Fire Risk in Metro Tunnels and Stations

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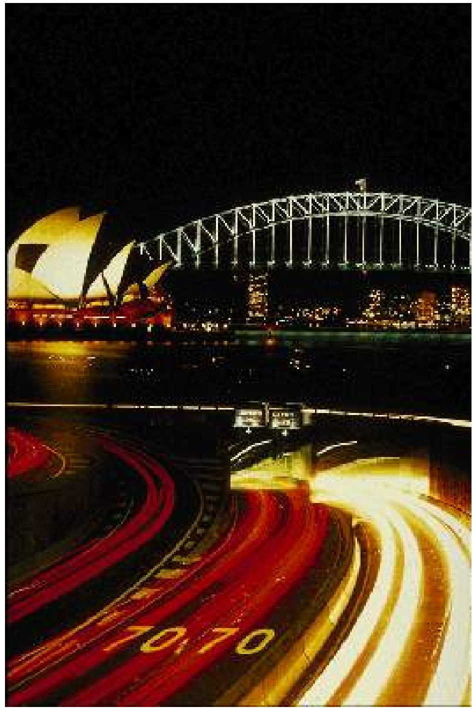

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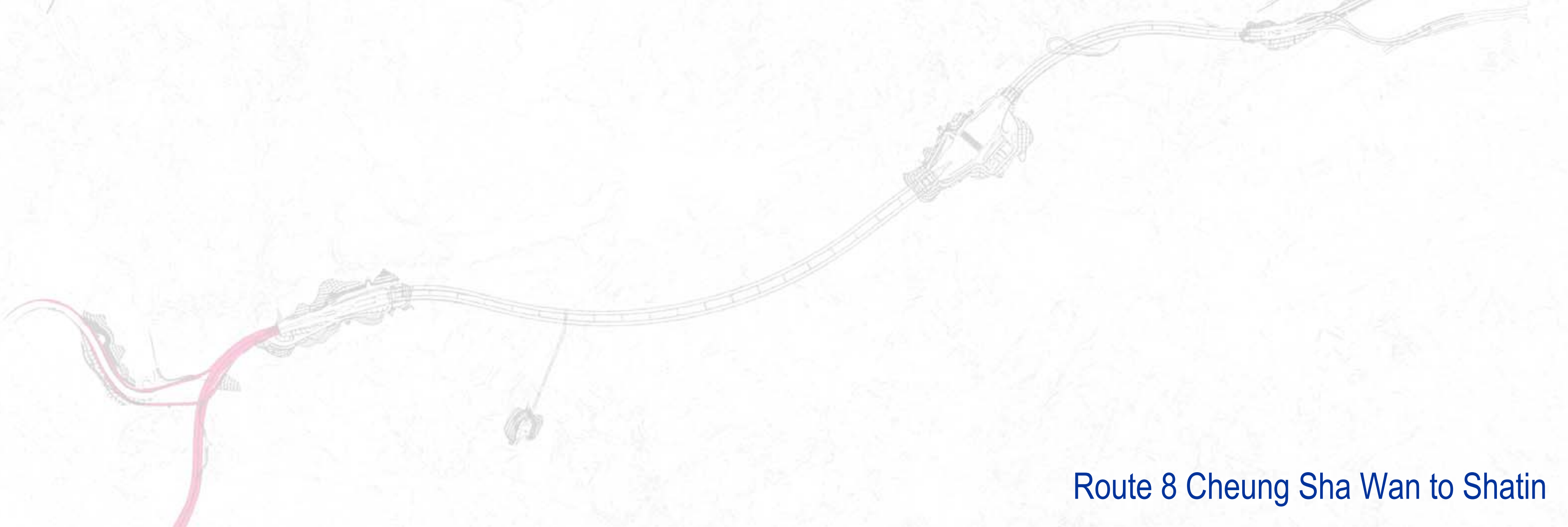
Metro Tunnels and Stations – General Characteristics

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



Route 8 Cheung Sha Wan to Shatin

Rail tunnels

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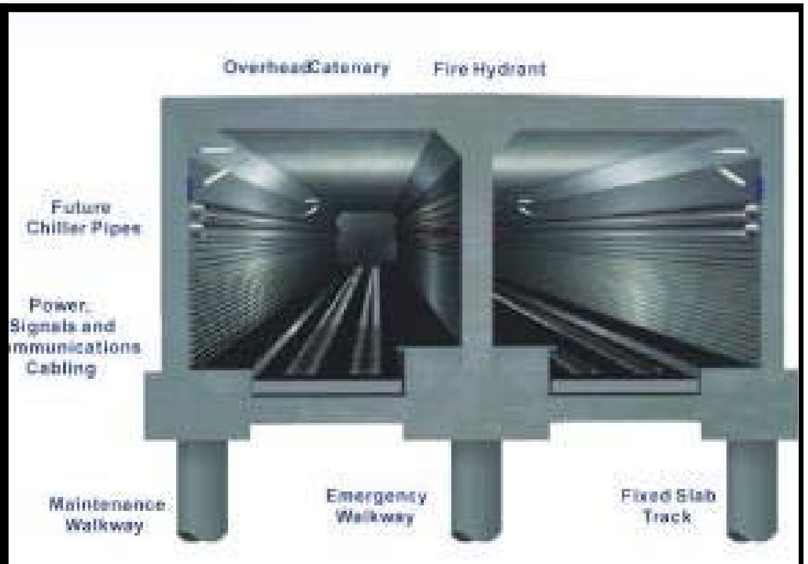
Tseung Kwan O Ext., HK

New Southern Railway, Sydney



West Rail, Mei Foo –
Nam Cheong tunnel , HK

Parammatta Rail Link, Sydney

GZ Metro

Stations and platforms, international

Berlin Hauptbahnhof Station, Germany

Stratford Station Concourse, UK

Federation Square, Melbourne

Stations and platforms, East Asia

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Guangzhou Line 4 (Huangzhou Station)

GZ Metro Line 1

KCRC West Rail DD400, HK

Nam Cheong Station, HK

Lai King Station, HK

Metro Tunnels and Stations
– Safety (or risk) characteristics

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- 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

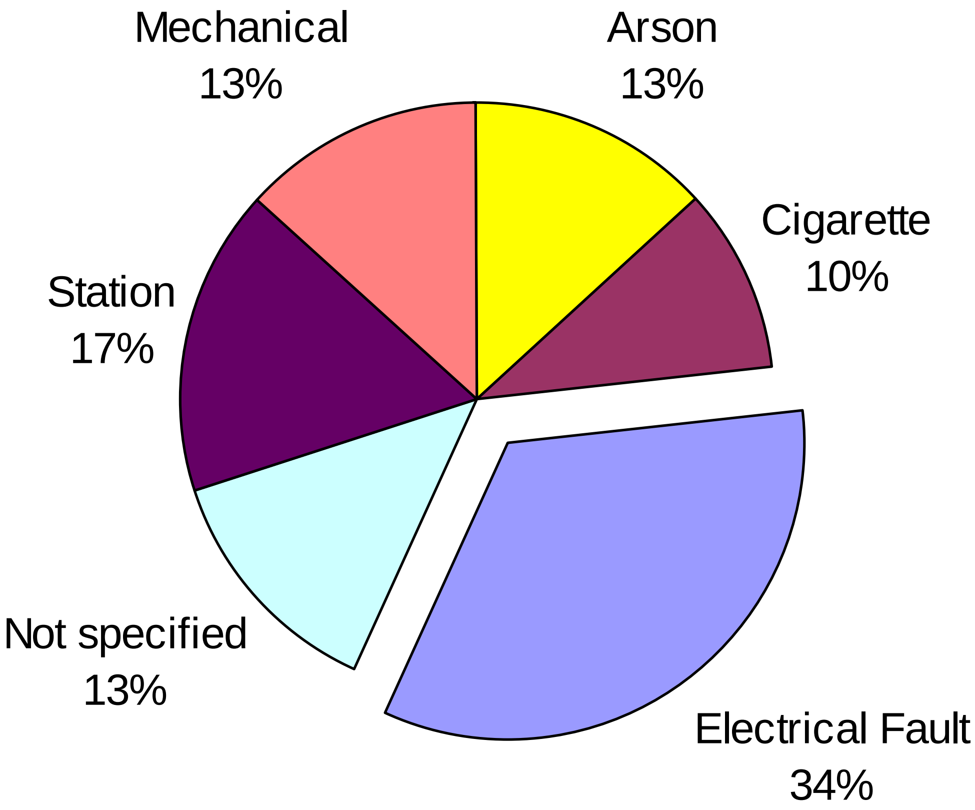
Metro Tunnels and Stations
– Objectives (of risk assessment)

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

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- 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

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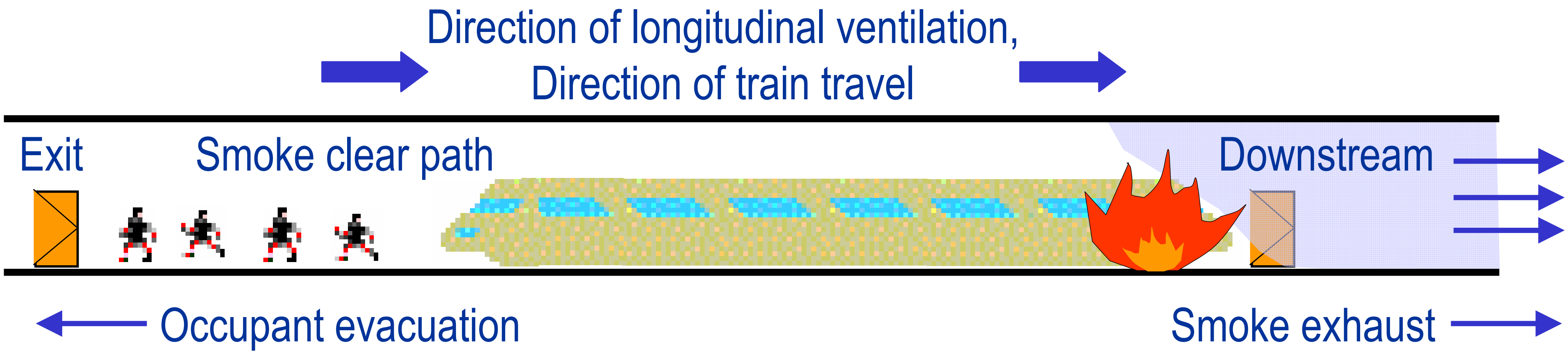
- Purpose is to detect, warn and control
- For stations, conventional building systems are provided
- For carriages/tunnels, the following are provided:
- Detection: – Smoke detectors in air-conditioned carriages
  – Heat detectors/CCTV may be used in tunnels
- Warning: – Communication systems include 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



Risk assessment concept

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- Risk is a measure of the consequence of an event, i.e.

  Risk = Probability $\times$ 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

Risk assessment application

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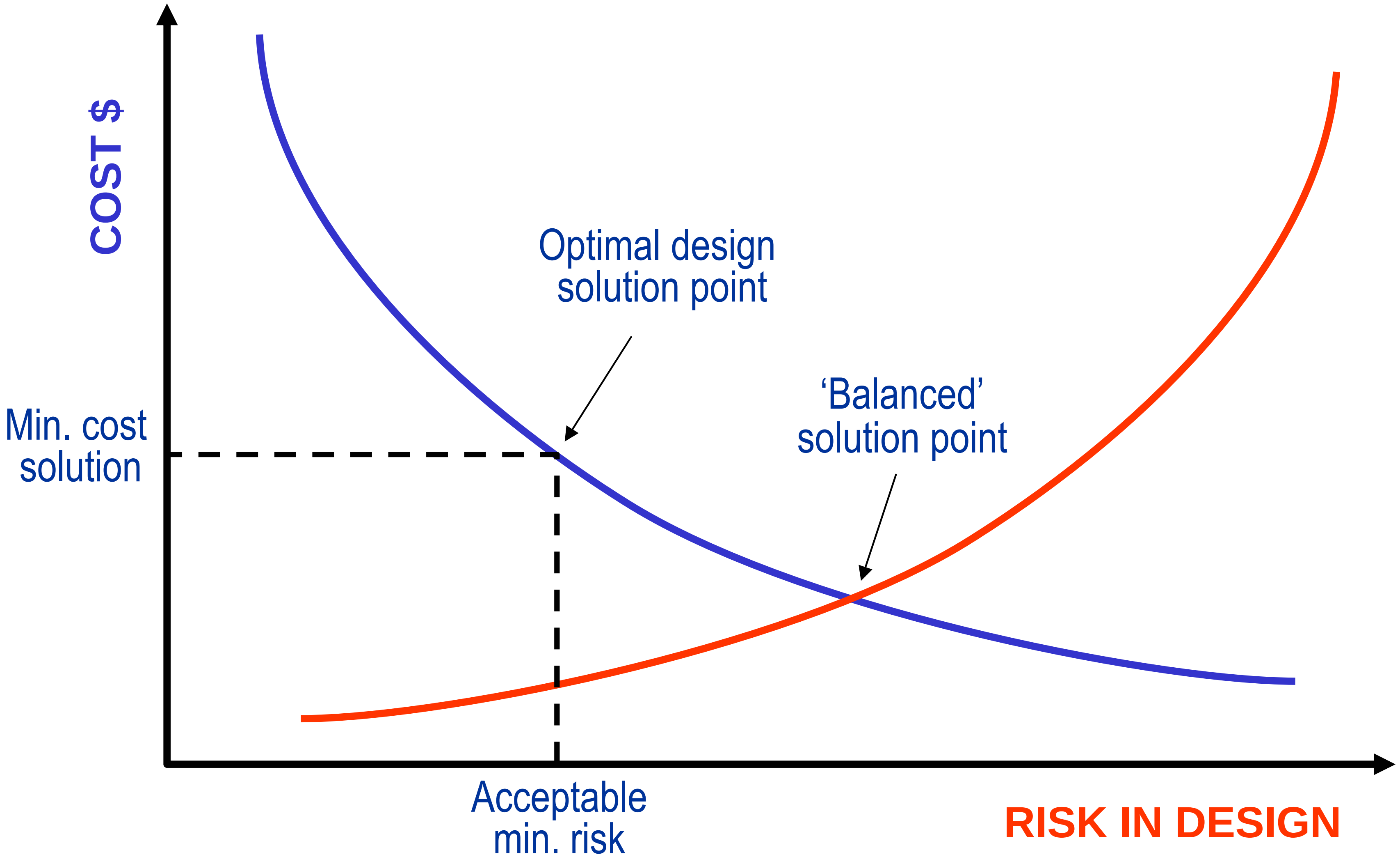
- Main use of risk assessment is as a tool to determine a *cost-effective solution* by:
  - Identifying important factors affecting life safety (or cost)
  - Identifying effective protection measures
- Effectiveness of each system is measured by its:
  - *Reliability* – likelihood of the system operating, and
  - *Efficacy* – how well it performs its intended function.
- A cost-effective solution is the least cost design meeting *acceptable level of safety* requirements

Optimal solution using risk assessment



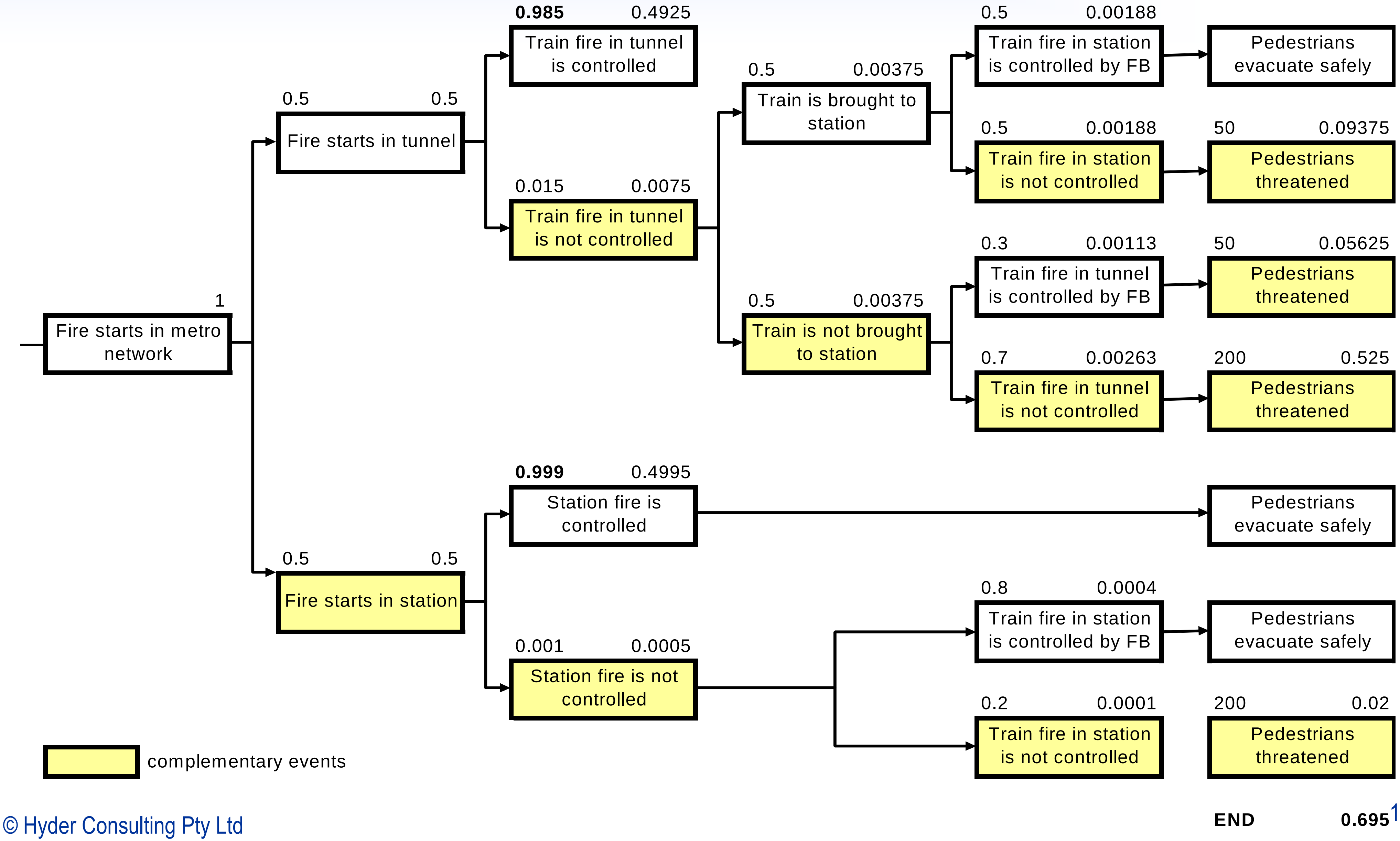
Risk parameters

Any parameter having an impact on the objective (ie life safety or cost) needs to be assessed.

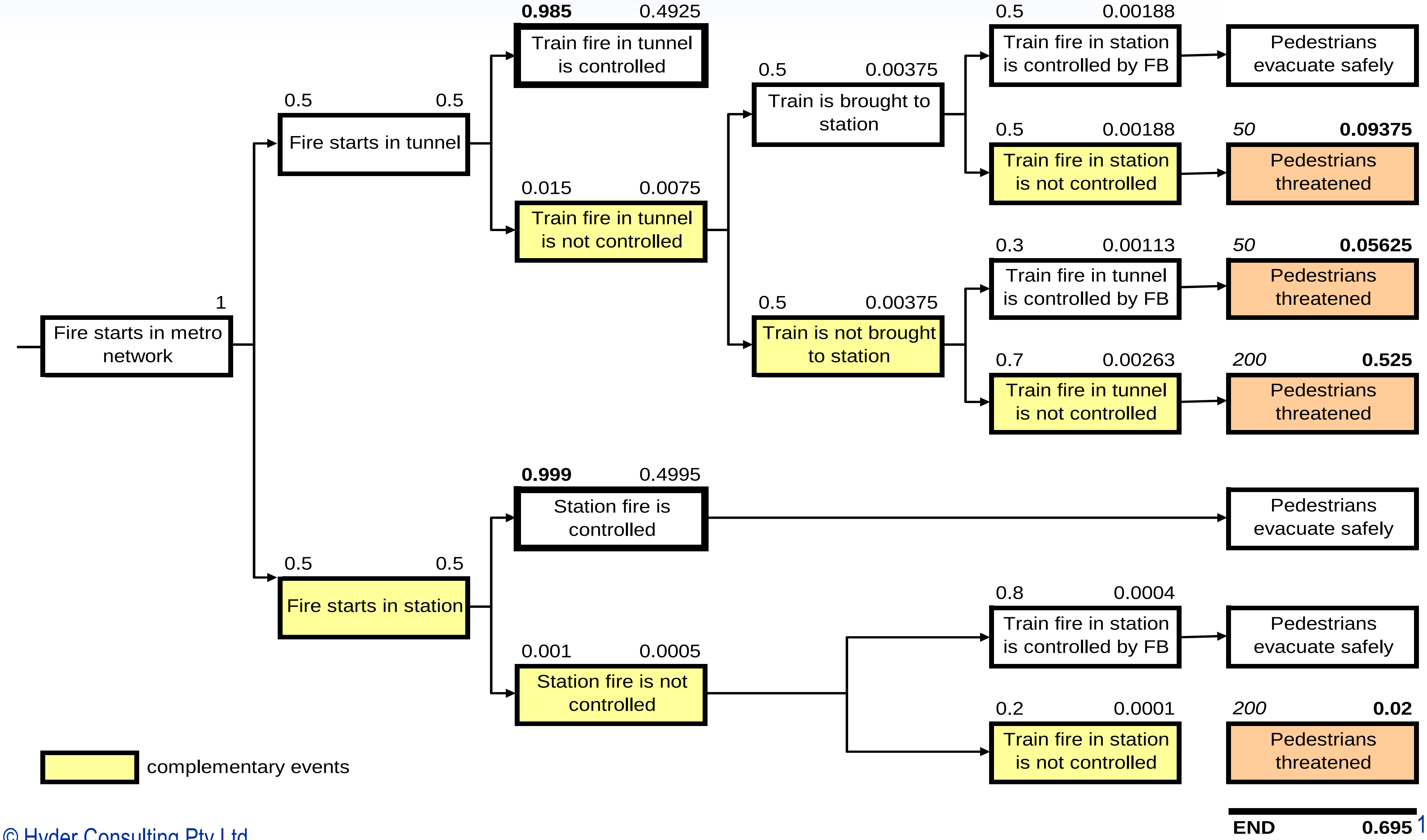
Important categories for life safety are:

- 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



Simple example using event tree



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:

  $$Risk_{event} = Probability_{event} \times Consequence_{event}$$

- The expected risk of the scenario is the cumulative sum of all the risks for unfavourable events:

  $$ERL = \sum Risk_{event}$$

Determining Consequences

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- 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)

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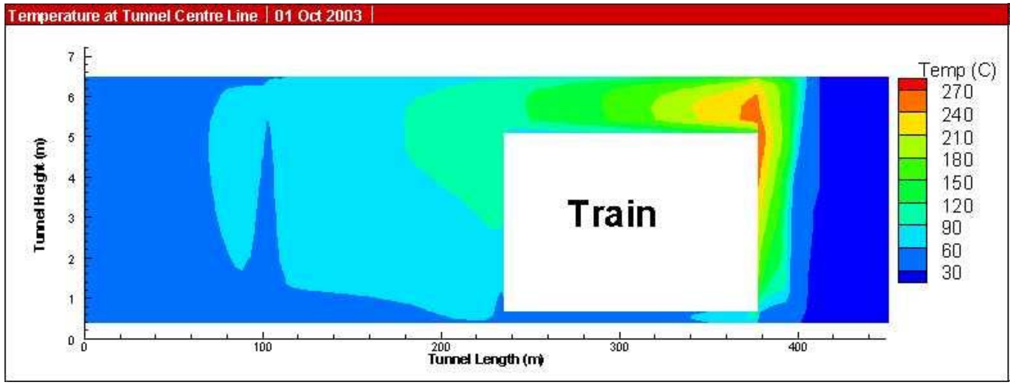
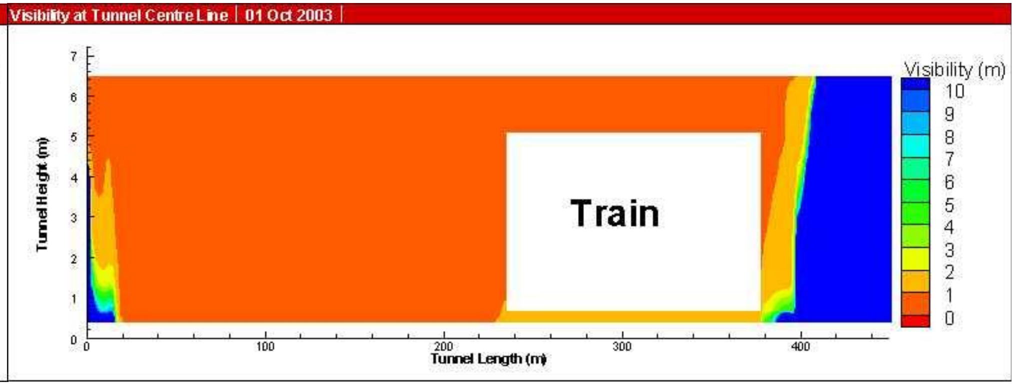
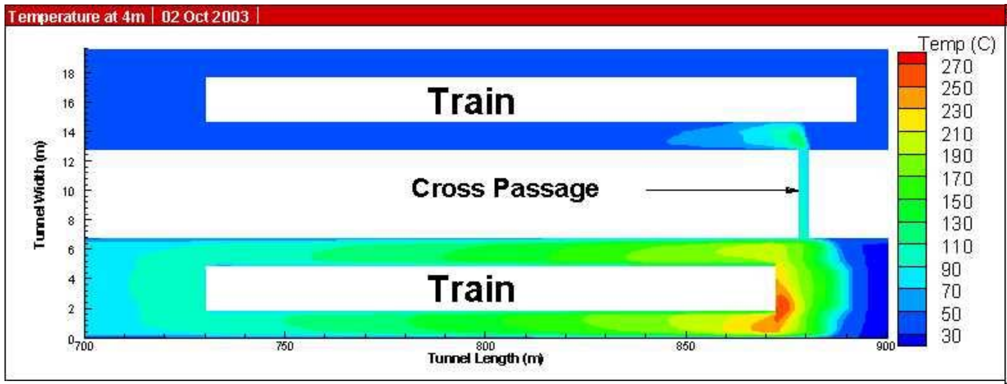
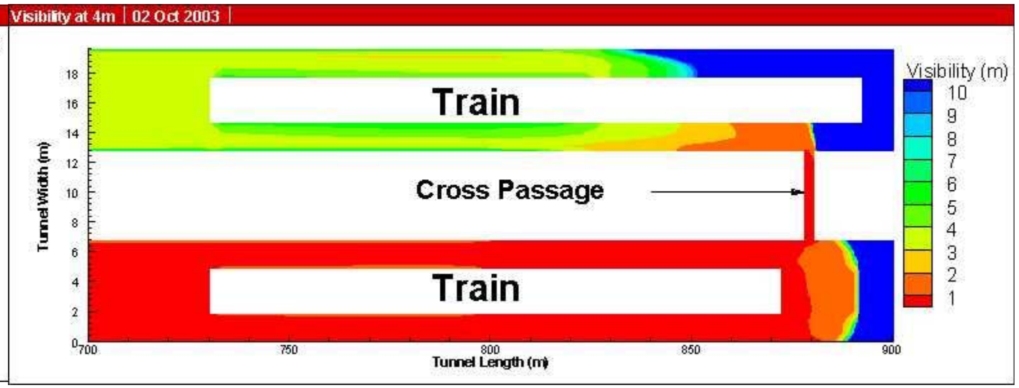




Temperature SECTIONAL VIEW Visibility





Temperature PLAN VIEW Visibility

Occupant evacuation

- Occupant movement speed affected by:
  - Crowding density
  - Visibility
  - Decision making
- Time to exit depends on:

  $t_{exit} = t_{detect} + t_{aware} + t_{response} + t_{movement}$

  where t_{detect} = time to detect and communicate fire cue

  t_{aware} = time occupant becomes aware

  $t_{response}$ = time to respond to cue

  $t_{movement}$ = 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

Parameter	Base	Min	END,min	Max	END,max
Fire start in station	0.5	0.1	**1.22**	0.9	**0.171**
Tunnel fire does not sustain development	0.95	0.7	**4.07**	0.99	**0.155**
Tunnel fire controlled by extinguishers	0.7	0.4	**1.37**	0.9	**0.245**
Train fire brought to station	0.5	0.1	**1.09**	0.9	0.305
Tunnel fire controlled by Fire Brigade	0.3	0.1	0.808	0.8	0.414
Station fire does not sustain development	0.99	0.9	0.875	0.999	0.677
Station fire controlled by automatic sprink.	0.9	0.5	0.775	0.99	0.677
Station fire controlled by Fire Brigade	0.8	0.5	0.725	0.95	0.68

Note: The END for the Base case is 0.695 (values <0.3 and >1.0 are shown in bold)

Summary

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- Important aspects of a risk assessment requires a good understanding of the potential hazards and scenarios
- Many difficult design parameters can be assessed with a simple risk concept: Risk = Probability × 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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