The CityLink Position**

Ultimate responsibility for the operation of the tunnels rests with the Tunnel Controller. In the Melbourne CityLink control room there are two operators. One operator assumes primary responsibility for the CityLink tunnels and the second operator assumes primary responsibility for the surface roads.

Despite the existence of computers the CityLink tunnel controllers make the decisions with respect to:

- Location of an incident for the purposes of smoke extraction
- Location of an incident for the purpose of single or multiple deluge operation
- Adequacy of emergency ventilation
- Closing of tunnels
- Declaring and initiating emergency evacuation
- Responding to multiple incidents

This means that ultimate responsibility for the operation of the emergency systems rests with the operator. A failure by the operator to act or to act appropriately will result in compromising the potential response by the combined safety systems in the tunnel to the detriment of the tunnel users.

To support the operator a computer interface has been developed which prompts the operator into considering critical facts which the operator must determine and enter into the computer.

For each variation on entered fact, it has been determined in advance how the thousands of computer controllable devices will be operated.

These pre-arranged computer responses are formulated well in advance of any incident and should be revised as new information, refurbishment and refinement of the safety subsystems occurs.

The computer which controls these functions is called the CCCS.

9.1 **Operation of the Computers**

Currently these high level pre-arranged computer responses do not fully extend to a second emergency in the same tunnel (as at 2007). Having reviewed the incident and identified several subsequent 'near misses', this is considered a weakness in the current computer system which should be remedied.

The operators have both a CCCS Operator Reference Manual and CCCS Operator Guide.

Paragraph 1 of both the Introduction to the CCCS Operator Reference Manual and CCCS Operator Guide state:
“Under no circumstances should the information contained in this document be construed as operational instructions or procedures for how to manage actual traffic and for/or emergency incidents in the Burnley and Domain Tunnels. It is left to the operator of the MCL to formulate specific operational procedures for the usage of the TIMS Subsystem functionality in managing tunnel incidents as deemed required.”

The CCCS Operator Reference Manual explains the tunnel incident management subsystem and provides guidance to the operator on how to use the computer interface for control of the tunnel in an incident. Importantly ultimate responsibility for the operation of the tunnels emergency systems rests with the tunnel controller.

In Clause 1.3.2 of the Emergency Management Functions section of the Operator Reference Manual notes the key features of the emergency incident management as:

```
1. Activate/deactivate emergency mode
2. Smoke extraction control by firebox number
3. Smoke extraction damper motion and fault status monitoring
4. Deluge zone device control by firebox number
5. Deluge zone device and fault status monitoring
6. Play RRB/PA deluge message
7. Selection and execution of tunnel evacuation plans
```

Page 15 Clause 2.2.2 describes the process for activation of the emergency incident management section.

A valid firebox number must be added before the active emergency mode can be enabled. Invoking emergency mode:

"provides the tunnel operator with access to the emergency devices and tunnel evacuation controls. The TIM Screen allows the operation of the smoke extraction, deluge and evacuation plan controls for that tunnel in any order" [Clause 2.2.2]

This means that the current tunnel operator has a choice about the order in which the critical emergency systems are executed; i.e. Smoke extraction, deluge and evacuation. Furthermore the correct location of the 'firebox' is critical for the smoke extraction, deluge and evacuation responses by the computers.

In the CCCS Operator Guide a series of exercises require the operators to train on:

- Creating a new traffic incident response over an existing traffic incident response (thereby contemplating multiple traffic incidents)
- Activating emergency mode during a normal traffic incident (thereby contemplating escalation of a normal traffic event to an emergency)
- Creating an emergency incident job
• Creating a non emergency traffic incident response while dealing with an emergency incident (multiple incidents)

• Changing the firebox location within an existing active emergency job (encouraging operator judgement)

• Modifying an existing emergency incident job to include implementation of a traffic plan (encouraging multiple tasking)

• Operating smoke extraction devices

• Creating a new emergency job over an existing emergency job (for multiple emergency incidents including multiple but separately located fires requiring deluge operation)

• Implementation of closed tunnel evacuation plan (evacuation route is only selectable if it is an emergency in the incident tunnel)

It should be noted that operators are advised to seek independent confirmation of deluge zone operation ‘e.g., By viewing the associated camera image’.

Importantly when managing traffic and emergency incidents in the tunnel the operator has facilitated access to the correct camera footage of the incident area as determined by the firebox number entered by the tunnel operator. This is how the computer systems facilitate operator access to the correct video footage in an emergency.

In this way the operator directly impacts both the order and the nature of the computer control systems response to an emergency, and is ultimately responsible for the initiation of the emergency response.

Furthermore there is a 'Melbourne CityLink Tunnel System Contingency Plan' which systematically characterises incidents and documents the response. At page 24 of the report lane closure is prescribed as the response for a stopped heavy commercial vehicle, while a fire ‘in a tunnel’ necessitates tunnel closure.

A detailed review of the computer logs and analysis of the tunnel operators’ control screens confirmed that not only were procedures followed – but that the operator was sufficiently confident in the use of the systems that he changed the suggested deluge zone operation to optimise the response (in accordance with the procedures).

10. **CITYLINK IN CONTEXT**

10.1 **SYDNEY HARBOUR TUNNEL**

Sydney Harbour Tunnel is the oldest urban high volume road tunnel in Australia. Inspection of Sydney Harbour Tunnel control centre and interviews with its Operations Manager and operators revealed a highly motivated; safety focussed and well resourced tunnel operation.

Importantly despite being Australia’s oldest tunnel reinvestment in system upgrades, innovative technology and training suggests its performance in
an emergency will be comparable (if not superior) to much more recent tunnels (although this state of readiness in no way is a guarantee of the outcomes).

Examples of the innovation observed in the Sydney Harbour Tunnel include:

- Laser projected full portal ‘stop’ signage
- Computer based image analysis of video material searching for the ‘signature’ of smoke and not merely obscuration of a lane
- Predetermined multiple incident control capability of emergency systems

Each of these systems post dates the tunnels completion. They are integrated with the tunnel safety systems.

As at 2007 none of these more advanced system features were fully operational under automated command at the more modern CityLink.

10.2 LANE COVE TUNNEL

Lane Cove Tunnel is Australia’s most recent high volume urban tunnel. It has none of the new features noted above at Sydney Harbour Tunnel. Furthermore the tunnel has little practical ability to regulate traffic flow through it. The ventilation system is similar to Melbourne CityLink in that it is of the longitudinal type. Unlike CityLink there is no smoke extraction and accordingly in an incident it is absolutely essential that traffic not be congested and highly undesirable that there be a multiple incident. This means that in a number of important respects the performance of Australia’s most recently opened road tunnel is more constrained than Australia’s oldest (Sydney Harbour) and CityLink.

This comparison clearly demonstrates the importance of not only design but ongoing improvement and development of tunnel safety systems in this type of dynamic infrastructure.

The design of the tunnel must be tailored to the particular application. Melbourne CityLink’s high volume of traffic, high proportion of freight and critical role in Melbourne’s traffic flow justify its investment in 3 lanes, advanced emergency ventilation, fire suppression systems and investment in 24 hour monitoring and control.

The effectiveness of these systems was demonstrated by the system response to the Burnley Tunnel crashes on 23 March 2007.
11. **TRAINING**

Prior to the incident on 23 March 2007 the following training regime was in place at CityLink.

All Traffic Control Room Operators (“TCRO”) participate in a range of regular training activities.

11.1 **MONTHLY MEETINGS**

All TCRO's are expected to attend a monthly meeting. This meeting is independent of the shift. These meetings focus upon changes in plans, procedures of work instructions as well as a discussion of monthly reports, general business and incidents of note. From time to time, there are guest speakers to explain future projects which may have impact upon the control room.

11.2 **EMERGENCY MANAGEMENT EXERCISES**

Every three months, an emergency management exercise is undertaking.

11.3 **TRAINING AND SKILLS MAINTENANCE**

All TCRO’s spend at least a full day a year on practical assessments and scenario based training which includes taking TCRO's out into the field and through specific procedures in work instructions, including turning on actual tunnel devices.

For example, the operation of the deluge and smoke extraction systems is conducted by each TCRO and other TCRO’s are positioned in the tunnel to observe their effect.

Individual operator training manuals are used to check what training has been completed and which courses they have attended. These training manuals are supplemented by a five year training plan which is developed for each of the operators. Operators are also provided with an opportunity to attend various topic related conferences and training courses.

11.4 **BI-ANNUAL TRAINING BOOK**

Every TCRO is required to complete two training books each year. Formal staff assessments are completed at the completion of each bi-annual training book. This ongoing process of training and review is subject to TCRO input. All staff are encouraged to put input into the training process. The structure of the training books attempts to cover every aspect of the operation of CityLink for every twelve month period.

11.5 **OPERATIONAL AREA FAMILIARISATION**

Each TCRO has seven dedicated days per year to familiarise themselves with any modifications to CityLink and/or spend time in the field observing the system. This is done in conjunction with surveillance instant response
and maintenance crews. This gives the TCRO’s practical exposure to the operations of the tunnel.

11.6 PERFORMANCE REVIEWS

The Traffic Operations Manager conducts quarterly discussions with Road Service and Traffic Department staff to discuss ongoing projects as well as job performance.

11.7 NEW TCRO TRAINING

A six month training course is used for new TCRO’s. Training begins with one month ‘off shift’ where the new TCRO’s work directly with the roadway and other assets. The next five months is conducted on shift with both the tunnel and open road operator. A new TCRO is periodically assessed on their progress and then undergoes a final assessment. These assessments are conducted in two phases. Firstly, is the ability to operate the open roadway and secondly, to determine their ability to operate the tunnels.

11.8 INTERNAL AUDITOR COURSE

The training of staff includes an internal auditor course which focuses on work instructions and procedures. This allows the TCRO’s to be involved in both understanding the importance of procedures and secondly, being able to manage matters which do arise in a systematic and an informed way.

11.9 EMERGENCY COORDINATION CENTRE COURSE

One TCRO has attended training at a Multi-Agency Emergency Response and Emergency Management of Australia training course at Mt Macedon.

11.10 ADVANCED TRAFFIC MANAGEMENT

Personnel from the Road Services and Traffic Departments at CityLink have attended the advanced Worksite Traffic Management course. This course provides information necessary to develop, implement, control and monitor traffic management plans for work sites on or adjacent to the carriageway under CityLink’s control, these focus on:

- Driver behaviour and Performance; and
- Hazard risk management.

11.11 ATOG CONFERENCE

The Australian Tunnel Operator’s Group (ATOG) holds informal meetings. Operators attend these meetings and share information about tunnel operation, events and responses. From time to time, guest speakers make presentations at the ATOG meetings.
The use of multifaceted training programs for the tunnel operators is entirely consistent with the quick, accurate and expert response to the incidents on 23 March 2007.
12. **EMERGENCY EXERCISES**

CityLink conducts both full scale and desktop exercises on a regular basis. Because CityLink is scheduled critical infrastructure, specific details of these exercises are not included in this report. However, in preparing this report, all material requested was provided. Details of exercises, lessons learnt and responses have been reviewed.

In summary, desktop exercises were held in 2001, 2002, 2003, 2005, 2006 and 2007. The agencies attending the desktop exercises vary depending upon the scenario being tested.

In addition to the desktop exercises, major field exercises were conducted in January 2004 and January 2007. Each of the full scale exercises involved multiple agencies and their personnel and involved the complete closure of the Burnley Tunnel.

An examination of the documents produced, as well as the inspection of the CityLink tunnels and control rooms has confirmed that a range of actions have been taken by CityLink to deal with issues revealed by the exercises. These improvements include:

- Refining the relationship between radio rebroadcasts and public address messages in terms of clarity and volume within the tunnel.
- Reviewing the effective management of continuous radio rebroadcast messages and manual public address announcements from the control room.
- Improving PA messages in the safe tunnel.
- Reducing the number of control steps required to initiate an evacuation.
- Upgrades of directional exit signs.
- Improvements to directional signage in cross passages (being upgraded as part of the CityLink Aesthetics Project).
- Development of an evacuation plan for the safe tunnel.
- Introduction of no smoking requirements.
- Modification to use of flashing strobes and walkway lights in the safe tunnel.
- Tunnel control room logging improved by introducing electronic logging.
- Improvements to Incident page on computer control system.
- Pre-recording of all radio read broadcast and public address messages
- Messages to evacuate duplicated in both audible and written forms via the radio read broadcast, public address and traffic information (TIMS) signage.
13. CITYLINK AESTHETICS PROGRAM

At the time of writing this report, CityLink is embarking upon a major ‘aesthetic’ refurbishment program. An inspection was undertaken of the full scale mock representation of the upgrade. Observations have also been undertaken of progressive aesthetic upgrades to the tunnel during the course of preparation of this report. It is beyond the scope of this report to comment fully on the aesthetic upgrade, however it should be noted that:

- The upgrade is not merely “aesthetic”. The effect of the upgrade will most likely be a significant improvement in tunnel safety due to increased effectiveness of the as built tunnel infrastructure through better signage, lighting and emergency passage marking.

- Given the under-utilisation of the emerging cross passages on 23 March 2007, such improvements are appropriate.

- The upgrade program had commenced prior to the incident. The incident upgraded the priority of the upgrade program.
14. **RECOMMENDATIONS**

On the basis of the review conducted, the following recommendations are made:

**14.1 TUNNELS GENERALLY**

14.1.1 That a centrally administered database of tunnel incidents be created to facilitate open data collection and analysis of tunnel incidents with the objective of identifying emerging trends or recent problems.

14.1.2 Tunnels should be designed and operated to promote consistency of vehicles speed.

14.1.3 That vehicle speeds in tunnels, and vehicle separation should be regulated to appropriately manage the safety of users and the flow of vehicles.

14.1.4 That the impact of speed cameras in the tunnels upon driver behaviour (and in particular consistency of speed and driver distraction), be examined with a view to – if necessary – developing an improved approach for regulating speed in the tunnels which optimises the consistency of vehicle speed - across all vehicle types and in all lanes and does not distract drivers from the primary driving task.

14.1.5 That where possible, and subject to the geotechnical constraints of doing so, future tunnels be provided with emergency lay-bys, shoulders or such other equivalent stranded vehicle protection which allow disabled vehicles which cannot exit a tunnel, to park without undue risk of being crashed into by other passing traffic within the tunnel.

14.1.6 That the risks caused by underground intersections both from diverging and converging traffic flows be acknowledged and actively managed in the road tunnels.

14.1.7 That the number of horizontal curves be minimised and/or engineered so as to maximise the sight distances available to motorists.

14.1.8 That elements be included within the design that assist drivers maintain safe speeds and vehicle separation in the tunnel.

14.1.9 That greater emphasis be placed on the design of emergency egress pathways which will be chosen by evacuees in preference to the tunnels themselves, as emergency escape routes.

14.1.10 That a performance standard for the emergency control systems be developed. This standard should include requirements for system capacity to respond to emergencies and command emergency systems, specifications including advice on redundancies and directions on the use of control systems with single point failures.
14.1.11 A driver education program on safe driving in tunnels be developed.

14.1.12 An effective vehicle separation requirement between trucks and cars be developed and enforced for vehicle separation in tunnels.

14.1.13 An assessment be made of the potential neighbourhood impact of emergency ventilation emissions following an incident and appropriate measures be put in place to mitigate such risks.

14.2 **RECOMMENDATIONS FOR THE CITYLINK TUNNELS AND THEIR APPROACHES (APPLICABILITY TO OTHER TUNNELS SHOULD BE DETERMINED ON A CASE BY CASE BASIS)**

14.2.1 The impact on hydrant pressure and volume of three or more deluge zones operating should be investigated to assist preparing response plans for multiple incident (multiple deluge) events.

14.2.2 That CityLink upgrade their existing emergency egress pathways so as to make them more attractive to tunnel users in the event of an emergency.

14.2.3 That the performance of the City Link emergency control computers be regularly assessed and (when necessary) upgraded in order to ensure that in an emergency the operator can command all emergency equipment in an effective and timely manner. Such assessments must be in the context of realistic incident scenarios and take due account of the need for accurate and effective responses within a very short period of time.

14.2.4 That the role of driver distractions in causing motor vehicle crashes be incorporated in all aspects of tunnel related design including placement of driver information signs well before a tunnel entrance (so a not to distract the driver in the tunnel portal region and optimise their driving performance).

14.2.5 That there be a reasonable delay between lowering the speed limit in the tunnel and activation of speed cameras in the tunnel.

14.2.6 That the 80 km/h speed limit be managed as a maximum speed limit, and CityLink maintain its practice of reducing this speed to manage user safety.

14.2.7 The tunnel should be configured so that during normal tunnel operations emergency egress paths, refuges, cross passages and emergency communications devices are obvious to the passing motorist (without being an undue distraction to the driving task).

14.2.8 That there be a public advertising campaign on the importance of keeping a safe distance from the vehicle in front (and advising what a safe distance is).

14.2.9 That devices be installed to assist motorists determine what constitutes a safe separation distance within the tunnels.
14.2.10 That improved methods be developed to more effectively persuade tunnel users to evacuate to a place of safety via the cross passages, escape tunnels, or refuges, in the event of an emergency.

14.2.11 That radio rebroadcast messages be simplified. E.g. "evacuate now".

14.2.12 With respect to the emergency services communication systems within CityLink, a clear set of procedures be developed which ensures:

14.2.12.1 The tunnel operator and emergency services are constantly aware of the current state of emergency communications' capability.

14.2.12.2 In the event that emergency communications capability is degraded, a mitigation strategy is available to manage the residual risk it poses.

14.2.12.3 Such emergency communication systems should be operable in both the active tunnels and in the refuge cross passages and any other areas likely to be accessible during an emergency.

14.2.13 A procedure be developed to manage the risk to tunnel neighbours from ejected toxic gases in an emergency (e.g. Ventilation system shutdown on adjoining high rise buildings)

14.3 TECHNOLOGY WITHIN THE TUNNEL CONTROL ROOM

14.3.1 That ensuring the most effective order of tunnel control commands is utilised and/or developed and that this order have regard to both the time taken to put a command into action and the effect on other control systems of making the command. (e.g. Emergency ventilation, evacuation and deluge activation)

14.3.2 That a systems performance review be undertaken in order to determine how to optimise the fastest and most effective response of the deluge system when activated.

14.3.3 An upgrade of the emergency response capability of the computer control system to allow an operator to more readily respond to more than one emergency without the need to manually configure elements of the emergency response systems.

14.3.4 A system performance validation process be implemented to ensure that, collectively, all emergency systems and sub systems will operate effectively during real incidents. Such a program is in addition to, and not to the exclusion of, testing the functional performance of sub-systems such as deluge, ventilation, messaging, and lane closures separately.

14.3.5 A review of the effectiveness of the emergency tunnel closure capability of CityLink with a view to installing upgraded systems if
that review demonstrates that traffic did not respond as quickly as was desired to the “Stop Tunnel Closed” command.

14.4 WITH RESPECT TO EMERGENCY SERVICES

14.4.1 MFESB reassess the suitability of their two-way radios for use in a high noise environment such as the CityLink tunnels during the activation of emergency ventilation fans.

14.4.2 That the possibility of MFESB and other emergency services’ personnel having special access to mobile telephone emergency service and/or if that is considered inappropriate or not possible, special training on the limitations of the use of mobile phones in an emergency be investigated.

14.4.3 That the procedure of entering the incident tunnel during an emergency be reviewed with special emphasis on the risks posed to MFESB members in the event of a sudden and unanticipated degradation in conditions.

14.4.4 That the approach to fighting fires in the deluge zone be re-assessed in the context of the risk of rapid degeneration in the tenability within the deluge zone in the case of credible rapid fire growth or failure of emergency systems within that zone to support the MFESB operations.

14.4.5 That the procedures amongst firemen for entering such a deluge zone be reviewed and the practice of entering the zone alone be revisited.

14.5 SPEED LIMITS

14.5.1 That the speed limit inside the tunnel be reflected by the speed limit outside the tunnel on both entrance and exits. Accordingly, the reduction in the speed from 100 km/h to 80 km/h in the zone between the Westgate Bridge and the Burnley Tunnel is supported.

14.5.2 That the speed limit in the tunnel not be reduced generally or reduced for particular classes of vehicles.

14.5.3 The speed limit should be regarded as a maximum speed and reduced when needed to maintain safety.

14.5.4 Measures which decrease the time it takes to slow (and if necessary stop) vehicles in tunnels should be sought and continuous improvement in this aspect of tunnel control perused.

14.6 LANE CHANGING

14.6.1 A prohibition on lane changing is not supported. While it is highly desirable that the design of new tunnels should minimise the requirement for lane changing, an analysis of the Burnley Tunnel clearly indicates that with merging traffic from Kings Way and the decrease in useable lanes from three to two prior to the merging lane in the area several hundred metres preceding the tunnel.
entrance, coupled with the loss of the left hand lane after exiting the tunnel, demands lane changing for effective traffic movement. However, new tunnels should be designed so as to minimise the need for lane changing and where practically possible, prohibit them.

14.7 **SPEED RESTRICTIONS ON CLASSES OF VEHICLES**

14.7.1 Speed restrictions on classes of vehicles would create greater tunnel risks. It is extremely undesirable to have vehicles travelling at different speeds in the tunnel. Changing the speeds applicable to different classes of vehicles would exacerbate problems which already exist with differential speeds within the tunnel including lane changing and vehicle separation. Exit grades from tunnels directly impact speed differences between vehicles.

14.7.2 Truck speeds should not be reduced in the CityLink tunnels. To do so would reduce the overall safety for users by substantially increasing the speed differential of cars and trucks, and thereby increase the need for undesirable lane changes and congestion. This effect would be most pronounced in the steep exit area of the Burnley Tunnel where the 6%+ grade already makes maintaining the speed limit impossible for many trucks.

14.8 **RESTRICTION ON HEAVY VEHICLES IN RIGHT LANE**

14.8.1 The habit of Victorian drivers passing to the left hand side of slower vehicles is potentially extremely dangerous on all roads. In Europe ‘undertaking’ is a mandatory licence suspension offence. If passing was restricted to the right hand side (and enforceable) and slow vehicles were required to move left (and was enforceable) the issues with slow vehicles in right lanes would largely be resolved. However the observed practice of trucks travelling in groups – jostling for leadership on the basis of slightly different settings on their maximum speed governors – coupled with a culture intent on demonstrating which truck is fastest (leading to pods of trucks engaging in protracted 1 and 2 km/h passing manoeuvres – across all lanes) – is undesirable. Accordingly I recommend serious consideration be given to excluding trucks from the right lane where there are 3 or more lanes for traffic in that direction. Such a requirement cannot be responsibly imposed in CityLink because of the current network configuration and severe grades, but should be considered in future tunnels.

If there was not the restriction from three lanes to two lanes prior to the entrance to the Burnley Tunnel and the merging of traffic from Kings Way in the left lane, I would recommend that heavy vehicles not be permitted to travel in the right of the three lanes in CityLink. However, this pre-existing configuration of the tunnel does not, in my opinion, allow for restriction of heavy vehicles from the right lane without the risk of severely compromising the flow of traffic from the Westgate Bridge into the Burnley Tunnel and dangerously disrupting traffic flow through the tunnels.

A detailed analysis of this option is beyond the scope of this investigation.
14.9 MANAGING RISKS OF SMOKE AND GAS ON NEIGHBOURS

In an emergency there is a foreseeable risk that toxic material may leave the ventilation towers of the tunnel and intercept neighbouring properties. A risk mitigation strategy, such as notification protocol for shutting windows and turning off neighbours’ ventilation systems should be developed to mitigate this risk.

14.10 DRIVER EDUCATION

14.10.1 The New Drivers Handbook (Solo Driving) (Vic Road 2007) should be expanded with respect to Safety in Tunnels – especially with regard to:

- Safe distances
- Lane changing
- Driver distraction
- Special dangers in tunnels
- Emergency behaviour
- Self rescue
- Emergency response

14.10.2 Driving tests for all categories of vehicles should include specific questions concerning the correct behaviour for road users in the event of a vehicle breakdown, congestion, an accident or a fire in a tunnel, on a tollway, freeway, on a bridge etc.

14.11 VEHICLE MATERIALS

14.11.1 The toxicity and flammability of modern vehicles be examined as a contributory factor in both tunnel and surface road personal injuries.

14.12 PUBLIC AWARENESS

14.12.1 The most important message for tunnel users is that unless directed otherwise they should not stop in a tunnel.

14.12.2 An advertising campaign which stresses the importance of the separation between vehicles to maintain safety in a tunnel. I further recommend that the advertising campaign stress the importance of not stopping immediately behind the vehicle in front. The exact separation distance to be recommended is a matter of debate but should be in the order of several car lengths. In practice, despite regulation, this has never been achieved in any
tunnel in the world. It is acknowledged that there is technology available which could enforce such a separation if required.

14.13 **KEEP LEFT**

14.13.1 Redrafting existing “keep left” laws to make them readily enforceable on all roads (focus on all multi lane highways).

14.13.2 Make drivers aware that travelling in the right lane at any speed that disrupts traffic flow in that lane is a safety risk (even travelling at the speed limit).
15. APPENDICES
15.1 **APPENDIX A – NON THEMED COMBINED TIMELINE**

**Key**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck 1</td>
<td>Heavy articulated vehicle</td>
<td>Stops in left lane of tunnel</td>
</tr>
<tr>
<td>Truck 2</td>
<td>Heavy articulated vehicle</td>
<td>Stops behind two cars, also stopped behind truck 1</td>
</tr>
<tr>
<td>Truck 3</td>
<td>Heavy articulated vehicle</td>
<td>Crashes into vehicles in tunnel</td>
</tr>
<tr>
<td>Truck 4</td>
<td>Heavy articulated vehicle</td>
<td>Travelling in right (3rd) lane at time of crash. Hit by truck 3 as truck 3 swerve from the left lane across lane two and into the truck on lane 3. Truck 4 also has a car pushed in front of it by manages to stop before crushing the vehicle and its occupant.</td>
</tr>
</tbody>
</table>

**Burnley Tunnel Timeline for incident of 23 March 2007**

<table>
<thead>
<tr>
<th>TIME</th>
<th>EVENT</th>
<th>SOURCE</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00:00</td>
<td>Beaurau of Emergency Services Telecommunications – while conducting routine maintenance, transfers several transport hubs communications including CityLinks to another site which has less capacity and services a number of other major public locations. This deceases the availability of emergency communications to the transurban tunnels as well as other exiting users.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9:30:00</td>
<td>Telecomunication tower taken off line</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By Arnold Dix 145 : 174 9 June 2011
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:52:00</td>
<td>CityLink Tunnel Operator dealing with broken down vehicle on surface road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 09:52:30</td>
<td>Most vehicles brake lights seen activating in downhill section of tunnel as drivers attempt to maintain &lt;80kph to avoid automated speed camera fines/or loss of licence</td>
<td>All downhill Cameras including 52 Stop C</td>
<td>Maintaining lawful vehicle speeds downhill is a major driver focus for cars and trucks. This internal speedometer focus can distract driver from the primary driving task.</td>
</tr>
<tr>
<td>09:52:30</td>
<td>Truck comes to stop in left lane. Computer identifies stopped vehicle</td>
<td>Camera 53 Stop C Camera 52 Stop F (C52_Melbourne_095 209_user 24 H_x) Camera 54 Stop F</td>
<td>Computer identifies stopped vehicle. Two show vehicle image alarms activate slightly before vehicle stops. Traffic observed to be flowing comparatively unobstructed. There was no mechanical or other fault which required the truck to stop. Prudent practice for trucks is that they do not stop on restricted carriageways such as bridges.</td>
</tr>
<tr>
<td>09:52:42</td>
<td>Stopped vehicle alarm AID 716 (deluge zone 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>09:52:45</td>
<td>AID alarm 718 has two sequential stopped vehicle alarms indicates stopped vehicle near Fire Box B19 (Truck 1)</td>
<td>CCCS log</td>
<td>There is CCTV footage of Truck 1 slowing before alarm.</td>
</tr>
<tr>
<td>09:52:49</td>
<td>Driver of stopped truck exits truck cabin and proceeds on foot to inspect the rear of his truck</td>
<td>CCTV</td>
<td></td>
</tr>
<tr>
<td>09:52:58</td>
<td>Tunnel Controller (TCRO) displays visual images from camera (AID 718) on his monitor (Op2)</td>
<td>CCCS log and recorded CCTV images from TCRO's CCTV screen</td>
<td>TCRO follows standard procedure to review alarm so that he is fully aware of the situation to which the alarm relates. He clicks on camera icon on the computer system associated with AID 718 and views stopped vehicle on CCCS monitor. He then contacts two Incident Response Officers in area of breakdown to respond.</td>
</tr>
<tr>
<td>09:53:11</td>
<td>TCRO acknowledges AID alarm 718</td>
<td>CCCS log</td>
<td>TCRO clicks on relevant icon on computer system to acknowledge alarm.</td>
</tr>
<tr>
<td>09:53:24</td>
<td>Trucks which later crashes into other vehicles enters tunnel</td>
<td>Camera 36</td>
<td>Group of trucks travelling along CityLink as a group. They are travelling at similar speeds.</td>
</tr>
<tr>
<td>09:53:37</td>
<td>Tunnel operator opens computer plan execution window on main tunnel</td>
<td>CCCS log</td>
<td>The computer system can rapidly close</td>
</tr>
</tbody>
</table>
control computer (CCCS) to facilitate process of closing left lane to protect the stopped truck.

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:53:37 to 9:54:05</td>
<td>TCRO:</td>
<td>CCCS log</td>
<td>TCRO clicks on incident reports tab on electronic message log to indicate a new incident job and commences filling in electronic incident report. He opens plan execution window in the CCCS overview screen and types in eight digit job incident number. He scrolls through a range of lane closure options and selects Burnley Tunnel, closure on left lane, and such closure to be to Fire Box 32. He then loads, executes and starts plan.</td>
</tr>
<tr>
<td></td>
<td>• Initiates incident report in relation to stopped vehicle (Truck 1) and ‘close left lane’ plan for Burnley Tunnel to Fire Box B32 (plan no. 991011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Takes necessary steps for this traffic management plan to be loaded from database onto the plan executor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Executes plan which results in message from the computer system reporting what the system is doing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Starts this traffic management plan which commands the traffic management devices within the Burnley Tunnel and its approaches.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Initiates playing of RRB/PA message 148 in Burnley Tunnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TCRO monitors and acknowledges numerous alarms being generated by the slow/stopped traffic around the stopped vehicle (Truck 1) – five (5) alarms.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:53:42</td>
<td>Truck of class 2.2 Dangerous goods (Nitrogen) passes through Burnley Tunnel</td>
<td>Camera 53 Stop C and Camera 54 Stop F</td>
<td>Impact if cylinders breached is not known. (e.g. oxygen depletion, thermal impact). This vehicle is not involved in the crashes but illustrates the range of goods travelling through tunnel.</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9:53:44</td>
<td>Operator 1 dealing with broken down car on surface road</td>
<td>Operator 1 recorded video of TCRO’s CCTV selection</td>
<td>Record from computer system shows operator one dealing with incident on the surface road.</td>
</tr>
<tr>
<td>09:53:59</td>
<td>Wig wags seen flashing in view of Camera 68. speed change being implemented</td>
<td>Video</td>
<td>Around the variable speed message signs are flashing yellow ‘wig wags’ which are designed to alert drivers to a speed change in the tunnel.</td>
</tr>
<tr>
<td>09:54:00</td>
<td>Driver of stopped truck gets back into his cabin</td>
<td></td>
<td>Had driver not returned to his cabin he would almost certainly have been killed in the following crashes.</td>
</tr>
<tr>
<td>09:54:04</td>
<td>Left lane closure plan loaded into computer</td>
<td>CCCS log</td>
<td></td>
</tr>
<tr>
<td>09:54:05</td>
<td>Left lane closure plan started - Plan implementation confirmed by Operator</td>
<td>CCCS log</td>
<td>Starting the plan initiates hundred of pre arranged changes to the configuration of signage devices and other electromechanical systems within the tunnel.</td>
</tr>
<tr>
<td>09:54:12</td>
<td>operator confirms plan to proceed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
</tr>
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</tr>
</tbody>
</table>
| 09:54:12   | RRB message playing – message 148                                    | VES front end computer log  
CCCS computer log (09:54:14) | This is one of the pre-arranged actions with a lane closure plan.       |
| 09:54:12+  | Wig wags start on VSLS Camera 40 after trucks which crashes into other vehicles passes. (changes observed from 12 seconds past minute (E36VS02 and E36VS01) | Camera 20  
Camera 40  
Camera 41 | Trucks which are involved in the crashes just past the first speed message sign before they change. |
<p>| 09:54:14   | RRB message 148 commences in Burnley Tunnel                         | CCCS log                | Message regarding reduced speed and lane closure.                       |
| 09:54:14   | Twig truck changes lanes from centre to left lane (stopped truck can be seen in distance), Mc Cain truck under camera with unobstructed view to Twig truck. (Twig truck obscures view of stopped truck) | CCTV                    |                                                                          |
| 09:54:16   | Computer comands variable speed limit sighns to change to show 60    | CCCS                    |                                                                          |</p>
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:54:17</td>
<td>Sign displays change from 80 to 60 on E37Vso2 &amp; E37Vso1</td>
<td>VES front end computer</td>
<td></td>
</tr>
<tr>
<td>09:54:17</td>
<td>Back computer says that speed has changed</td>
<td>Back computer</td>
<td></td>
</tr>
<tr>
<td>09:54:18</td>
<td>VSLS speed change as truck 2 passes sign</td>
<td>Camera 52 Stop F</td>
<td>Speed signs seen changing on both sides of tunnel.</td>
</tr>
<tr>
<td></td>
<td>(Computer CCCS log records change at 9:54:18 and 9:54:19 – running a little late)</td>
<td>Camera 52 Stop F</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Camera 52 Stop F</td>
<td>Camera 52 Stop F</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Camera 51 Stop C</td>
<td>Camera 51 Stop C</td>
<td></td>
</tr>
<tr>
<td>09:54:18</td>
<td>VSLS vicinity B2 and B18 change to 60km/h</td>
<td>AID cameras 702 and 718</td>
<td>Cross reference to video Camera 38.</td>
</tr>
<tr>
<td></td>
<td>Truck 2 passing VSLS at time of speed change</td>
<td>Camera 51 Stop C</td>
<td></td>
</tr>
<tr>
<td>09:54:18</td>
<td>Truck 3 approaching variable speed sign displaying reduced 60 k/hr</td>
<td>Camera 52 Stop F</td>
<td>Apparently unobstructed view in tunnel between truck 3 and speed limit sign change.</td>
</tr>
<tr>
<td></td>
<td>signage without any vehicle obstructions.</td>
<td>Camera 51 Stop C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unobstructed sight line to sign and truck 2 from truck 3 (Truck 3, McCain)</td>
<td>Camera 51 Stop C</td>
<td>The McCain truck ultimately crashes into several other vehicles. At the time of the crashes it is travelling comparatively fast.</td>
</tr>
<tr>
<td>Time</td>
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<td>Source</td>
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<tr>
<td>09:54:22+</td>
<td>Vehicles slowing in all lanes (nearly stopping), smoke from wheels of truck 4 under braking in lane 3. Most vehicles near stopped</td>
<td>Camera 53 Stop C</td>
<td>Incident is near the bottom of a steep decline. Most vehicles had substantially reduced their speeds. Truck 4’s tyres are seen smoking under heavy braking before the crashes occur.</td>
</tr>
<tr>
<td>09:54:26(a)+</td>
<td>Truck 3 McCain swerves from left hand lane into centre lane hitting vehicle travelling in centre lane.</td>
<td>Camera 53 and witness statements</td>
<td>Truck 3 swerves right and sideswipes car in centre lane.- minor damage to the car as driver conducts evasive manoeuvre.</td>
</tr>
<tr>
<td>09:54:26(b)+</td>
<td>Truck 3 (McCain) and Truck 4 (K &amp; S Freighters) collide in right hand lane</td>
<td>Camera 53</td>
<td>Truck 3 swerves across centre lane and crashes into Truck 4 in the right lane.</td>
</tr>
<tr>
<td>09:54:27a</td>
<td>Black car (car 3) observed being crushed under McCain Truck (Truck 3) as truck re-enters left lane causing collision with white ute (Car 2)</td>
<td>Camera 54 Stop F</td>
<td>Truck 3 deflects off Truck 4. Truck 3 then drives over a black vehicle (Car 3) (which explodes) and crashes into a white ute (car 2).</td>
</tr>
<tr>
<td>09:54:27b</td>
<td>White ute rear breached by crushed black car. Black car (car 3) being run over by McCain Truck with explosion under truck</td>
<td>Camera 54 Stop F</td>
<td></td>
</tr>
<tr>
<td>09:54:27c</td>
<td>Explosion continues with white ute (car 2) pushed into rear of truck</td>
<td>Camera 54 Stop F</td>
<td>Both the black car and the white ute</td>
</tr>
<tr>
<td>Time</td>
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<td>Comment</td>
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</tr>
<tr>
<td>09:54:27</td>
<td>Vehicle pushed up tunnel wall by Mc Cain Truck</td>
<td>Camera 54 Stop F</td>
<td></td>
</tr>
<tr>
<td>09:54:28</td>
<td>K &amp; S freighter (truck 4) observed pushing subaru (car 4) sideways with black car (car 3) being crushed and white ute crushed by Mc Cain Truck</td>
<td>Camera 54 Stop F</td>
<td></td>
</tr>
<tr>
<td>09:54:29</td>
<td>Tunnel controller acknowledges completion of pre-accident left lane closure plan</td>
<td>CCCS</td>
<td>Much activity in CCCS event logs as electromechanical devices communicate activity back to main computers for lane closure plan.</td>
</tr>
<tr>
<td>09:54:29</td>
<td>Explosion[s] and fire in Burnley Tunnel</td>
<td>AID Camera 718</td>
<td>Cross reference to video camera no 52. TCRO witnesses the collisions, explosion[s] and fire via camera AID 718, with which he has been monitoring the stopped vehicle (Truck 1). He follows standard procedure and assesses the situation.</td>
</tr>
<tr>
<td>09:54:29</td>
<td>First stop Alarm seen in AID camera right hand lane</td>
<td>Camera 53 Stop C</td>
<td>Red arrow indicates AID has detected irregularity</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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<tr>
<td>09:54:30</td>
<td>TCRO acknowledges prompt for completion of 'one left lane closed' plan</td>
<td>CCCS log</td>
<td>This confirms all the steps in the 'one lane closed' plan (no. 991011) have been sent to the tunnel devices.</td>
</tr>
<tr>
<td>09:54:29 to 9:55:14</td>
<td>TCRO retrieves and enters job incident number for the stopped vehicle incident, and enters the location of the incident (Firebox 18), on the Tunnel Incident Management Page (TIMP). He selects from the TIMP a plan to close the Burnley Tunnel upstream from the incident whilst allowing traffic downstream from the incident to clear the Tunnel as normal through the exit portal</td>
<td>TCRO and control room supervisor, CCCS</td>
<td>Both the TCRO and control room supervisor co-operatively and effectively respond to the incident.</td>
</tr>
<tr>
<td>09:54:32</td>
<td>Twig truck stop detected by AID lane one alarm</td>
<td>Camera 53 Stop C</td>
<td>Computer detection identifies twig truck stopped in lane 1</td>
</tr>
<tr>
<td>09:54:26 – 9:54:33</td>
<td>Emergency braking right lane, Van, and two following semi trailer vehicles and valiant nearly collide</td>
<td>Camera 52 Stop F</td>
<td>Nearly another crash. Several near misses are observed as motorists perform emergency braking manoeuvres.</td>
</tr>
<tr>
<td>09:54:33</td>
<td>Camera 44 shows overhead variable message sign changing</td>
<td>Camera 44</td>
<td></td>
</tr>
<tr>
<td>09:54:35</td>
<td>AID in camera alarm lane 2 Camera 53</td>
<td>Camera 53 Stop C</td>
<td></td>
</tr>
<tr>
<td>09:54:39</td>
<td>Variable message sign observed to change to red message over left lane</td>
<td>Camera 67</td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>EVENT</td>
<td>SOURCE</td>
<td>COMMENT</td>
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</tr>
<tr>
<td>09:54:40</td>
<td>Radio message playing B33 left lane closure Message finishes at 9:55:40</td>
<td>Ves front end computer</td>
<td></td>
</tr>
<tr>
<td>09:54:40</td>
<td>Rigid Truck nearly crashes in centre lane (heavy braking)</td>
<td>Camera 52 Stop F</td>
<td>Nearly another car/truck crash</td>
</tr>
<tr>
<td>09:54:42</td>
<td>People evacuating from vehicles involved in incident</td>
<td>Camera 54 Stop F Camera 55 Stop C</td>
<td>People involved in initial collisions and explosions rapidly self rescue (those that are able to).</td>
</tr>
<tr>
<td>09:54:46</td>
<td>Camera 46 left lane green turns off (turns to red at 9:54:48)</td>
<td>Video 46</td>
<td>Computer in process of lane closure</td>
</tr>
<tr>
<td>09:54:49</td>
<td>Numerous stopped vehicle alarms begin in the vicinity of AID 718 and spread back up the Burnley Tunnel Truck driver in K &amp; S truck (truck 4) (lane 3) leaves cab at same time person observed leaving region of crashed car/truck lane 3</td>
<td>CCCS log Camera 54 Stop C</td>
<td>First people seen evacuating post incident</td>
</tr>
<tr>
<td>09:55:04</td>
<td>TCRO (surface road) activates 'break glass' alarm in TCR and telephones MFESB to confirm receipt.</td>
<td>ADT Fire Monitoring records for ASE No.3205001621</td>
<td>CityLink controllers are co-operatively responding to emergency. The surface road controller activates the break glass alarm while the tunnel controller</td>
</tr>
<tr>
<td>TIME</td>
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</tr>
<tr>
<td>09:55:07</td>
<td>Emergency Services Telecommunications Authority log alarm requesting</td>
<td>Emergency services log</td>
<td>manages the computer control system.</td>
</tr>
<tr>
<td></td>
<td>MFESB to Burnley Tunnel</td>
<td></td>
<td>confirm alarm activated on fire indicator panel at 9.55.04</td>
</tr>
<tr>
<td>09:55:12</td>
<td>Tunnel controller opens incident management page</td>
<td>CCCS log</td>
<td>Tunnel operator is commencing Emergency response via computer plans.</td>
</tr>
<tr>
<td>09:55:13+</td>
<td>Person observed leaving region of right lane truck 4/car crash zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>and sits behind truck in lane 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:55:14</td>
<td>Tunnel controller loads « close tunnel » plan for Burnley Tunnel</td>
<td>CCCClog</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(no.990758)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:55:15</td>
<td>Tunnel controller starts « close tunnel » plan for Burnley Tunnel</td>
<td>CCCS log</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(no.990758)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:55:18</td>
<td>Operator confirms to computer that emergency plan should be</td>
<td>CCCS log</td>
<td>This is a critical descision. Once implemntation of plan begins the</td>
</tr>
<tr>
<td></td>
<td>implemnted</td>
<td></td>
<td>tunnel operator is committing to a</td>
</tr>
<tr>
<td>Time</td>
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<td>Comment</td>
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</tr>
<tr>
<td>09:55:19</td>
<td>First person observed to offer rescue help (from truck in centre lane)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:55:28</td>
<td>Burney Tunnel Clossed Signs Activated</td>
<td>CCCS</td>
<td>Tunnel Portal Closed to new traffic.</td>
</tr>
<tr>
<td></td>
<td>The message becomes “Danger Tunnel Closed” 9:55:31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:55:32</td>
<td>“Turn engines off” signs on variable emergency signs</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>09:55:37</td>
<td>TCRO enables emergency mode on console in order to access emergency plans ‘smoke extraction’, ‘deluge’ and ‘evacuate tunnel’</td>
<td>CCCS log</td>
<td></td>
</tr>
<tr>
<td>09:55:38</td>
<td>‘Close tunnel’ plan in relation to Burnley Tunnel completed (no 990758)</td>
<td>CCCS log</td>
<td>This confirms all steps in the plan have been sent to the tunnel devices. This includes VMS, LUS, VSLS and TIMS signage.</td>
</tr>
<tr>
<td>09:55:38</td>
<td>Traffic at stand still</td>
<td>Camera 48 Stop F</td>
<td>Traffic comes to halt with no more obvious “near misses”</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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<tr>
<td></td>
<td></td>
<td>CCCS log (09:55:38)</td>
<td></td>
</tr>
<tr>
<td>09:55:38 - 48</td>
<td>Tunnel controller decides to reject initial emergency response plan and to manually re-configure the event location.</td>
<td>Witness statements &amp; CCTV log</td>
<td>The TCRO recognises that the collision impact has been so severe that the location of the incident has moved. Consequently he disables the emergency mode, reconfigures the computer, and implements a revised response. This demonstrates a high degree of competence by the operator.</td>
</tr>
<tr>
<td>09:55:48</td>
<td>Burnley Tunnel emergency mode disabled</td>
<td>CCCS log</td>
<td>This is an automatic outcome of TCRO updating incident location from B18 to B19.</td>
</tr>
<tr>
<td>09:55:52</td>
<td>Burnley Tunnel emergency mode enabled</td>
<td>CCCS log</td>
<td>This is an automatic outcome of TCRO updating incident location from B18 to B19.</td>
</tr>
<tr>
<td>09:55:54</td>
<td>TCRO clicks the ‘ON’ TAB on the computer system to start smoke extraction</td>
<td>CCCS log</td>
<td>There are approximately 274 actions/entries in the CCCS log associated with this action affecting jet fans, exhaust fans, axial fans, LUS and other signage, lighting, backlayering</td>
</tr>
<tr>
<td>Time</td>
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<tr>
<td>09:56:01</td>
<td>TCRO requests deluge zone B19E048 to open</td>
<td>CCCS TIM log</td>
<td>First request for deluge operation</td>
</tr>
<tr>
<td>09:56:03</td>
<td>• Message ID220 stops playing in Burnley Tunnel</td>
<td>CCCS log</td>
<td>Full text of message ID241 attached. Note that TCRO states that he requested message prior to requesting</td>
</tr>
<tr>
<td></td>
<td>• TCRO requests playing of RRB/PA message ID 241 in Burnley Tunnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
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<td>Source</td>
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</tr>
<tr>
<td>09:56:04</td>
<td>Burnley Tunnel deluge warning message played via radio rebroadcast</td>
<td>VES front computer log</td>
<td></td>
</tr>
<tr>
<td>09:56:06</td>
<td>Broadcast of message ID241 commences in Burnley Tunnel</td>
<td>CCCS log</td>
<td></td>
</tr>
<tr>
<td>09:56:18</td>
<td>Some Cars near incident trying to move away from other cars</td>
<td>Camera 52 Stop F</td>
<td>Drivers creating gaps – trying to escape in vehicles</td>
</tr>
<tr>
<td>09:56:19</td>
<td>People walk away from crash zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:56:30</td>
<td>TCRO again requests deluge zone B19E048 to open</td>
<td>CCCS TIM log</td>
<td>This is a second request initiated because TCRO has not yet witnessed deluge commence on CCTV. It is not anticipated that there will be a delay in deluge system firing.</td>
</tr>
<tr>
<td>09:56:32</td>
<td>Burnley Tunnel deluge warning message played on PA</td>
<td>VES front computer</td>
<td></td>
</tr>
<tr>
<td>09:56:41</td>
<td>Traffic Operations Manager requests deluge zone B19E048 to open</td>
<td>PMCS log</td>
<td>This is the 3rd attempt to fire the deluge</td>
</tr>
</tbody>
</table>

warning of deluge operation

deluge zone to open.
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:56:49</td>
<td>Deluge appears in zone B19E048</td>
<td>AID camera 718</td>
<td>Cross reference to video camera 54.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Camera 54 Stop F</td>
<td>system. This is conducted by the Traffic Operation Manager. He does this to ensure that the second request for eluge by the TCRO has not switched off the deluge command.</td>
</tr>
<tr>
<td>09:56:59</td>
<td>Burnley Tunnel deluge warning (241) over radio rebroadcast system</td>
<td>VES front computer log</td>
<td></td>
</tr>
<tr>
<td>09:57:01</td>
<td>TCRO requests deluge zone FSPE049 to open</td>
<td>CCCS TIM log</td>
<td>This is the first attempt to open deluge zone 49.</td>
</tr>
<tr>
<td>09:57:03</td>
<td>Traffic Operations Manager requests deluge zone B19E047 to open</td>
<td>PMCS log</td>
<td>From camera vision it was evident that deluge zone B19E048 did not cover the full extent of the fire and the third zone was initiated.</td>
</tr>
<tr>
<td>09:57:10</td>
<td>Deluge appears zone B19E047</td>
<td>AID camera 718</td>
<td>Cross reference to video camera 54.</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
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</tr>
<tr>
<td>09:57:12+</td>
<td>Deluge functioning comencing in tunnel - people also evacuating</td>
<td>Camera 54 Stop F</td>
<td>Zone</td>
</tr>
<tr>
<td></td>
<td>generally towards elevated platform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:57:13</td>
<td>Deluge zone B19E049 reported open</td>
<td>CCCS TIM log</td>
<td>The commencement of this zone is not visible in CCTV footage.</td>
</tr>
<tr>
<td>09:57:16</td>
<td>Deluge visibly operating</td>
<td>Camera 52 Stop F</td>
<td>Deluge Impact clear</td>
</tr>
<tr>
<td>09:57:22</td>
<td>TCRO requests tunnel evacuation mode for Burnley Tunnel</td>
<td>CCCS log</td>
<td>This set up evacuation via the Domain Tunnel.</td>
</tr>
<tr>
<td>09:57:22</td>
<td>TCRO requests SAFE tunnel evacuation mode for Burnley Tunnel</td>
<td>CCCS log</td>
<td>TCRO changed plan to evacuate via the Domain (safe) Tunnel. Burnley Tunnel devices configured to evacuate via the Domain Tunnel.</td>
</tr>
<tr>
<td>09:57:26</td>
<td>TCRO loads and starts plan EVAC BT – CLOSE SAFE Domain Tunnel</td>
<td>CCCS log</td>
<td>TCRO sets up Domain Tunnel to accept evacuees. This closes the Domain Tunnel and implements RRB message to instruct evacuees. Plan involves changes to TIMS messages to read ‘WALKOUT’ and ‘EVACUATE’.</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
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</tr>
<tr>
<td>09:57:27</td>
<td>Burnley Tunnel deluge warning plays over tunnel PA</td>
<td>VES front computer log</td>
<td></td>
</tr>
<tr>
<td>09:57:30</td>
<td>Message ID 241 warning of deluge operation stopped in radio rebroadcast and PA in Burnley Tunnel</td>
<td>CCCS log, VES log</td>
<td></td>
</tr>
<tr>
<td>09:57:41</td>
<td>• EVAC BT – CLOSE SAFE Domain Tunnel Plan completed</td>
<td>CCCS log</td>
<td>All steps in this plan have now been sent to the Tunnel devices.</td>
</tr>
<tr>
<td></td>
<td>• Message ID 136 begins playing on PA system in Domain Tunnel</td>
<td>CCCS log</td>
<td>Full text of message 136 attached.</td>
</tr>
<tr>
<td></td>
<td>(VES 9:57:40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09:57:43</td>
<td>Tunnel speed sign changes</td>
<td>Camera 108</td>
<td>Sequenced lane closures implemented by computers.</td>
</tr>
<tr>
<td>09:57:43++</td>
<td>Domain Tunnel lanes closing – from right to left – traffic observed slowing and going into left lanes</td>
<td>Camera 108</td>
<td></td>
</tr>
<tr>
<td>09:57:53 - 55</td>
<td>Emergency cross passage lighting comes on</td>
<td>Camera 48 stop F</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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</tr>
<tr>
<td>09:58:03</td>
<td>Evacuation observed</td>
<td>Various AID cameras including nos. 701, 715, 716 and 718.</td>
<td>Cross reference to video cameras nos. 37, 51, 52 and 54.</td>
</tr>
<tr>
<td>09:58:05 – 9:59:18</td>
<td>Wheel chair assembled and disabled evacuation along road commenced</td>
<td>Camera 52 stop F</td>
<td>Wheelchair evacuees most pro-active of all tunnel users. Disabled and children are offered assistance by other tunnel users.</td>
</tr>
<tr>
<td>09:58:22</td>
<td>Domain tunnel observed to have changed signage for lanes - traffic moving from right lane to centre lane and then left lane</td>
<td>Camera 110 stop F</td>
<td></td>
</tr>
<tr>
<td>09:58:23</td>
<td>Evacuation from vehicles on mass including pram. Both roadway and elevated walkway used</td>
<td>Camera 50 Stop C</td>
<td></td>
</tr>
<tr>
<td>09:58:15</td>
<td>People begin evacuation of cars Camera 48 area F</td>
<td>Camera 48 F</td>
<td></td>
</tr>
<tr>
<td>09:58:37</td>
<td>Radio broadcast “tunnel closed – immediate evacuation” on Burnley Tunnel PA system (message 227)</td>
<td>VES Front End Computer Log</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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</tr>
<tr>
<td>09:59:08+</td>
<td>People evacuating vehicles</td>
<td>CCTV footage</td>
<td>Evacuation gains momentum</td>
</tr>
<tr>
<td>09:58:41`</td>
<td>Many people emerge from cars and begin evacuation along road away from fire</td>
<td>Camera 52 F</td>
<td></td>
</tr>
<tr>
<td>09:59:25</td>
<td>Cross Passage light visible. People moving both up and down the tunnel</td>
<td>Camera 48 Stop F</td>
<td></td>
</tr>
</tbody>
</table>
| 10:00:32  | Person in Valiant returns and opens bonnet                            | Camera 52 F | Why? Numerous instances of people returning to areas of danger.  
   The risk for evacuees is that the ventilation system will not be able to resist smoke's natural tendency to travel along the roof against the flow of air. Backlayering poses a real threat to evacuees in a tunnel fire. In this section of the tunnel, these risks were greater because it was in a downhill section of the tunnel - and smoke tends to travel up hill as it is hot and buoyant. |
| 09:59:33  | Radio broadcast tunnel closed – immediate evacuation                   | VES Front Computer |                                                                                                                                 |
| 09:59:44  | Computer prompts operator to confirm “back layering” is not an issue (acknowledged 9:59:57) | CCCS |  
   The risk for evacuees is that the ventilation system will not be able to resist smoke's natural tendency to travel along the roof against the flow of air. Backlayering poses a real threat to evacuees in a tunnel fire. In this section of the tunnel, these risks were greater because it was in a downhill section of the tunnel - and smoke tends to travel up hill as it is hot and buoyant. |
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00:17</td>
<td>Radio broadcast tunnel closed – immediate evacuation&quot; on Burnley Tunnel</td>
<td>VES Front Computer Log and CCCS log</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tunnel radio rebroadcast system (message 227)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00:40</td>
<td>First MFESB truck unit in Burnley Tunnel entrance</td>
<td>Camera 41 stop f</td>
<td></td>
</tr>
<tr>
<td>10:01:00</td>
<td>MFESB representative arrives in TCR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:01:14</td>
<td>Radio broadcast tunnel closed – immediate evacuation&quot; over Burnley Tunnel</td>
<td>VES Front Computer Log and CCCS log</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tunnel PA system (message 227)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:01:29</td>
<td>Domain tunnel restricted to left lane only</td>
<td>Camera 99</td>
<td></td>
</tr>
<tr>
<td>10:01:51</td>
<td>Fire cabinet door at B15 opened.</td>
<td>CCCS log</td>
<td>Evacuees from truck near cabinet but it is not visible.</td>
</tr>
<tr>
<td>10:02:10</td>
<td>Cross passage entered</td>
<td>Camera 48</td>
<td></td>
</tr>
<tr>
<td>10:02:12</td>
<td>Radio broadcast tunnel closed – immediate evacuation&quot; in Burnley Tunnel</td>
<td>VES front computer Log</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------</td>
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<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>10:02:37++</td>
<td>People observed returning to vehicles near incident scene (esp Truck drivers)</td>
<td>CCTV</td>
<td>People appear unaware of gravity of structures.</td>
</tr>
<tr>
<td>10:02:37+</td>
<td>Emergency services vehicle arrives up entrance from kings way into tunnel (Police?) Fire vehicle already in tunnel and stopped</td>
<td>Camera 41 Stop C</td>
<td></td>
</tr>
<tr>
<td>10:02:55</td>
<td>Radio broadcast “tunnel closed – immediate evacuation” played in Burnley Tunnel over radio rebroadcast system</td>
<td>VES Front computer</td>
<td></td>
</tr>
<tr>
<td>10:03:02</td>
<td>Two adults with pusher identify cross passage and change egress direction. Assisted by other adults to get up on the walkway. Begins many people using cross passage</td>
<td>Camera 48 Stop F</td>
<td>First person observed to head to cross passage in this area. Go as a group – not as individuals</td>
</tr>
<tr>
<td>10:03:30</td>
<td>Person nears fire cabinet and shows interest in it</td>
<td>CCTV</td>
<td></td>
</tr>
<tr>
<td>10:03:37</td>
<td>Fire cabinet door at B18 opened.</td>
<td>CCCS log</td>
<td>Assumed to be MFESB.</td>
</tr>
<tr>
<td>10:03:49</td>
<td>Message 227 stops in Burnley Tunnel.</td>
<td>CCCS log</td>
<td></td>
</tr>
<tr>
<td>10:04:07 +++</td>
<td>People start entering Domain tunnel – about same time as last vehicles leave (left lane)</td>
<td>Camera 110</td>
<td>Safe transfer of people from Burnley Tunnel to Domain Tunnel commenced</td>
</tr>
</tbody>
</table>

By Arnold Dix 167 : 174 9 June 2011
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:04:43</td>
<td>MFESB entering Burnley Tunnel in Truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:04:56</td>
<td>Grant street polution alarm</td>
<td></td>
<td>Notice to adjoining buildings? Pollution from a tunnel fire may pose a risk to the health of neighbours.</td>
</tr>
<tr>
<td>10:04:59</td>
<td>Pedestrian observed running towards incident to take photographs</td>
<td>Camera 52</td>
<td>Inquisitive behaviour can cause injury and death</td>
</tr>
<tr>
<td>10:05:00</td>
<td>First fire fighter with fire hose enters deluge zone to fight fire (only fights fire for 40 seconds)</td>
<td>Camera 54 Stop F</td>
<td>No breathing apparatus used</td>
</tr>
<tr>
<td>10:05:07</td>
<td>People helping disabled ? person in chair onto walkway and into cross passage</td>
<td>Camera 48 Stop F</td>
<td>Many instances of people helping each other</td>
</tr>
<tr>
<td>10:06:01</td>
<td>Polution Grant Street</td>
<td>CCCS</td>
<td>Risk of injury to neighbours unknown</td>
</tr>
<tr>
<td>10:06:28</td>
<td>B17 fire door open</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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<tr>
<td>10:06:31</td>
<td>B18 fire cabinet door open</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>10:06:32</td>
<td>B15 open</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>10:06:32</td>
<td>Tunnel air contamination alarm</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>10:06:37</td>
<td>FIRE FIGHTERS PASS BY INSPECTING CARS</td>
<td>Camera 48 stop f</td>
<td></td>
</tr>
<tr>
<td>10:06:37</td>
<td>Evacuees emerge from cross passages back into tunnel – pushing wheel chair/pram up elevated walkway 10:07:33</td>
<td></td>
<td>Several tunnel users appear to reject the cross passage option for safe evacuation.</td>
</tr>
<tr>
<td>10:06:43</td>
<td>Cross passage door to domain tunnel opened for evacuation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:06:45</td>
<td>Camera 58 shows smoke clearing</td>
<td>CCTV</td>
<td>Emergency ventilation is rapidly establishing stable emergency conditions</td>
</tr>
<tr>
<td>10:06:54</td>
<td>B17 cabinet door opened</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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<tr>
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<td>----------------------------------------------------------------------</td>
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<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>10:07:01 to 10:07:30</td>
<td>Live to air broadcast begins in Burnley Tunnel from control room</td>
<td>CCCS log</td>
<td>VES Log</td>
</tr>
<tr>
<td>10:07:06</td>
<td>B17 fire cabinet opened</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:07:29</td>
<td>Fire Brigade stop downstream approaching into smoke</td>
<td>Camera 58</td>
<td></td>
</tr>
<tr>
<td>10:07:30</td>
<td>Live to air broadcast stops in Burnley Tunnel.</td>
<td>CCCS log</td>
<td>VES Log</td>
</tr>
<tr>
<td>10:08:01</td>
<td>MFESB Fire Engine stops proximate to incident site in view of camera 58</td>
<td>Camera 58</td>
<td>Emergency ventilation creates environment suitable for vehicle access in incident tunnel to a point near the crash site</td>
</tr>
<tr>
<td>10:08:40</td>
<td>MFESB personnel (x3) and Police (x2) heading to incident along road upstream of incident</td>
<td>Camera 52 Stop F</td>
<td>Fire and emergency services personnel proceed to incident on foot through congested traffic.</td>
</tr>
<tr>
<td>10:08:47</td>
<td>Person in wheel chair comes back from cross passage onto road and evacuates up stream on road with assistance from able bodied people.</td>
<td>Camera 48 F</td>
<td>Another example of evacuees &quot;rejecting&quot; cross passages as an evacuation option</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
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</tr>
<tr>
<td>10:09:01</td>
<td>Fire brigade arriving on foot at incident site (no ba)</td>
<td>CCTV</td>
<td></td>
</tr>
<tr>
<td>10:09:21</td>
<td>Police (?) on foot approach incident scene</td>
<td>CCTV</td>
<td></td>
</tr>
<tr>
<td>10:09:25</td>
<td>Fireman enters deluge zone without any hose</td>
<td>Camera 54 Stop F</td>
<td>Fire fighter walks around in deluge zone without any apparent tenability issues (Out again at 10:10:17). Risks to firemen are real and ongoing.</td>
</tr>
<tr>
<td>10:10:35</td>
<td>3 Police and 1 Fireman with breathing apparatus pass by on way to scene</td>
<td>Camera 52 F</td>
<td>Some personnel arriving on foot.</td>
</tr>
<tr>
<td>10:10:52</td>
<td>First fireman with breathing apparatus and fire hose enters deluge area</td>
<td>Camera 54 Stop F</td>
<td>A series of fire fighters come and go over the next few minutes using appropriate apparatus such as BA</td>
</tr>
<tr>
<td>10:12:36</td>
<td>Police car seen driving contra flow King Street exit to into the Domain Tunnel</td>
<td>Camera 123</td>
<td>Some emergency services choose to access incident site via non incident tunnel.</td>
</tr>
<tr>
<td>10:13:38</td>
<td>Person enters cross Passage near incident</td>
<td>Camera 53</td>
<td>First person observed near scene to use cross passage</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------</td>
<td>--------</td>
<td>-----------------------------------------------------------</td>
</tr>
<tr>
<td>10:12:53</td>
<td>B17 cabinet door opened</td>
<td>CCCS</td>
<td>People in tunnel are considering the use of equipment in the fire box.</td>
</tr>
<tr>
<td>10:13:15</td>
<td>B17 cabinet opened</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>10:13:43</td>
<td>Refuge fan smoke detected (ref03PO3)</td>
<td>CCCS</td>
<td>Significance not known</td>
</tr>
<tr>
<td>10:13:50</td>
<td>B16 cabinet door opened</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>10:15:10</td>
<td>B14 fire cabinet door opened</td>
<td>CCCS</td>
<td></td>
</tr>
<tr>
<td>10:16:07</td>
<td>Cross passage low pressure alarm</td>
<td>CCCS</td>
<td>Significance not known</td>
</tr>
<tr>
<td>10:30</td>
<td>Customer Service area becomes aware of telecommunications issue</td>
<td></td>
<td>Emergency servies are having communications issues in the tunnel</td>
</tr>
<tr>
<td>10:30 to 11am</td>
<td>Other site customers removed from the shared communications tower - customers other than Domain and Burnley Tunnels transferred to alternative communications tower to provide increased capacity to emergency effort</td>
<td></td>
<td>Capacity of emergency</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Source</td>
<td>Comment</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------------------</td>
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<td>--------------------------------------------------------------</td>
</tr>
<tr>
<td>10:48:04</td>
<td>Deluge system shut down</td>
<td>Deluge sys</td>
<td>Fires are sufficiently low to turn deluge systems off.</td>
</tr>
<tr>
<td>10:48:50</td>
<td>Smoke reduces around camera 56 enough to reveal wet road and a fireman</td>
<td>Camera 56</td>
<td>Once visibility returns the extent of damage is revealed.</td>
</tr>
<tr>
<td>11:03:12</td>
<td>Deluge disabled.</td>
<td>CCCS log</td>
<td></td>
</tr>
<tr>
<td>11:15:00</td>
<td>MFESB declares fire under control.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CCCS log refers to the time events are logged into the CCCS log which is System (CCCS) Time.  
CCCS TIM log refers to the time events are logged into the TIM Server log which is a sub-system of the CCCS.  
PMCS log refers to the time events are logged through the PMCS FEC which is an alternate computer to control and monitor the tunnel.  
TCRO refers to the Tunnel Control Room Officer  
Many cameras show visibility maintained down stream of incident for entire incident duration (e.g., Cameras 73 to Camera 80)
# Appendix B – Documents Reviewed

<table>
<thead>
<tr>
<th>No.</th>
<th>Document Name</th>
<th>What It Is</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Static Copy of CityLink MFB Correspondence dated 5 July 2007.pdf</td>
<td>Letter from the Fire Investigation &amp; Analysis Unit of the MFB to Victorian Govt Solicitors dated 5.7.07</td>
</tr>
<tr>
<td>2</td>
<td><a href="http://www.vicroads.vic.gov.au/Home/Roads">http://www.vicroads.vic.gov.au/Home/Roads</a> And Projects/Road Projects/Inner City/ CityLink.CityLink Legislation.htm#ECD</td>
<td>Web link to CityLink Legislation</td>
</tr>
<tr>
<td>3</td>
<td>BBC News Lorry accident 7.8.07.pdf</td>
<td>Web link - story regarding 4 lorries that crashed in a tunnel on the M25 NE London</td>
</tr>
<tr>
<td>4</td>
<td>Tunnel Closures Jan-07 to Nov-07 Rev-2007.4.ppt</td>
<td>List of proposed tunnel closures for the period.</td>
</tr>
<tr>
<td>5</td>
<td>CCCS Data 23032007.xls</td>
<td>CCCS log</td>
</tr>
<tr>
<td>6</td>
<td>Document.pdf</td>
<td>Spreadsheet showing vehicle traffic into the Burnley Tunnel for each 15 minutes between 9 and 10 on 23 March 2007.</td>
</tr>
<tr>
<td>7</td>
<td>Traffic Make up Domain – 23 Mar 07 (0900-1000).xls</td>
<td>Summary of vehicles entering the Domain Tunnel between 0900 and 1000 on 23 March 2007 each 15 minutes</td>
</tr>
<tr>
<td>9</td>
<td>CML0001.pdf</td>
<td>Melbourne CityLink - Tunnel Systems Contingency Plan – Final 2006 (Rev 3)</td>
</tr>
<tr>
<td>10</td>
<td>CML0002.pdf</td>
<td>Vol 4 Part 1 Sect 1 – Structure and Overview Chap 1 – Chapter 1 Structure and Scope of the Maintenance Procedures Manual</td>
</tr>
<tr>
<td>11</td>
<td>CML0003.pdf</td>
<td>Report on the TLO Discussion Exercise 6 December 2002</td>
</tr>
<tr>
<td>12</td>
<td>CML0004.pdf</td>
<td>Exercise Evacuate 8 4 January 2004 – Exercise Report SES</td>
</tr>
<tr>
<td>13</td>
<td>Burnley Tunnel – 005025210v2.doc</td>
<td>Draft timeline</td>
</tr>
<tr>
<td>14</td>
<td>07.08.27 – Radio recordings – 5 005020272v9.doc</td>
<td>Timeline – Attachment 1 – transcript of recorded messages</td>
</tr>
<tr>
<td>15</td>
<td>29.8.07 – Attachment 2 – Door 005021839v3</td>
<td>Timeline – Attachment 2 – list of door openings logged</td>
</tr>
<tr>
<td>No.</td>
<td>Document Name</td>
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</tr>
<tr>
<td>16.</td>
<td>Dampers and Fans.xls</td>
<td>Damper and fans timeline data – not integrated</td>
</tr>
<tr>
<td>17.</td>
<td>Image0006.gif</td>
<td>Ventilation flow graph</td>
</tr>
<tr>
<td>18.</td>
<td>Image0005.gif</td>
<td>Ventilation flow graph</td>
</tr>
<tr>
<td>19.</td>
<td>Attach-Trm-405-__26FOMXY5Q.ZIP</td>
<td>Schedules of tunnel devices for the Burnley and Domain Tunnels</td>
</tr>
<tr>
<td>20.</td>
<td>07.07.27 Burnley Tunnel – Time 005007505v20.doc</td>
<td>Timeline updated with deluge zone numbers</td>
</tr>
<tr>
<td>21.</td>
<td>Img-9131519-0001.pdf</td>
<td>Operator procedures – closures, diversion plans and contra flow</td>
</tr>
<tr>
<td>22.</td>
<td>Img-9131516-0001.pdf</td>
<td>Tunnel Closure and evacuation</td>
</tr>
<tr>
<td>23.</td>
<td>Img-9131517-0001.pdf</td>
<td>Stationary Vehicle/object on CityLink</td>
</tr>
<tr>
<td>24.</td>
<td>Img-9131518-0001.pdf</td>
<td>TRC Operator Procedures</td>
</tr>
<tr>
<td>25.</td>
<td>Img-9131519#-0001.pdf</td>
<td>Vehicle Fires</td>
</tr>
<tr>
<td>26.</td>
<td>200760323_log 0846_1346.xls</td>
<td>Log – VES front end computer log – note that if you click on the cell you want in the source timestamp column you will get the time down to the 10th of a second.</td>
</tr>
<tr>
<td>27.</td>
<td>M-MCL_CC_100005_0.doc</td>
<td>TIM</td>
</tr>
<tr>
<td>28.</td>
<td>M-MCL_CC_100006_0.doc</td>
<td>Tunnel Incident Management Subsystem</td>
</tr>
<tr>
<td>30.</td>
<td>Burnley Tunnel Incident Video Footage.xls</td>
<td>Excel list of all incident video footage</td>
</tr>
<tr>
<td>32.</td>
<td>Report on the TLO Discussion Exercise , 6 December 2002</td>
<td></td>
</tr>
<tr>
<td>33.</td>
<td>Translink Operations Exercise Evacu 8 Take 2, 23 October 2005 Exercise Report</td>
<td></td>
</tr>
<tr>
<td>35.</td>
<td>Summary of CityLink Tunnel Incidents - FY 0607.ppt</td>
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<td>36.</td>
<td>Summary of Damage Assessment and Repairs 12.12.07 Transurban</td>
<td></td>
</tr>
<tr>
<td>37.</td>
<td>Damage Assessment Report – Melbourne City Link Tunnel Fire 26.3.07</td>
<td></td>
</tr>
<tr>
<td>39.</td>
<td>Melbourne CityLink Tunnel Project – detailed design Southern Links Tunnel Wet Fire Protection Services</td>
<td></td>
</tr>
<tr>
<td>40.</td>
<td>CFD Simulation of Deluge Suppression for the Metropolitan Fire and Emergency Services Boards – Connell Wagner 26 Oct 2007</td>
<td></td>
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<tr>
<td>41.</td>
<td>The decision to decide – A discussion on Tunnel Fire Safety</td>
<td>A paper forwarded by MFB</td>
</tr>
</tbody>
</table>
15.3 **Appendix C – The Author**

*Arnold Dix*

- Adjunct Professor of Engineering QUT 2005 - 2010
- Associate Professor of Medicine (Science, Mental Health and Adversity) UWS 2008+
- World Road Association PIARC WG6 Australian Delegate – Tunnel Ventilation safety and Environment since 2000+
  - Secretary Fire Safety and Environment
  - Task leader and Task participant – many projects
  - Full committee member
- International Tunneling Association (United Nations Affiliate)
  - Chairman - Contractual practices group
  - Legal Counsel to ITA Executive
- COSUF – ITA special organization on operational safety in Tunnels.
- United States National Fire Protection Association
  - Underground Fixed Guideway Transit Systems Committee NFPA 130 – 2004 +
    - Full member
  - Road Tunnels Committee NFPA 502 - 2005 +
    - Full voting member
- Society for Social Management Systems, Japan (Full member at invitation of Japanese Government) - Centre of excellence disaster engineering program for Japan; 2006 +