Fire Risk in Metro Tunnels and Stations

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Metro Tunnels and Stations – General Characteristics

- Limited to metropolitan area (hence the name)
- Entire network is underground
- Interspersed by stations every 500 – 800m
- Predominantly one-way flow (ie single bore)
Rail tunnels

- Tseung Kwan O Ext., HK
- New Southern Railway, Sydney
- Parammatta Rail Link, Sydney
- GZ Metro
- West Rail, Mei Foo – Nam Cheong tunnel, HK
Stations and platforms, international

Berlin Hauptbahnhof Station, Germany

Stratford Station Concourse, UK

Federation Square, Melbourne
Stations and platforms, East Asia

Guangzhou Line 4 (Huangzhou Station)
KCRC West Rail DD400, HK

Nam Cheong Station, HK

GZ Metro Line 1
Lai King Station, HK
Metro Tunnels and Stations
– Safety (or risk) characteristics

- Traffic is well controlled, hence low accident rates
- Combustible material is controlled, hence low fire hazard
- Closely spaced stations allow train to continue to the station to allow passenger evacuation and fire-fighting
- Single bore tunnels lack escape passages unlike twin bore tunnels, hence relatively higher risk
- Large concentration of users, hence any incident places many passengers at risk
Metro Tunnels and Stations
– Objectives (of risk assessment)

Risk assessment is used as a design tool to:

- Identify relevant fire risks
- What factors cause incidents/disasters
- Determine key factors for improving safety
- Determine recommendations for cost-effective fire protection measures
Literature Review – Statistics

- Cause of fires in metro rails:
  - Ignition from mechanical/electrical failure, fuel from debris, cabin material & baggage, terrorist activities?
Literature Review – Statistics

- Rate of occurrence:
  - Small rail fire ~ a few a year
  - Severe rail fire ~ 0.5 a year worldwide (Anderson & Paaske)
- 30 severe incidents 1970-1987
  - 43 fatalities in 5 incidents (King’s Cross = 31)
- London underground, July 2005 (terrorist attack)
  - 50 fatalities (> sum of all past records)
- Demand for rail metro usage increasing
  - Throughput of 26 billion passengers a year
  - Hence potential exposure higher – ie more at risk
Literature Review
– Fire Hazard

- Carriage – main source of fuel + baggage
- Fire size typically between 6-20 MW
- Control of lining material will reduce likelihood of fire development but not necessarily reduce the fire size
- Terrorist factor ? Significant but highly indeterminate – best handled through a risk assessment approach
Literature Review
– Fire Protection Systems

- Purpose is to detect, warn and control
- For stations, conventional building systems are provided
- For carriages/tunnels, the following are provided:
  - Detection: – Smoke detectors in air-conditioned carriages
    – Heat detectors/CCTV may be used in tunnels
  - Warning: – Communication systems include break-glass, intercom
    phone or PA system for staff and passengers
  - Control: – Fire suppression systems in engine/equipment areas
    – Portable systems in passenger area
- Using risk assessment, the **optimal combination** of the above systems can be determined
Literature Review
– Smoke control in tunnels

- Smoke control is a key fire protection provision
- Strategy is to take advantage of longitudinal ventilation
  - Force smoke downstream in the direction of travel towards the ventilation shaft to be exhausted
  - Passengers take the smoke clear path upstream of air flow
- Smoke control need to accommodate egress requirements:
  - Escape stairs may be required for long tunnel sections
  - Escape stairs also used by fire fighters to gain access
- Train should continue to the next station to facilitate egress and fire-fighting access
Basic smoke control strategy – Schematics

Direction of longitudinal ventilation, Direction of train travel

Exit Smoke clear path

Occupant evacuation Downstream

Smoke exhaust
Risk assessment concept

- Risk is a measure of the consequence of an event, i.e.
  \[ \text{Risk} = \text{Probability} \times \text{Consequence} \]
- Consequence is the estimated measure of the event
  eg no of fatalities, cost of damage
- This is a generic approach – can be readily applied to assess situations where design is difficult to quantify
Main use of risk assessment is as a tool to determine a **cost-effective solution** by:
- Identifying important factors affecting life safety (or cost)
- Identifying effective protection measures

Effectiveness of each system is measured by its:
- **Reliability** – likelihood of the system operating, and
- **Efficacy** – how well it performs its intended function.

A cost-effective solution is the least cost design meeting an **acceptable level of safety** requirements.
Optimal solution using risk assessment

- Optimal design solution point
- ‘Balanced’ solution point
- Min. cost solution
- Acceptable min. risk

COST $ vs. RISK IN DESIGN
Any parameter having an impact on the objective (ie life safety or cost) needs to be assessed.

Important categories for life safety are:

- Fire scenarios – fire size, fire location (hard to predict)
- Fire detection system – detect and warn
- Fire protection systems – manage and control fire effects
- Egress provisions – provide safe egress passageway
  human behaviour consideration important
Simple example using event tree

Fire starts in metro network

- Fire starts in tunnel
  - Train fire in tunnel is controlled
    - Train is brought to station
      - Train fire in station is controlled by FB
        - Pedestrians evacuate safely
      - Train fire in station is not controlled
        - Pedestrians threatened
  - Train fire in tunnel is not controlled
    - Train fire in station is controlled
      - Train is brought to station
        - Train fire in station is controlled by FB
          - Pedestrians evacuate safely
        - Train fire in station is not controlled
          - Pedestrians threatened
    - Train fire in station is not controlled
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              - Pedestrians threatened

Pedestrians evacuate safely
Pedestrians threatened

End of tree

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Simple example using event tree

Fire starts in metro network

- Fire starts in tunnel
  - Train fire in tunnel is controlled (0.985) → Train is brought to station (0.5) → Train fire in station is controlled (0.5) → Pedestrians evacuate safely (0.09375)
  - Train fire in tunnel is not controlled (0.015) → Train fire in tunnel is not controlled (0.0075) → Train is brought to station (0.5) → Train fire in station is not controlled (0.00188) → Pedestrians threatened (0.05625)
  - Fire starts in tunnel (0.5) → Train is not brought to station (0.5) → Train fire in station is not controlled (0.00375) → Train fire in tunnel is not controlled (0.00263) → Pedestrians threatened (0.525)

- Fire starts in station
  - Station fire is controlled (0.999) → Pedestrians evacuate safely (0.4995)
  - Station fire is not controlled (0.001) → Train fire in station is controlled by FB (0.8) → Pedestrians evacuate safely (0.004)
  - Train fire in station is not controlled (0.2) → Pedestrians threatened (0.0001) → Train fire in tunnel is controlled by FB (0.0004) → Pedestrians threatened (0.02)

End (0.695)
The expected risk

- Each unfavourable event has a potential consequence.
- The consequence is the expected number of passengers threatened by the fire event.
- The expected risk of an unfavourable event is:
  \[ \text{Risk}_{\text{event}} = \text{Probability}_{\text{event}} \times \text{Consequence}_{\text{event}} \]
- The expected risk of the scenario is the cumulative sum of all the risks for unfavourable events:
  \[ \text{ERL} = \sum \text{Risk}_{\text{event}} \]
Determining Consequences

- The consequence of an unfavourable event is determined by direct computation or modelling.
- For example, to determine the unfavourable event for ‘Train fire in tunnel is not controlled’:
  - A large fire is modelled, say 20MW, using CFD
  - Occupant egress is simulated under untenable conditions
  - Occupants threatened by the effects of high temperatures
  - Occupant movement is limited by reduced visibility
Results of CFD simulation – FDS (Fire Dynamics Simulator)
Occupant evacuation

- **Occupant movement speed affected by:**
  - Crowding density
  - Visibility
  - Decision making

- **Time to exit depends on:**

\[ t_{\text{exit}} = t_{\text{detect}} + t_{\text{aware}} + t_{\text{response}} + t_{\text{movement}} \]

where

- \( t_{\text{detect}} \) = time to detect and communicate fire cue
- \( t_{\text{aware}} \) = time occupant becomes aware
- \( t_{\text{response}} \) = time to respond to cue
- \( t_{\text{movement}} \) = movement time to exit

- **Simulation models available for simulating occupant behavioural interaction with the environment.**
Sensitivity study

Purpose is to:
- Assess accuracy of assumptions (eg input values)
- Identify key factors by varying important parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base</th>
<th>Min</th>
<th>END,min</th>
<th>Max</th>
<th>END,max</th>
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</thead>
<tbody>
<tr>
<td>Fire start 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>
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<tr>
<td>Train fire brought to station</td>
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<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>
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<tr>
<td>Station fire does not sustain development</td>
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<td>0.9</td>
<td>0.875</td>
<td>0.999</td>
<td>0.677</td>
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<tr>
<td>Station fire controlled by automatic sprink.</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** (values <0.3 and >1.0 are shown in bold)
Summary

- Important aspects of a risk assessment require a good understanding of the potential hazards and scenarios.
- Many difficult design parameters can be assessed with a simple risk concept: \( \text{Risk} = \text{Probability} \times \text{Consequence} \).
- A sensitivity analysis allows important parameters to be identified and hence used to minimize risk in design.
- Various combinations of systems can be assessed to determine an optimal cost-effective design solution.
- This has been demonstrated for assessing fire risks in metro tunnels and stations.
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Thank you

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