Fire Risk in Metro Tunnels and Stations

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\textbf{Abstract} – The confined space inside a tunnel poses a peculiar set of risks to the users, especially in the event of a fire. There is limited escape facilities and restricted intervention access by emergency personnel in these structures. A major fire in a tunnel can result in costly damage to the infrastructure in terms of reparation and economic loss from downtime. This paper looks at the fire risks of metro tunnels, where a large number of users are potentially exposed to these risks. A brief literature review of tunnel incidents in the past is conducted to present the factors that have led to the occurrence of various disasters in these tunnels. A risk assessment technique for a limited analysis of fire risks in metro tunnels is presented. The method is based on a simplified model of estimating the consequences from these risks by calculating the effects of fires in a tunnel configuration and the impact on people that may be exposed to these effects. The factors contributing to the occurrence of fires in metro tunnels and their consequences are assessed and the effectiveness of various means of mitigating these risks is presented. The key factors that have a significant impact on the level of risks from both the contributing factors and the mitigation measures are identified. Means by which the contributing factors may reduce the level of risks in order to achieve a cost-effective design solution are discussed.

\textit{Keywords:} fire, risk, metro tunnels, stations, design

1. \textbf{Introduction}

Fires in metro tunnels and stations are becoming a growing concern and are creating worldwide attention over the years due to the increasing number of these tunnels being constructed and the large number of passengers that may be potentially exposed to the effects of fires. Due to the enclosed spaces of tunnels and stations in a metro environment, the means and their effectiveness of controlling smoke spread to allow safe evacuation of passengers are therefore particularly important.

Unlike conventional road and rail tunnels, metro tunnels are limited to the metropolitan area (hence the name) and the entire tunnel network is underground. The length of the tunnels
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is interspersed by stations to result in tunnel sections generally not more than 500m – 800m long. The tunnels are predominantly designed for one-way flow although in some cities, two-way tubes may be found. Single bore tunnels have a relatively higher risk to direct exposure to the fire effects due to the lack of protected escape passages for the passengers [1]. However, because the traffic is guided, as opposed to road tunnels, the cross-sections of metro tunnels are usually optimized and are therefore smaller than for roads. Due to the high control of traffic and combustible content, the accident rate is correspondingly lower for metro tunnels than for road tunnels – collision is effectively avoided. The feature of interspersed stations in metro tunnels also plays a significant role in fire safety – it enables the train to stop at a station to allow passenger evacuation and to provide fire-fighting activities. The greatest problem is to have a fire occurring within the tunnel and the train is unable to proceed to the closest station. This occurrence, however, is relatively rare. However, with increasing traffic and patronage, the consequential risk of an unfavourable incident is correspondingly increasing.

This paper looks at the fire risks of metro tunnels, where a significantly large number of users are potentially exposed to these risks. A brief literature review of tunnel incidents in the past is conducted to present the factors that have led to the occurrence of various disasters in these tunnels. A risk assessment technique for a limited analysis of fire risks in metro tunnels is presented. The assessment method is based on a simplified model of estimating the consequences from these risks by calculating the effects of fire in a tunnel configuration and the impact on people and infrastructure that may be exposed to these effects. The factors contributing to the occurrence of fires in metro tunnels and their consequences are assessed and the effectiveness of various means of mitigating these risks is presented. The key factors that have a significant impact on the level of risks from both the contributing factors and the mitigation measures are identified. The various fire protection measures that may reduce the level of risks are discussed.

2. Literature Review

2.1. Statistics

Factors contributing to causes of fires in metros are generally attributed to the following: sources of ignition from mechanical failure, electrical short circuits and carelessness; and sources of fuel from accumulations of combustible debris, combustible materials in car components and baggage. Intentional fires due to arsons are not insignificant and in recent times, threat from terrorist attacks may require consideration.

Fire statistics generally indicate that if fires are controlled in their early stages, the consequences are significantly reduced. The detrimental effects of fires become significantly greater and the ability to control them become significantly more difficult when fires become fully developed.

The probability of any potentially significant fire occurring in a metro network may be in the order of a few fires a year. These fires are likely to have been suppressed or self-extinguished prior to reaching their potential to become fully-developed and uncontrolled. Anderson and Paaske [1] estimated that the probability of a severe rail and metro fire occurs at a rate of approximately 0.5 per year worldwide. Of the 14 incidents that involved fire, 6 occurred in the tunnels.

Data from the Railway Gazette International for significant metro fires between 1970-1987 highlighted 30 incidents. Of these, there were 43 fatalities in 5 incidents, of which the King’s
Cross fire dominated with a count of 31. The main cause of fires was electrical in origin as shown in Fig 1.

The worst metro fire on record is the Baku metro fire in Azerbaijan on October 28, 1995 with 337 fatalities. The fire started accidentally from an electrical spark in the wiring near the gears under one of the cars. Since Azerbaijan’s Metro is nearly 30 years old, the cars were manufactured from materials that are prone to give off noxious fumes if they catch fire. It was estimated that about 90 percent of the material was flammable. The fire was on board a train between 2 stations and most died by CO poisoning.

The second most deadly metro fire occurred more recently on February 18, 2003 in Daegu, South Korea where 198 people lost their lives due to an arson fire. The fire was started in a train stopped at the Jungang-ro station of the Daegu Metropolitan Subway and then spread to a second train which had entered the station from the opposite direction.

In recent years, there have been instances of terrorism attacks in metro tunnels, selected on the basis of the potential to cause a high fatality count due to the potentially large number of passengers that are vulnerable to the effects of a large fire. The fire outbreaks that follow from terrorist attacks are quite different from a self-propagating fire. Bombs or accelerants are usually used and hence the fires usually start with a large blaze or have the potential to develop into a very large blaze quickly. Recent attacks on metro tunnels include the Moscow metro and more recently on the world’s oldest public underground railway the London Underground on 7th July 2005 in which more than 50 were killed.

According to the 2002 transport figures published by the European Union [2], the percentage of tram and metro users in the European Union accounted for about 1.1% of all domestic transport demand. This is equivalent to 57 billion passenger kilometers (pkm) or 124 pkm per person. This compares with 25, 33 and 71 billion pkm for USA, Japan and Russia. The growing demand for rail transport means that the design for safety for these carriers also has to cope with future increases.

2.2. Fire Hazard

The main source of fuel in a metro tunnel is the carriage itself. Because carriages are powered through electric traction, the main combustible items are the construction material of the carriage and any potential combustible baggage brought in by passengers. The potential fire size is usually limited to a peak heat release rate between 7-20MW. Stringent control of combustibles in the carriageway could further reduce the potential fire size to not more than a few megawatts.

2.2. Fire Protection Systems

To reduce the damage and hazard caused by fire in train tunnels, fire protections systems are used to various degrees of effectiveness. Smoke detection systems (usually mounted in the air...
ducts) are probably the most widely used in modern carriages to alert train staff of a fire. These
are not provided for older open (non-air-conditioned) carriages due to false alarms. Heat
detectors are also not usually employed due to the heat generated by the carriages. Fire
suppression systems are usually only installed in the engine or equipment compartments due to
weight and space limitations. For the passenger areas, smaller portable fire extinguishers may
be provided.

Communication systems such as break-glass type of alarms, intercom or help phone systems
are usually provided in modern carriages for passengers to alert train staff of an emergency.
Passengers can be alerted through PA systems and provide instructions for evacuation.

For underground stations, the conventional fire detection and protection systems used for
buildings are provided. Additional crowd control measures, such as reversing escalators (to exit
only) may be necessary to facilitate evacuation. Apart from hydrants and sprinklers used in
general station areas, gaseous (and sometimes water mist) suppression systems may be used in
equipment and electrical rooms.

Smoke control is a key element in fire protection for underground rail systems. Most rail
tunnels are longitudinally ventilated, i.e. ventilation is affected by air movement in the direction
of train travel (Fig 2). Smoke control is achieved by forcing the smoke towards the ventilation
shaft to be exhausted from the tunnel. The smoke is usually pushed in the direction of train
travel (downstream) and passengers are expected to move in the opposite direction (upstream)
along the tracks or walkways onto the oncoming fresh air. This form of longitudinal smoke
control system is widely adopted. Smoke is usually not permitted to flow into the adjoining
stations.

![Fig 2. Schematics of a basic smoke control strategy](image)

Because many metro stations do not have parallel or adjoining tunnels, intermediate escape
stairs for the passengers to reach the surface may be required for long tunnels. These stairs can
also serve to provide fire fighting access for fire brigades. Due to the difficulty of evacuating in
the tunnels, it is usually more effective to continue the train to the next station for the passengers
to disembark.

3. Design Framework

3.1 Fire characteristics

The fire characteristics in a metro tunnel are uniquely different from those in buildings. The
main fire load in a metro tunnel is the train itself and there is likelihood for the fire to spread
along the cars due to the effects of fire in the confined space. Unlike building fires, a train fire
may still be in motion within a tunnel and the air in the tunnel may also be flowing due to the

operation of the mechanical ventilation system. The dynamic nature of the fire and its severity therefore needs to be carefully considered.

In a building fire safety system, the provision of sprinklers is usually mandated in configurations considered to be of a relatively high risk. In tunnels, access difficulties have effectively mandated a requirement for a suppression system to be installed. However, due to its confined space, sprinklers are not always considered to be entirely beneficial. Concerns on the drawdown of the hot layer on the evacuating occupants and the increase in mixing of the smoke layer have been expressed as arguments against its use.

### 3.2 Fire protection systems

The smoke from a fire in the confined space of the tunnel is capable of filling out the tunnel relatively quickly and may be aided by the longitudinal flow of air in the tunnel. Train passengers are therefore potentially subjected to exposure to the rapid dispersion of smoke in the tunnel. Effective systems must therefore be put in place to provide adequate time for people to safely evacuate from the tunnel. These essentially include a number of fire safety systems that are similar to building systems.

An important design prerequisite for a tunnel is the ventilation system for maintaining a reasonable tunnel temperature. A smoke control system is usually an integral component of the ventilation system to provide safe conditions for evacuation in the event of a fire. This often leads to a number of ventilation and smoke control strategies available from which to achieve a cost-effective solution.

### 3.3 Design processes

The factors that have an impact on life safety in metro tunnel design include the tunnel length, train composition and headway, fire detection and warning systems, ventilation and smoke control, fire protection systems, egress strategy and provisions for fire brigade access and intervention. Incidental factors that may also have an influence and therefore require consideration includes signalling systems, emergency operations, and maintenance requirements.

From a design perspective, the key input parameters and system components are illustrated schematically in Fig 3. The three key input parameters are:

- Train (headway and composition),
- Tunnel configuration (size, length and cross-section) and
- Design fire (intensity, duration).

The design fire is dependent upon the train (fuel source), tunnel configuration (fire environment) and potential modifications from fire suppression means. These input parameters largely account for the determination of the design requirements for the fire safety systems. The three main system design components may be categorised as follows:

- Ventilation and smoke control system,
- Detection, warning and egress systems, and
- Active and Passive Fire protection systems.

These design processes primarily account for the determination of the performance levels necessary to comply with the design objectives which are effectively expressed as achieving an adequate level of life safety and to limit damage to the tunnel infrastructure. However, to date, quantitative means of demonstrating acceptance are not available in a regulatory format.
Fig 3. Key input parameters and system design components for Metro tunnels

4. Risk Analysis

4.1 General Concept

The method of assessing fire risk in tunnels and stations is based on the simple risk concept expressed as follows:

\[ R = P \times C \]  

Where

- \( R \) = Risk of event
- \( P \) = Probability of event occurring
- \( C \) = Consequence resulting from the event occurring
  (no of people exposed or cost from loss of infrastructure)

4.2 Risk Parameters

For the purpose of this exercise, the risk assessment is limited to life safety only. This does not necessarily detract from the overall utility of the model in that cost indicators can be incorporated in the analysis to determine a cost-effective solution. In addition, it may be necessary to include additional cost factors relating to fire damage, economic loss from downtime, reparation costs and perhaps even loss in public image resulting in reduced patronage.

The important risk parameters for life safety are as follows:

- Fire scenarios
- Fire detection system
- Fire protection systems
- Egress provisions
The impact on the risk levels for each of the above systems will need to be determined to reflect their effectiveness through measures of reliability (i.e. probability that the system will function) and efficacy (probability that the functioning system will achieve its intended design objective).

4.3 Risk Assessment

A simple risk event tree for a metro fire resulting in potential fatalities is shown in Fig 4.

![Event Tree](image)

**Fig 4. Event tree based risk assessment**

The probability of a fire becoming uncontrolled, especially when detected or noticed by staff or passengers are usually very low as shown in Fig 5.

The consequence parameter is the number of passengers that are exposed to the lethal effects of the fire. The expected number of deaths (END) is the sum of the product of all trailing events (probability of occurrence) and the expected consequences. The number of exposed passengers is determined with the aid of fire simulation models. Fig 6 shows the temperature and visibility profiles of a 20MW fire in a tunnel using a CFD model called FDS [6].
The results of the above analysis indicate that the critical chain of events contributing to the greatest threat to occupants is for an uncontrolled fire occurring in the tunnel section as shown in Fig 7.

**Fig 6. Results of CFD simulation model, FDS [6]**

**Fig 7. Critical chain of events for fires in metro**
5. Sensitivity Studies

The accuracy of a risk assessment is significantly dependent upon the factors that the results are sensitive to. Accordingly, these key factors will require more careful consideration in order to minimize the errors associated with their estimation. A sensitivity study may be conducted to identify the key factors in a risk analysis by varying the input values within a reasonable range.

A sensitivity study will be conducted in two categories: a) event sensitivity and b) design sensitivity. The former is associated with identifying the events that have an important impact on safety. For these events, their occurrence may not be realistically controlled although the probability of their occurrence can be influenced either by design decisions or through more effective operational management procedures. Knowledge of what the important events for the design are enables the development of more appropriate measures that are able to minimize the occurrence of those events that lead to high risk.

The latter category is associated with design options that have a more direct and significant impact on safety. These generally include the fire safety measures that are proposed for the design, for example, the systems for detection, suppression, ventilation and smoke control, etc. Knowledge of the important design factors enables a much more cost-effective design of the fire protection measures to be provided.

5.1 Event sensitivity analysis

Based on the simple event tree shown in Fig 4, the input values are varied as shown in Table 1. The ‘Positive Event Parameter’ column represents events that positively contribute to increasing safety. The ‘Min’ and ‘Max’ values reflect design variations that contribute to the risk and measures which mitigate its effects respectively.

<table>
<thead>
<tr>
<th>Positive Event Parameter</th>
<th>Base</th>
<th>Min</th>
<th>END,min</th>
<th>Max</th>
<th>END,max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire starts in station</td>
<td>0.5</td>
<td>0.1</td>
<td>1.22</td>
<td>0.9</td>
<td>0.171</td>
</tr>
<tr>
<td>Tunnel fire does not sustain development</td>
<td>0.95</td>
<td>0.7</td>
<td>4.07</td>
<td>0.99</td>
<td>0.155</td>
</tr>
<tr>
<td>Tunnel fire controlled by extinguishers</td>
<td>0.7</td>
<td>0.4</td>
<td>1.37</td>
<td>0.9</td>
<td>0.245</td>
</tr>
<tr>
<td>Train fire brought to station</td>
<td>0.5</td>
<td>0.1</td>
<td>1.09</td>
<td>0.9</td>
<td>0.305</td>
</tr>
<tr>
<td>Tunnel fire controlled by Fire Brigade</td>
<td>0.3</td>
<td>0.1</td>
<td>0.808</td>
<td>0.8</td>
<td>0.414</td>
</tr>
<tr>
<td>Station fire does not sustain development</td>
<td>0.99</td>
<td>0.9</td>
<td>0.875</td>
<td>0.999</td>
<td>0.677</td>
</tr>
<tr>
<td>Station fire controlled by automatic sprinklers</td>
<td>0.9</td>
<td>0.5</td>
<td>0.775</td>
<td>0.99</td>
<td>0.677</td>
</tr>
<tr>
<td>Station fire controlled by Fire Brigade</td>
<td>0.8</td>
<td>0.5</td>
<td>0.725</td>
<td>0.95</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Note: The END for the Base case is 0.695

END values exceeding 1 and less than 0.3 (indicating significant shift in the results) are highlighted in bold in Table 1. The first five parameters in Table 1 have a relatively significant impact on the risk of fires occurring within the tunnel section. The trend in the results indicates that fires occurring within the tunnel section are likely to lead to higher fatalities. This is consistent with many published fire safety strategies that recommend the affected train to proceed to the nearest station in a fire emergency [7],[8]. Reducing the occurrence of fires in the tunnel sections can therefore significantly improve the fire safety of the metro network. For example, there are special brake mechanisms that can be implemented which allow the train to continue on to the next station when activated in an emergency.
5.2 Design sensitivity analysis

For the design sensitivity analysis, focus will be made on fires occurring in the tunnel section. The ‘base case’ analysis as shown in Fig 4 indicates that fires in tunnels contribute to more than 90% of the risk to occupants.

A simple risk event tree for a metro tunnel fire incorporating fire protection design elements as outlined in the section on Design Framework is shown in Fig 2. The END represents the expected number of deaths given that a potentially significant fire occurred in the tunnel. In this example, the default events and the corresponding default values are as shown in Table 2.

![Event Tree Diagram]

**Fig 8. Simplified event tree for design sensitivity analysis**

**Table 2: Default events and values for risk event tree for tunnel design sensitivity study**

<table>
<thead>
<tr>
<th>Event</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>1</td>
<td>A fire is assumed to occur initially</td>
</tr>
<tr>
<td>E2</td>
<td>0.005</td>
<td>Fire not detected, no warning, not controlled and overwhelms the tunnel users unexpectedly</td>
</tr>
<tr>
<td>E3</td>
<td>0.95</td>
<td>High reliability due to minimal changes to system</td>
</tr>
<tr>
<td>E4</td>
<td>0.80</td>
<td>Considered for the period required for egress</td>
</tr>
<tr>
<td>E5</td>
<td>0.50</td>
<td>Proportion of exposed passengers at risk to fire before Fire Brigade arrives</td>
</tr>
<tr>
<td>E6</td>
<td>0.50</td>
<td>Assumes that fire is well-developed when FB arrives</td>
</tr>
</tbody>
</table>

The above evaluation suggests that the risk of tunnel fires is estimated to be in the order of 0.336 for a fire occurring in a tunnel that has the potential to develop into a severe fire. Using
this as a relative benchmark level for safety, the impact of the various design processes outlined above is evaluated.

The variation to the default values on the event probabilities are shown in Table 3.

Table 3: Variation in system design components

<table>
<thead>
<tr>
<th>#</th>
<th>Variation</th>
<th>E1</th>
<th>E2</th>
<th>E3*</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
<th>E7*</th>
<th>E8*</th>
<th>E9*</th>
<th>END*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>default</td>
<td>1</td>
<td>0.005</td>
<td>0.95</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
<td>60</td>
<td>30</td>
<td>15</td>
<td>0.336</td>
</tr>
<tr>
<td>2</td>
<td>Increased usage (2x)</td>
<td>2</td>
<td>0.6</td>
<td>120</td>
<td>60</td>
<td>30</td>
<td>1.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tunnel config. - bi-directional</td>
<td>3</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.36</td>
</tr>
<tr>
<td>4</td>
<td>Design fire – combustible material</td>
<td>0.5</td>
<td>0.6</td>
<td>0.75</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.75</td>
</tr>
<tr>
<td>5</td>
<td>Smoke control - poor installation</td>
<td>0.4</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.836</td>
</tr>
<tr>
<td>6</td>
<td>Smoke control - good installation</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.206</td>
</tr>
<tr>
<td>7</td>
<td>Detection – add CCTV</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.277</td>
</tr>
<tr>
<td>8</td>
<td>Warning – add operator</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.318</td>
</tr>
<tr>
<td>9</td>
<td>Egress - double exit spacing</td>
<td>180</td>
<td>150</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.53</td>
</tr>
<tr>
<td>10</td>
<td>Egress - no walkway</td>
<td>0.6</td>
<td>90</td>
<td>45</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.516</td>
</tr>
<tr>
<td>11</td>
<td>No active suppression system</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.13</td>
</tr>
<tr>
<td>12</td>
<td>No passive protection system</td>
<td>0.6</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.350</td>
</tr>
</tbody>
</table>

Note: Values not shown assume the default values.
* E3 = Only automatic suppression removed, portable extinguishers to passenger areas still provided.
E7 = number of people exposed if all systems fail
E8 = number of people exposed if active (smoke exhaust & sprinklers) systems fail
E9 = number of people FB can rescue upon arrival
* END values exceeding 2 are shown in bold

Based on the results shown in Table 3, the important tunnel design variables for life safety, ranked in the relative order of significance are as follows:
A. #11. No active suppression system
B. #4. Fire severity - combustible material
C. #3. Tunnel config. - bi-directional

The results are not unexpected as they all represent significant metro tunnel design parameters. The finding that the absence of an active suppression system as the most significant variable reflects the importance of keeping the fire severity under control. Unlike road tunnels, the range of metro fires is relatively small (7-20MW) due largely to the availability of combustible content being limited largely to the construction material of the carriages. This
The finding is also corroborated by a similar finding for buildings where it was determined that the heat release rate, the property characterising the design fire, is the single most important variable in fire hazard [9].

The quantification of the impact of these variables, achieved using a simplified risk approach, has enabled them to be delineated and ranked. The analysis can be further refined to undertake a more detailed evaluation within each of these design parameters in order to develop a suitable means of deriving more consistent values for design.

6. Discussion

The brief risk analysis and the corresponding sensitivity analysis demonstrated how event and design parameters that are important factors affecting the level of fire safety may be assessed and identified in order that appropriate actions can be taken. This may be achieved either in the design process or in the operational management, to minimize the risk to passenger safety in metro tunnels and stations. A proper fire risk assessment will incorporate many other factors in addition to those that were described in the above examples (e.g. various egress strategies) in order to assure that all relevant aspects affecting safety have been reasonably accounted for and represented in the overall risk results.

The risk assessment procedure that has been illustrated above can be extended to assist in formulating a cost-effective solution by assessing both the expected risk to life and the potential monetary losses due to fires in order to determine a low cost solution that adequately meets an acceptable level of fire safety. This can be readily achieved by providing expected cost losses associated with each of the consequences for the event terminations as has been done in evaluating the risk to life.

The acceptable criteria for the design of any new passenger rail tunnel are that an acceptable level of fire safety is achieved for staff, passengers, infrastructure and emergency services. Whilst the acceptable safety level is usually not defined, the use of a comprehensive risk analysis may be employed to demonstrate that the intended design objectives for fire safety have been met for a wide range of design scenarios. Means of reducing design variations for the selected variables are discussed below.

6.1 Suppression System

The effectiveness of an automatic suppression system in terms of its beneficial impact on life safety is relatively well established in building design and this has been demonstrated in this study. Because the fire hazard in a modern metro system is relatively low and well controlled, in comparison with road tunnels, for example, where there is little control in the type and quantity of combustible material in the traffic content, the range of potentially severe fires in metro tunnels is relatively limited. For this reason, the provision for automatic fire suppression is usually limited to the train itself and not the tunnel space and this has found to generally be satisfactory.

6.2 Fire severity

The range of fire severity has been considered for train fires occurring within the tunnels. The fire range is therefore limited, in comparison to say fires occurring within the stations. Similar to building design, fire severity represents an important design parameter that significantly affects the level of life safety but currently lacks a consistent means for its determination. Fires
have a relatively high degree of variation due to their dynamic characteristics, making them difficult to determine accurately. An appropriate means of taking into account the relatively wide range of possible fires is to consider a suitable range of fire scenarios. Modern carriages now have relatively strict requirements in terms of the type of materials allowed in the carriage construction and fitout.

6.3 Tunnel Configuration

The impact of tunnel configuration was evaluated by considering the traffic to be bi-directional. Tunnels with bi-directional traffic expose the risk of fire exposure to traffic in both directions and the increased risk was considered by increasing the risk of accidents 3-fold and slightly reducing the effectiveness of automatic suppression due to the potentially more catastrophic accidents that could result from a fire. As a result of the increased level of risk posed by bidirectional tunnels, as has been identified in this assessment, many modern metro tunnels tend to be uni-directional.

7. Conclusion

A risk assessment technique for a limited analysis of fire risks in metro tunnels and stations was presented. The method was based on a simplified model of estimating the consequences from these risks by calculating the effects of fires in a metro tunnel configuration and the impact on people that may be exposed to these effects. The factors that contributed to the occurrence of fires in metro tunnels and their consequences were assessed and the effectiveness of various means of mitigating these risks was discussed. The key factors that had a significant impact on the level of risks from both the contributing factors and the mitigation measures were identified. The risk assessment technique has the potential to incorporate a wide range of design considerations and may be readily extended to include cost consequences for determining optimal configurations capable of achieving cost-effective solutions that will provide a high level of fire safety.

References


**Leong Poon** has over 25 years experience in the areas of fire risk and occupant modelling for a wide range of building and infrastructure types. He is the author of over 60 publications in this field and has developed significant innovations in fire engineering techniques for performance-based design in Australia. Leong has a PhD in fire characterisation and human behaviour in occupant movement – both of which are the key parameters in the determination of life safety in fires. He has applied his expertise on fire risk to develop cost-effective fire safety solutions for a wide range of building types and infrastructure projects. These include buildings with large atriums, multi-level shopping centres, sports stadiums, convention centres, airports, high-rise buildings, road and rail tunnels and underground stations. Leong is a member of the Standards Australia committee FP-023 on Tunnel Fire Safety at the time of writing this paper.

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