Rail Tunnel Fire Safety

SaRS Asia Pacific webinar 15/09/2021

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Contents

- Past fire incidents in rail tunnels
- Safety factors and stakeholders
- International and national standards for fire safety
- Risk assessment methodologies
- Equipment and vehicles
- Fire evacuation strategies
- Q & A session

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Mosen Ltd

- Engineering consultancy specialising in tunnel ventilation, fire safety and Computational Fluid Dynamics (CFD)
- Established in 2007
- Based in the UK, with representation in Australia
- Delivered designs and advice to many infrastructure projects world-wide

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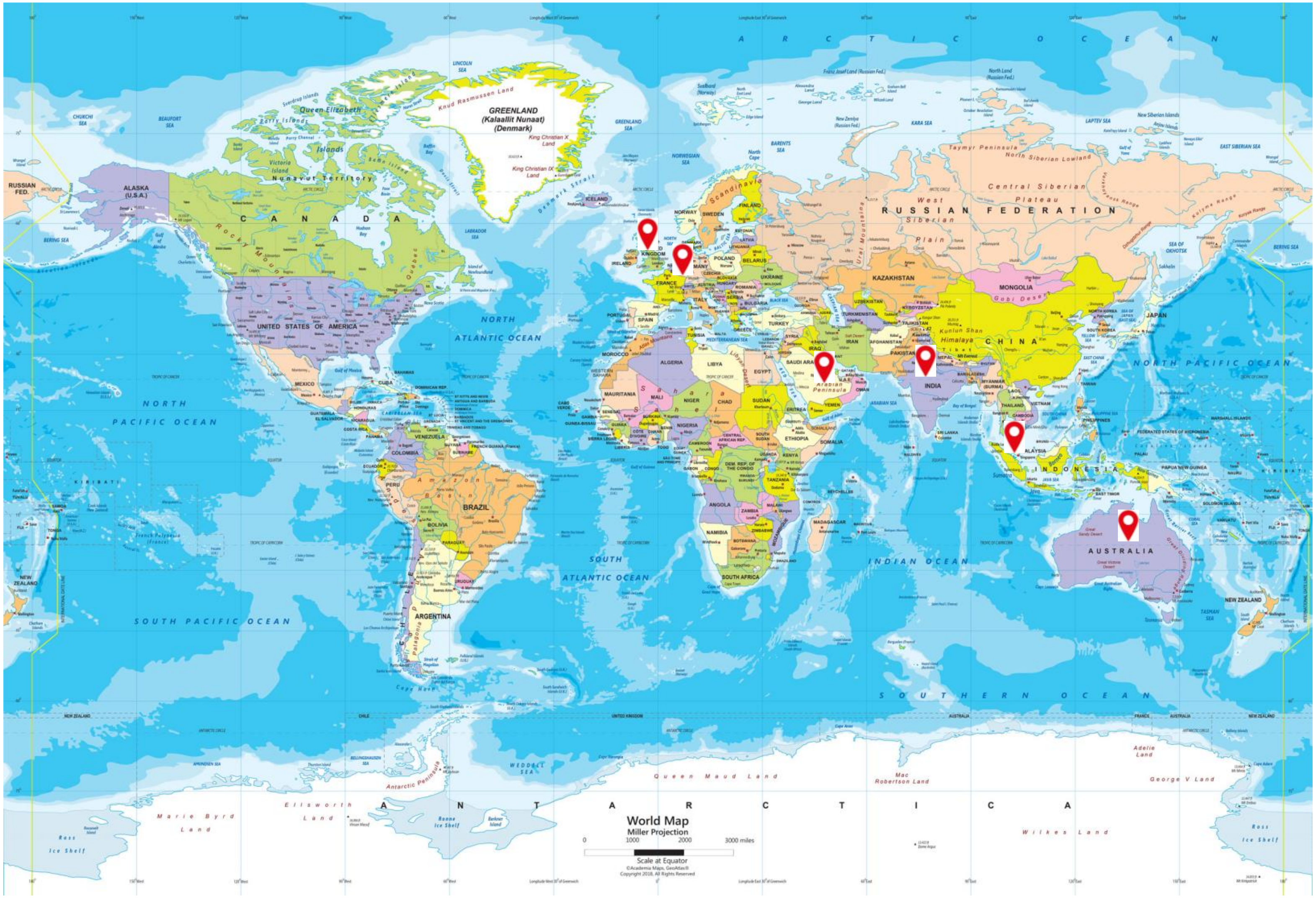
Geographic Scope



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Regulatory & Legal Framework

- Presentation strongly influenced by legal framework in countries where Mosen Ltd has operated
- Comments will be made regarding other legal frameworks and regulatory requirements

Past fire incidents in rail tunnels

King's Cross Fire, UK, 1987

- Fire started under a wooden escalator serving the Piccadilly line
- Erupted in a flashover into the underground ticket hall (→"trench effect")
- Killed 31 people and injured 100
- Started by a lit match being dropped onto the escalator
- Fire Precautions (Sub-surface Railway Stations) Regulations 1989 introduced
- Wooden escalators were gradually replaced with metal escalators on the London Underground

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7 July 2005 London bombings

- Series of 4 coordinated suicide attacks – including 3 bombs on London Underground trains
- 52 killed and more than 700 injured
- Limited smoke production - trains smouldered, but did not burn

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Hong Kong MTR Firebombing, 2017

- Firebomb attack (arson)
- Approach to Tsim Sha Tsui station
- 18 passengers injured, 4 critically
- Smoke inhalation and burns

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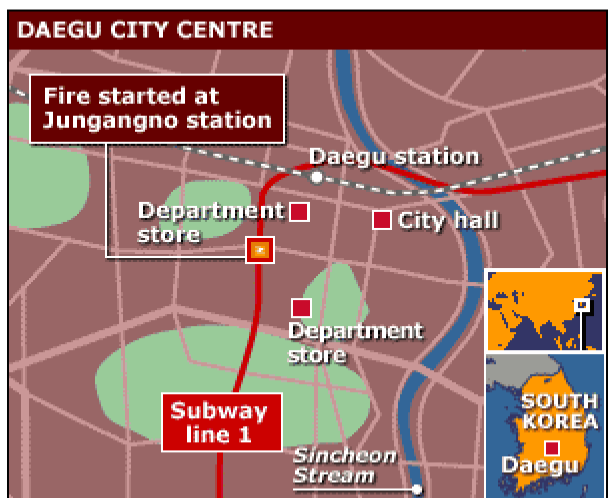
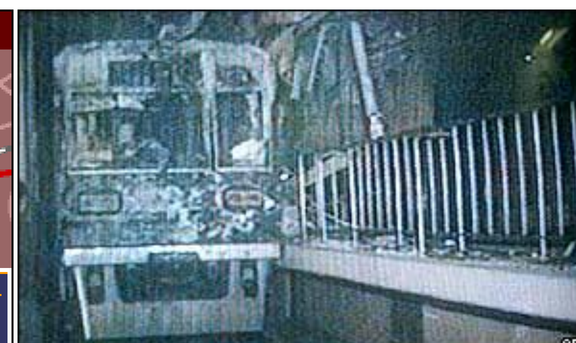
Daegu Station, South Korea, 2003

- Arson attack
- 182 deaths
- Two subway trains destroyed
- Doors locked on second train





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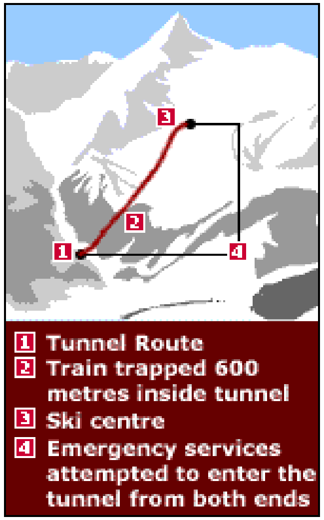
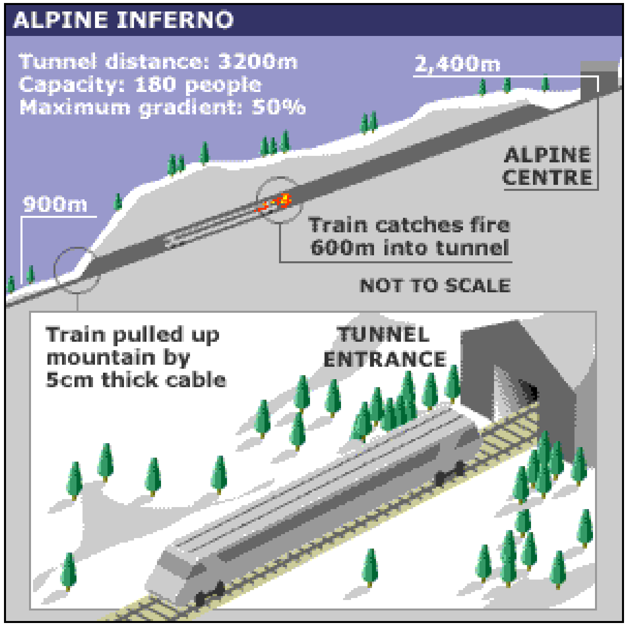
Kaprun, Austria, 2000

- Austrian Funicular Railway Tunnel
- 155 deaths
- 3.3 km tunnel
- Electrical fault?
- Strong chimney effect
- Doors failed to open





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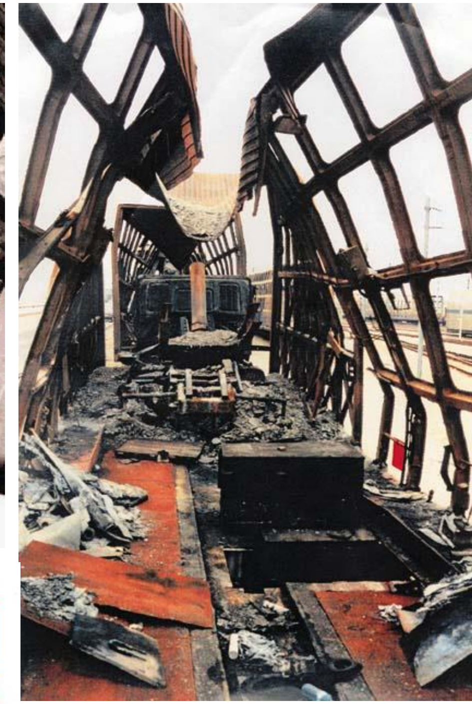
Channel Tunnel Fires

- 50 km long Channel Tunnel
- Opened in 1994
- Four fires on trucks being carried through the tunnel: 1996, 2006, 2008, 2015
- None fatal, but with some injuries due to smoke inhalation & damage to tunnel
- Four fire suppression stations constructed in 2011 (deployed in 2015 fire)



VUE GÉNÉRALE
GENERAL VIEW FIGURE 1

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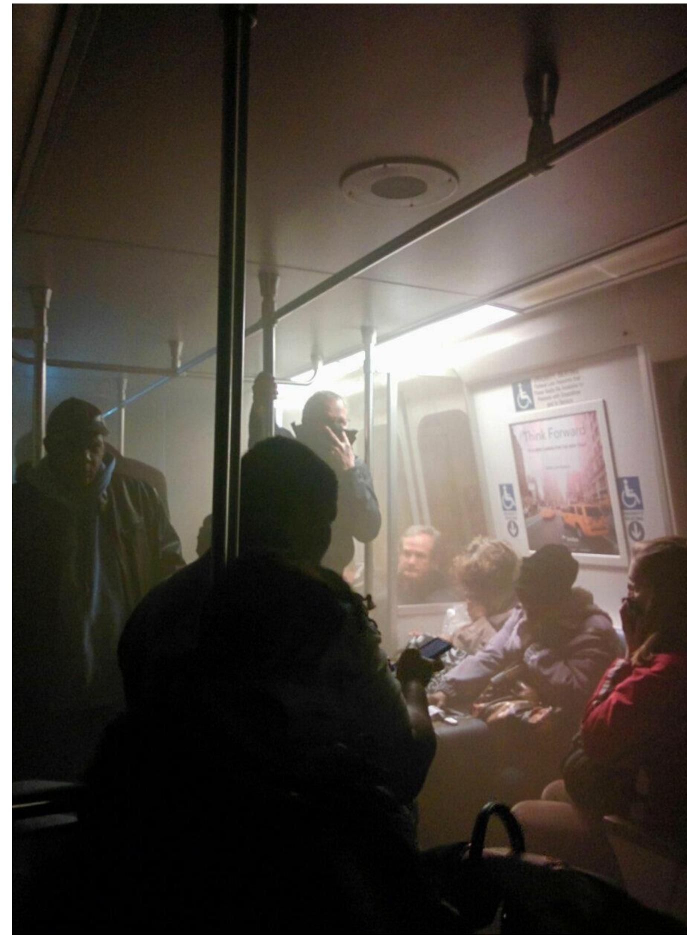
L’Enfant Plaza Station, Washington DC, 2015

- Arcing from third rail
- 91 people were injured, and one passenger died
- Inadequate tunnel ventilation
- Railcar ventilation not shut down
- Emergency responders initially went to wrong tunnel
- Ineffective inspection and maintenance practices



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Ang Mo Kio MRT Station, Singapore, 2015

- Electrical panel caught fire in a substation
- No injuries
- Train operations disrupted for over 2 hours

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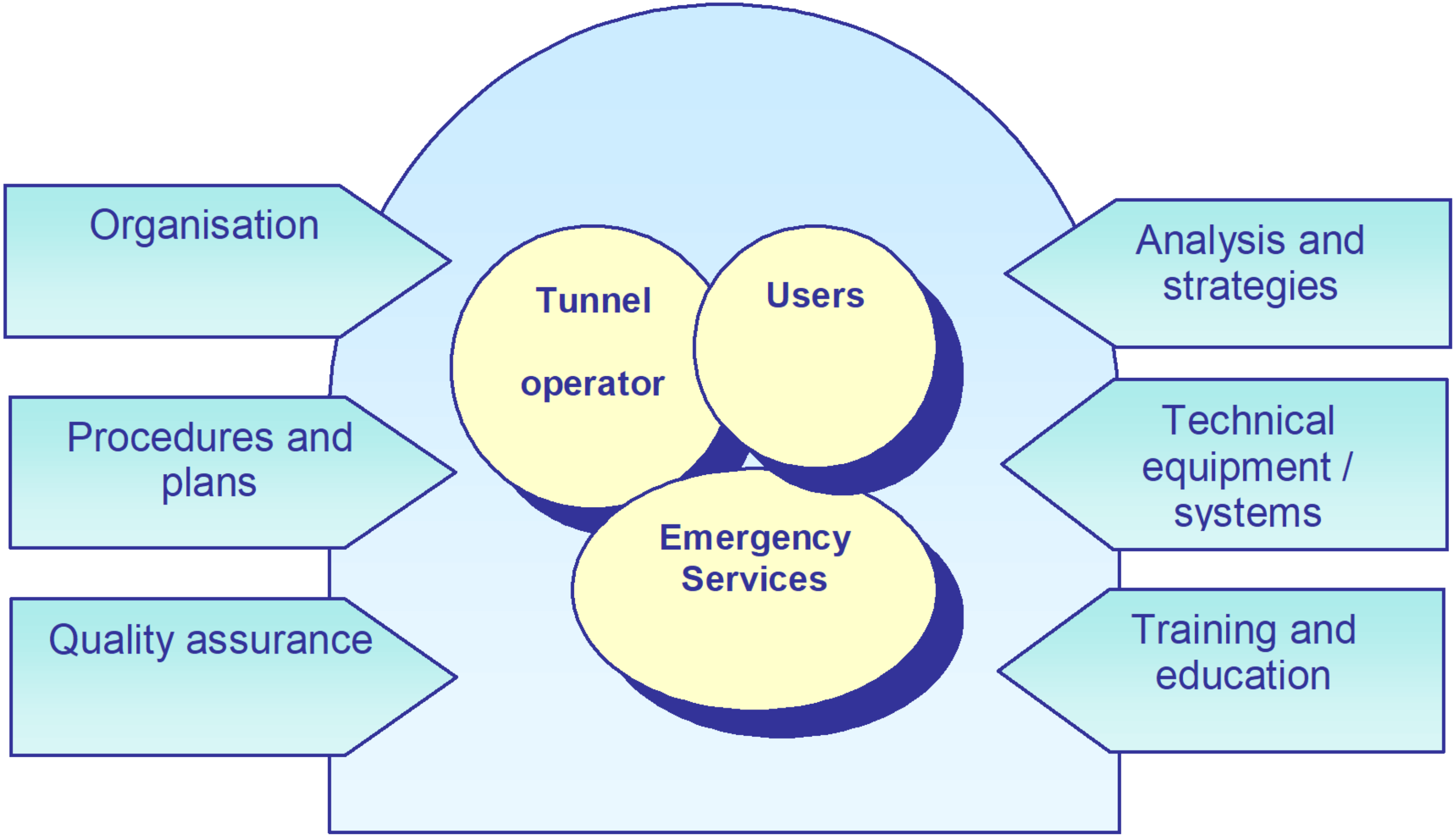
Safety Factors and Stakeholders

Safety Factors and Stakeholders



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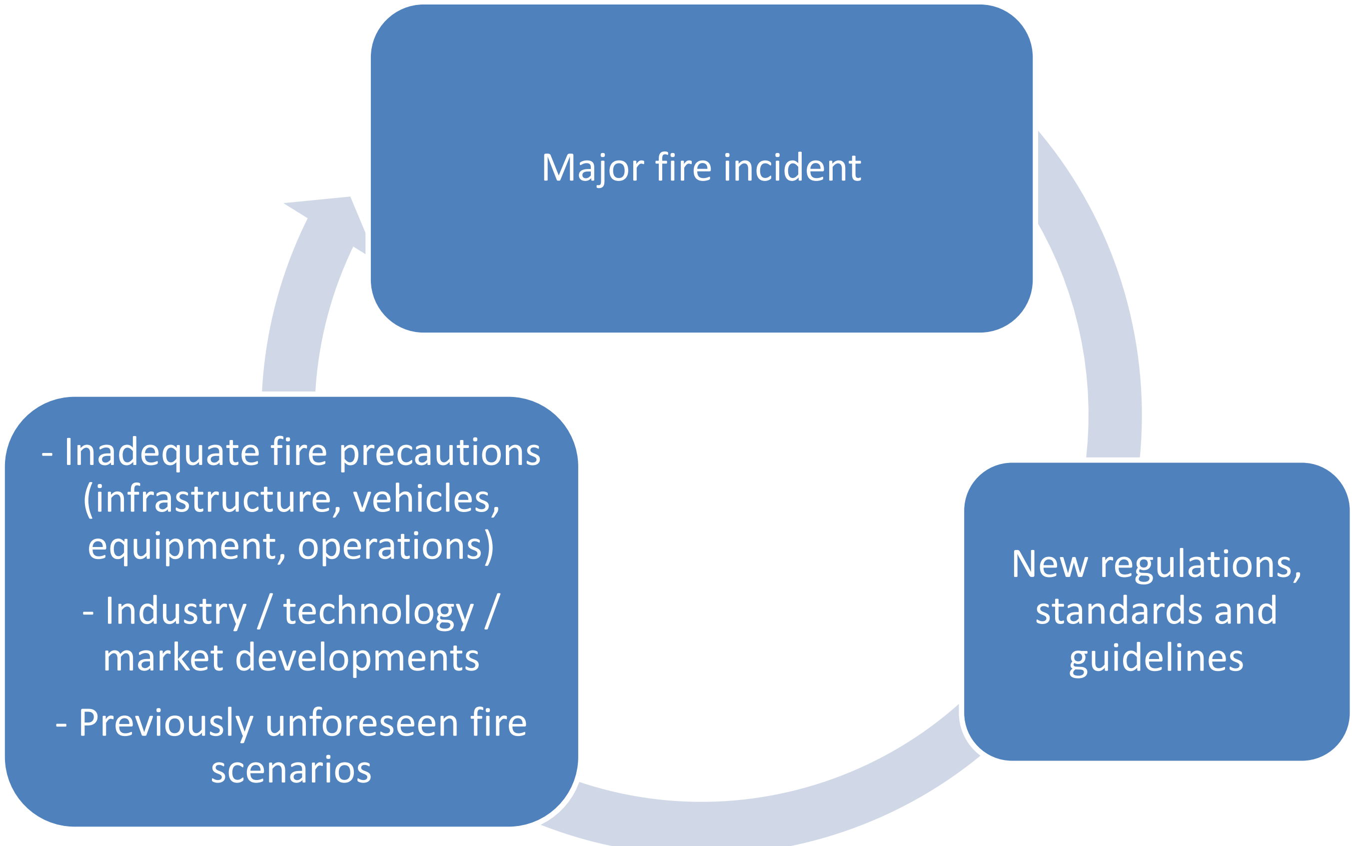
The Regulatory Cycle



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International and national standards for railway fire safety

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Underground Railway Fire Safety Standards

- NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems → North America, Middle East and associated countries
- European Union: Technical Specification for Interoperability, Safety in Railway Tunnels / Stations
- Australian Standard AS-4825, Tunnel fire safety

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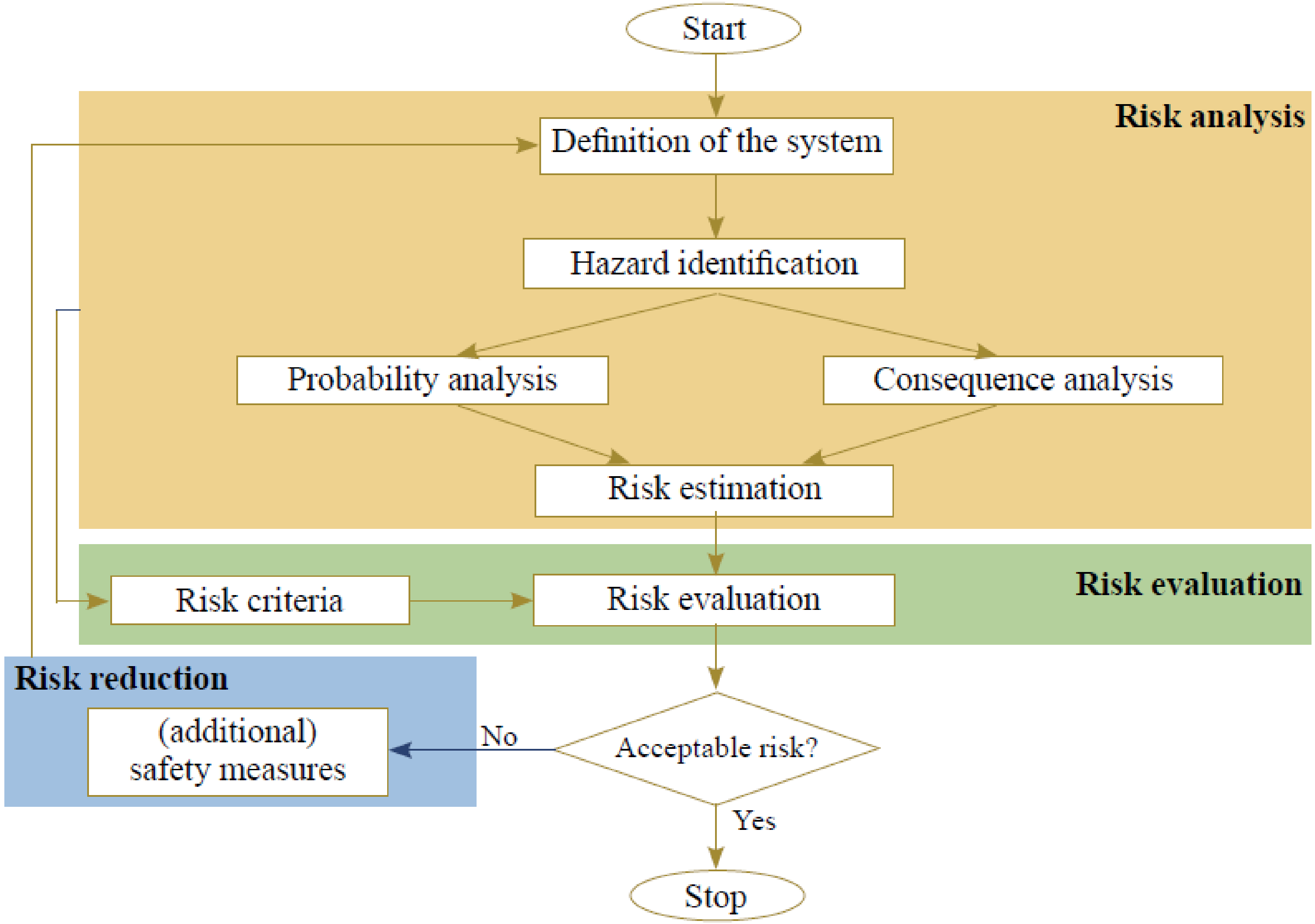
Common Safety Method

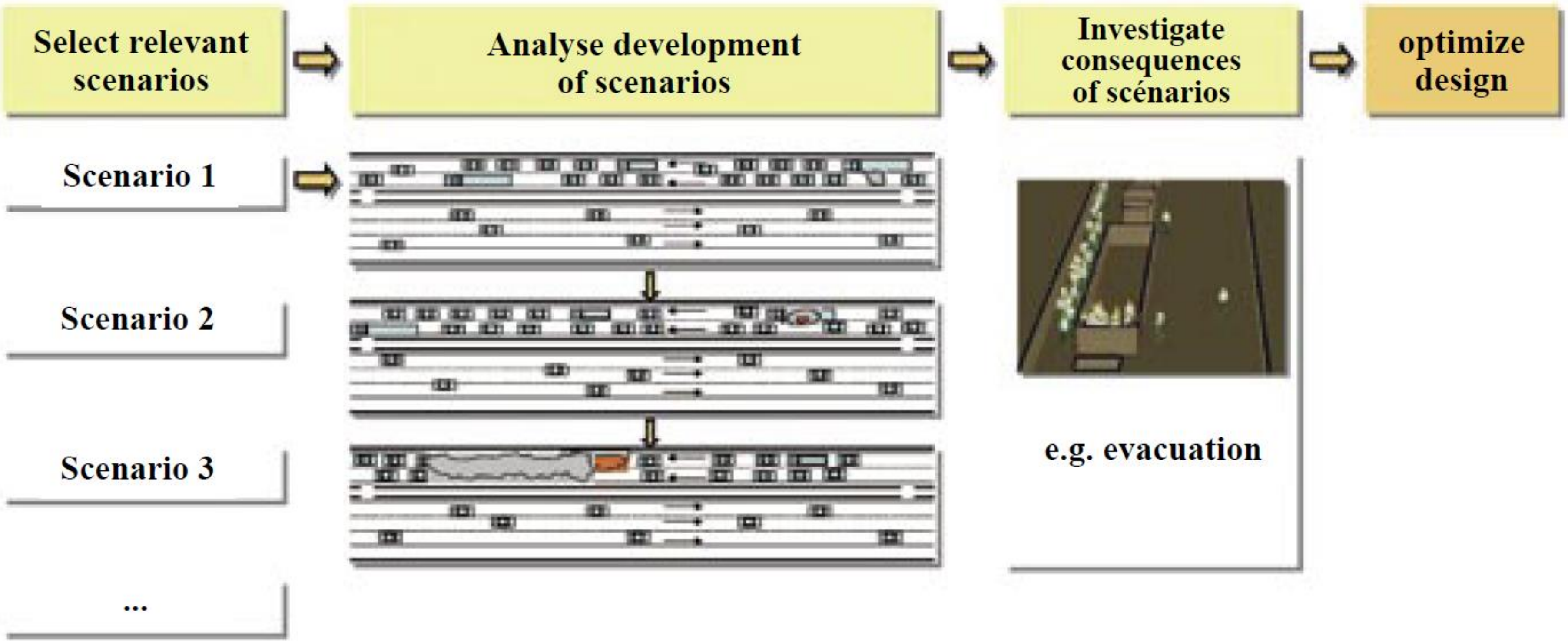
- European Railway Safety Directive (2004/49/EC)
- Risk acceptance principles:
  - application of codes of practice
  - comparison with similar systems (reference systems)
  - explicit risk estimation

Risk assessment methodologies

Risk Assessment



Scenario-Based Approach



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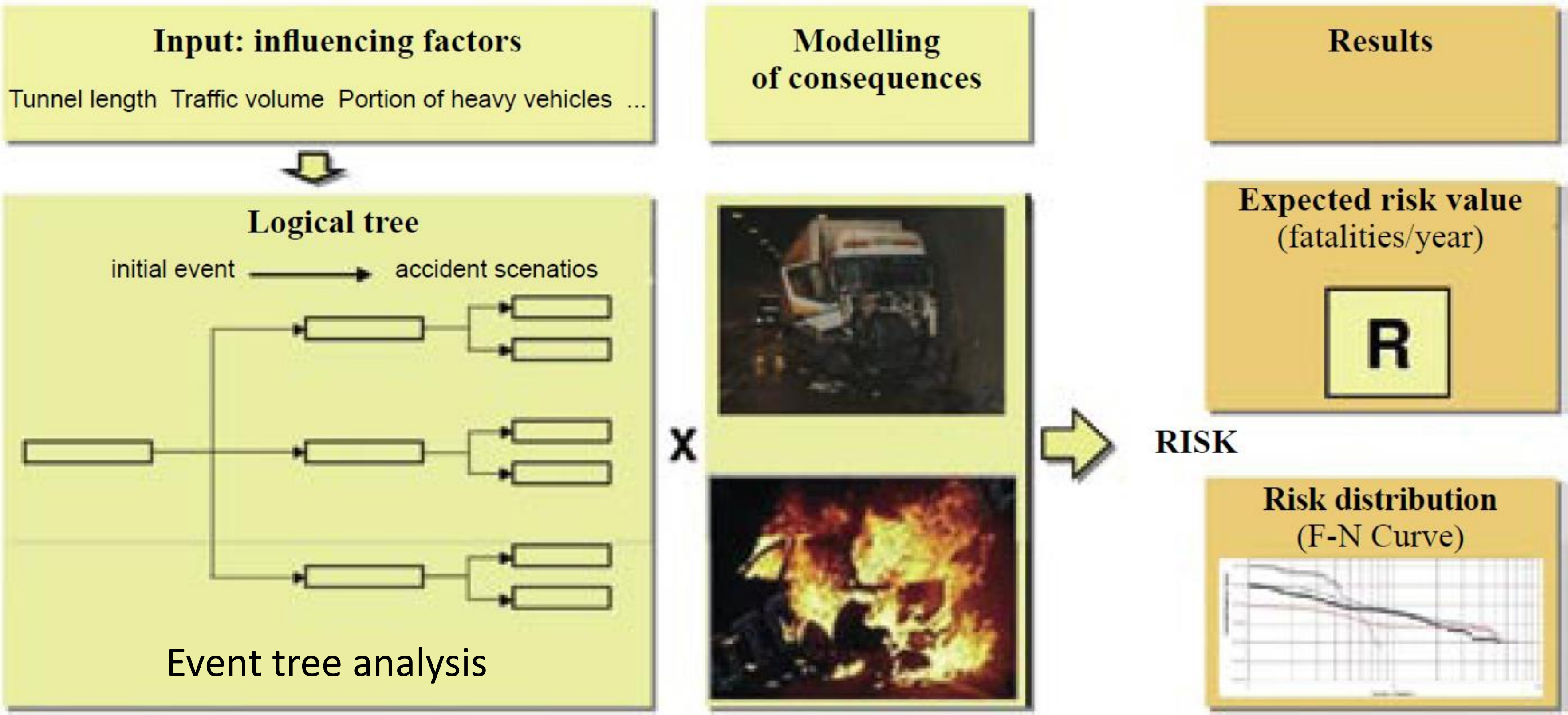
System-Based Approach



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ALARP and SFAIRP

- "As Low as Reasonably Practicable" – UK principle 
- "So Far As Is Reasonably Practicable" – Australian principle 
- Similar, but not identical principles

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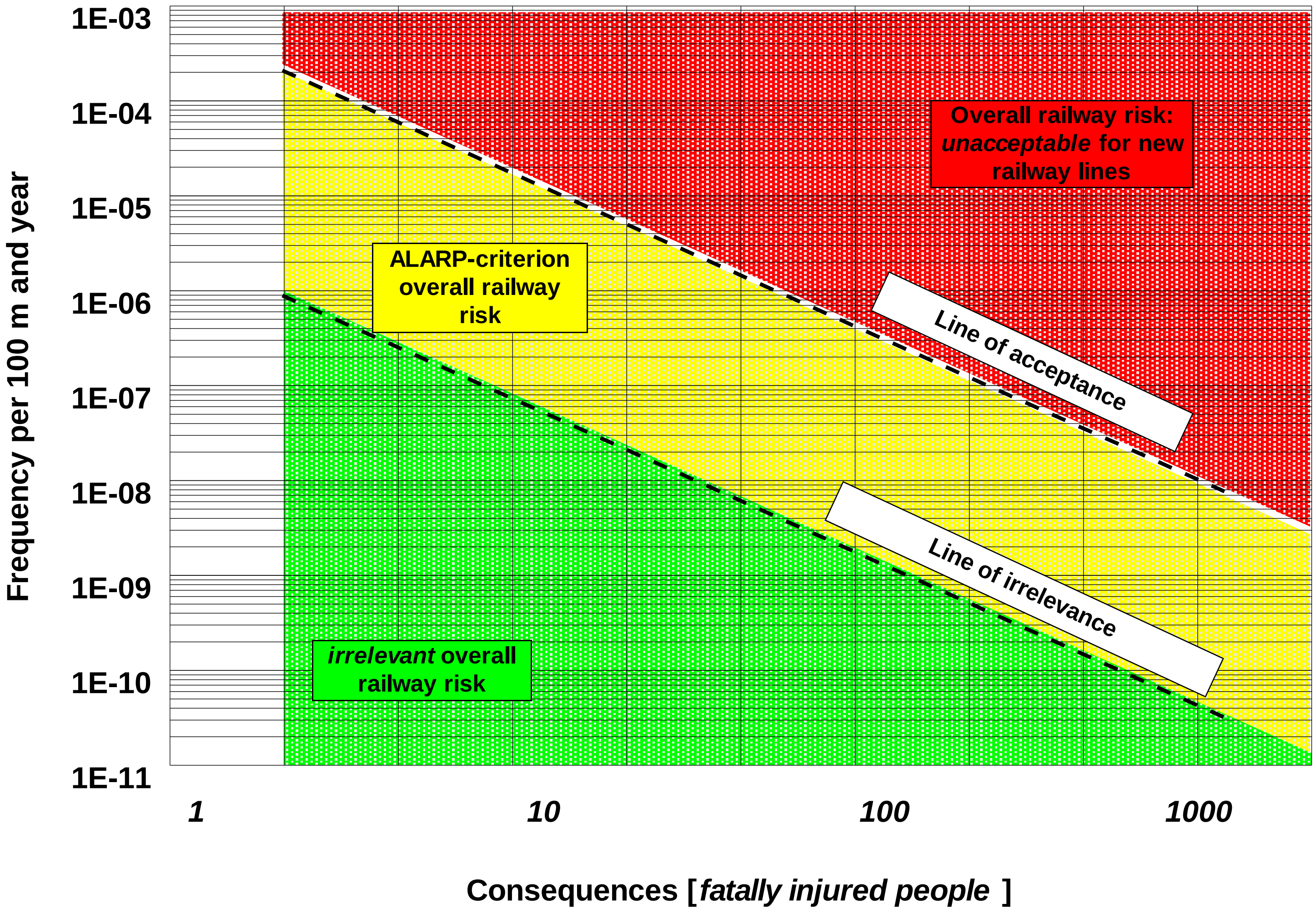
Frequency / Consequences Curve



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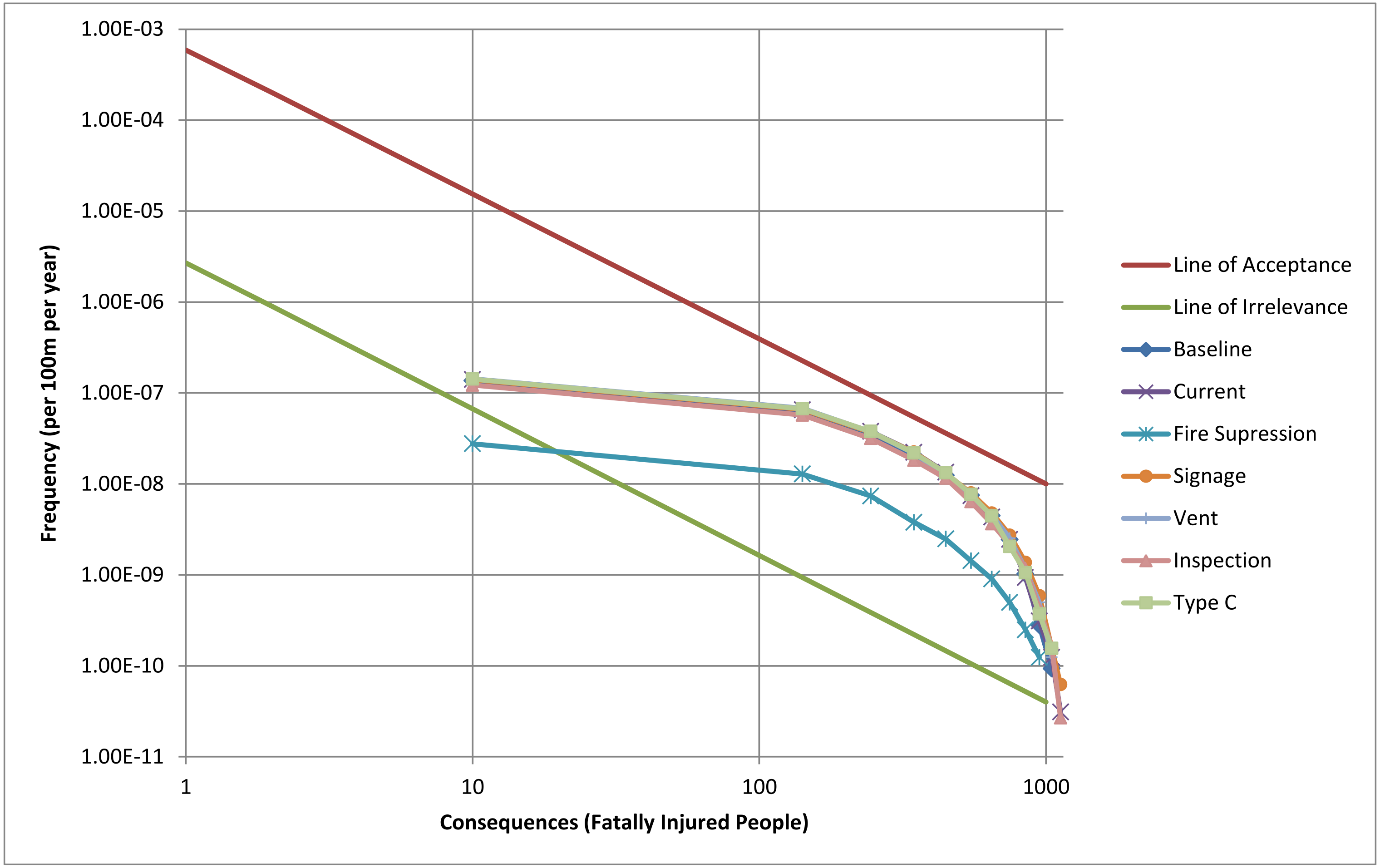
Analysis of Alternative Mitigation Measures



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Test of Disproportionality

- *Edwards v National Coal Board* [1949]
- Australian & UK guidance: costs typically should not exceed (10 x benefits)

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Fire Safety Engineering

- Fire Safety Engineering = ‘The provision of fire safety by quantitative methods based on science’ (UK Department of the Environment)

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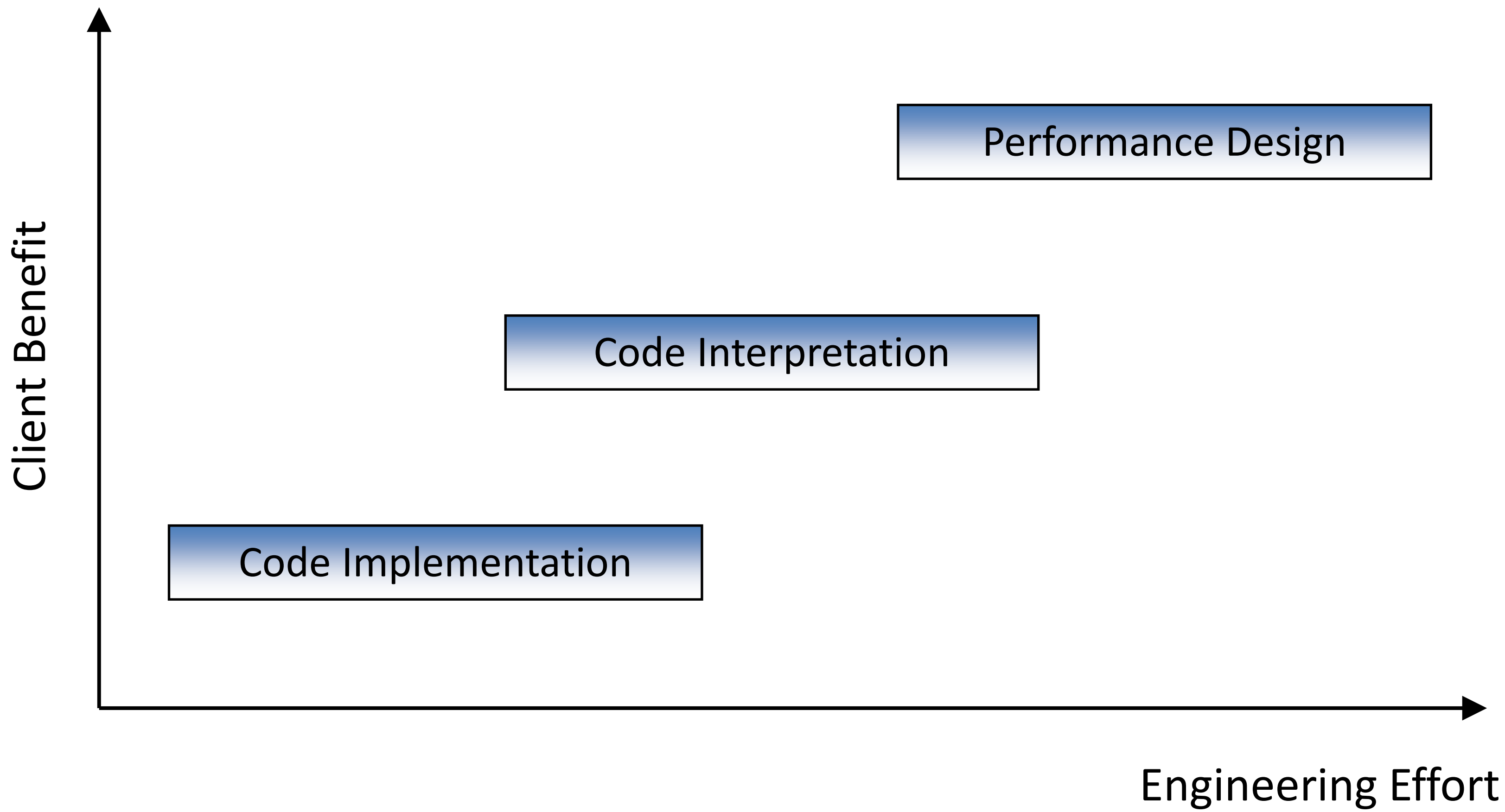
Prescriptive – Performance Design Continuum



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Examples of Performance-Based Fire Safety Engineering Standards

- BS 7974:2001 Application of fire safety engineering principles to the design of buildings - Code of practice
- BS 9999:2008 Code of practice for fire safety in the design, management and use of buildings
- Singapore Fire Safety Engineering Guideline 2015
- Typical criterion is that full evacuation of infrastructure can be completed while tenable conditions are maintained

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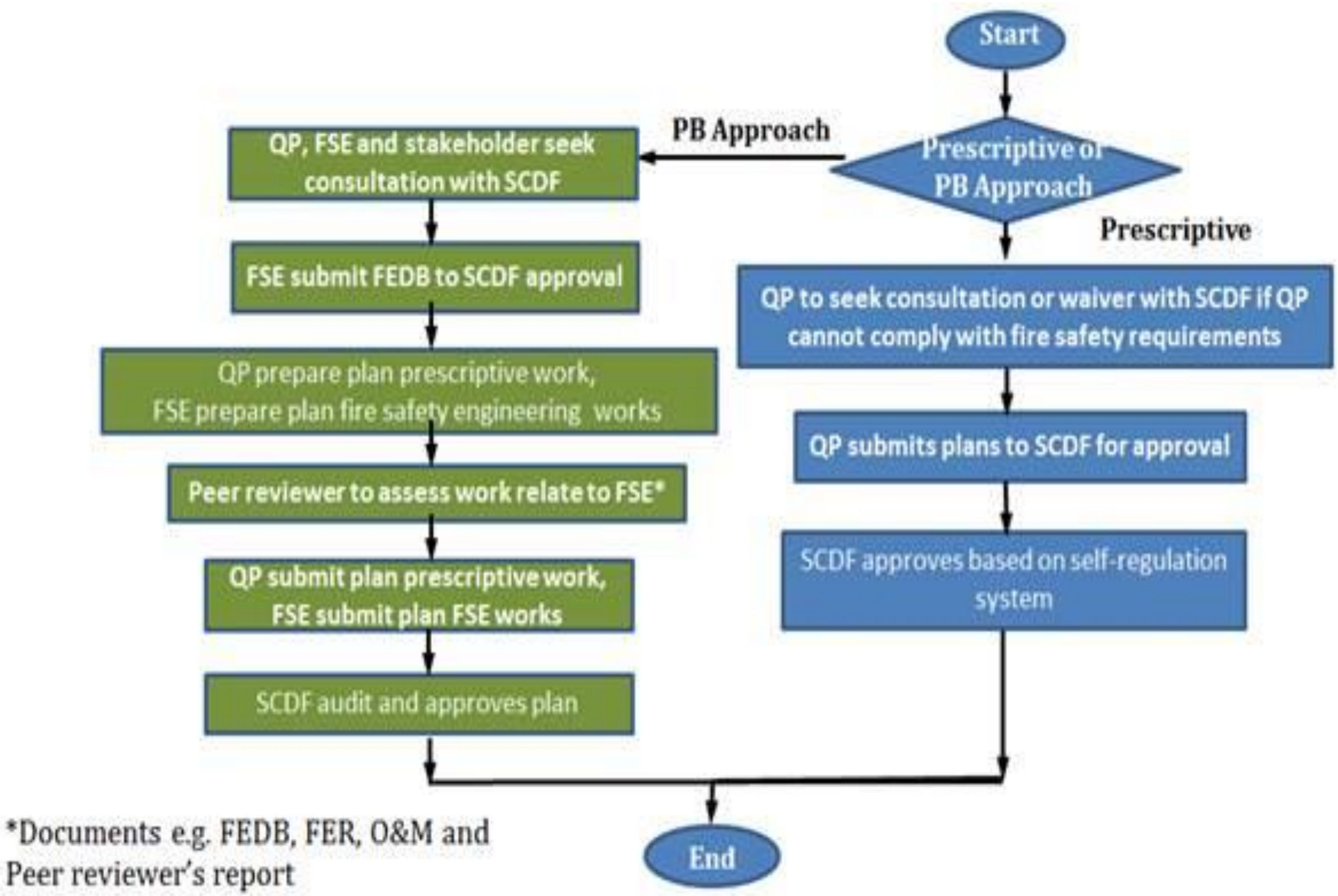
Singapore Fire Authority Submission Process



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Equipment and vehicles

Fire Heat Rate from Trains

Determined by

- Calorific value of combustible materials (including seats, internal linings, carpets, cables etc) plus luggage and other “imported” fire loads
- Ignition source – including accelerant from a possible arson attack
- Rate of fire growth – affected by reaction-to-fire properties of rolling stock materials

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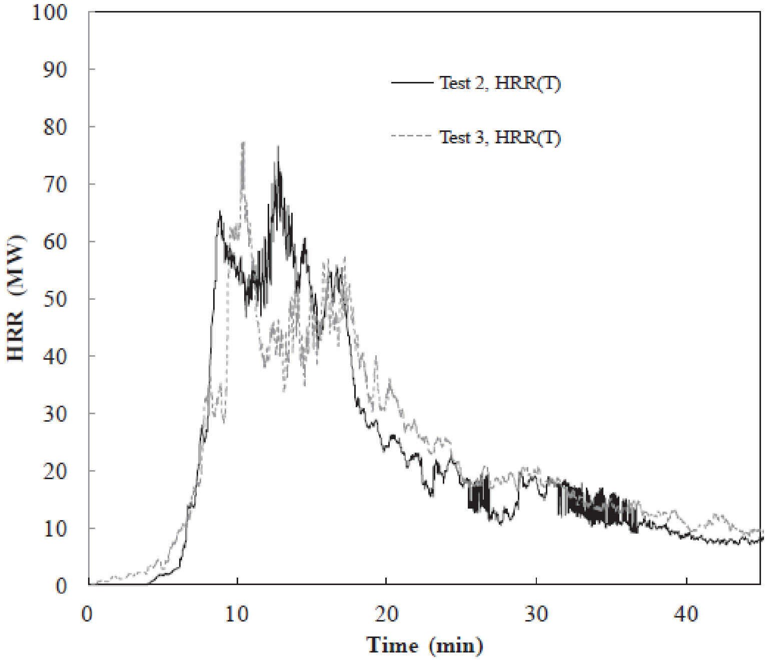
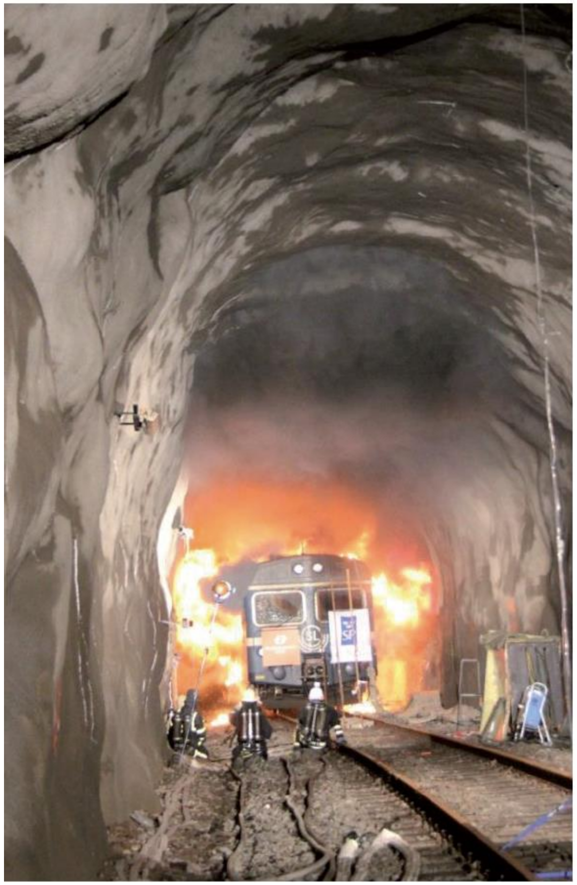
Fire Tests

- METRO project, Sweden (2012)
- Peak 77 MW fire HRR
- Stockholm Public Transport Type X1 carriage
- Built by ASEA in 1967–75, last unit taken out of service in April 2011





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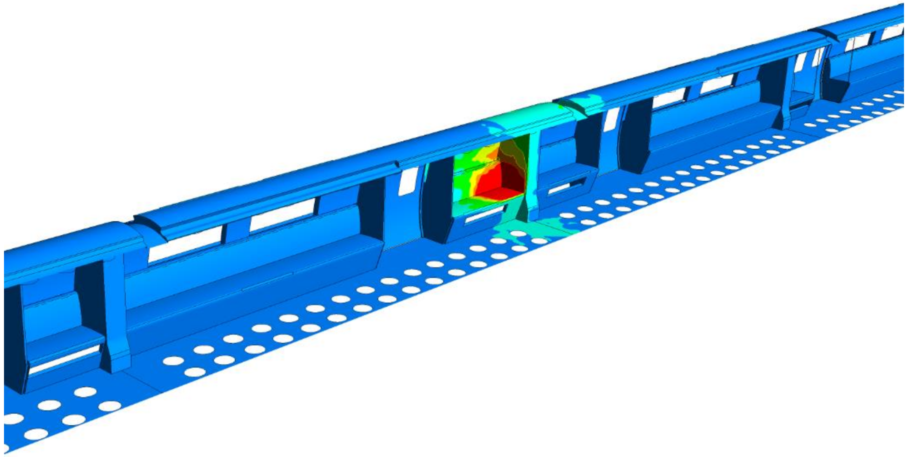
CFD Modelling of In-Train Fire Spread



- Fire spread triggered by radiant and convective heat flux to neighbouring surfaces
- Relies on cone calorimeter test results for reaction-to-fire properties of surfaces
- Similar to reality, can be difficult to sustain combustion – large ignition sources required

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Rolling Stock Fire Standard - Europe

BS EN 45545-2:2013

BSI Standards Publication

Railway applications — Fire protection on railway vehicles

Part 2: Requirements for fire behaviour of materials and components

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European Regulation

L 356/394 EN Official Journal of the European Union 12.12.2014

COMMISSION REGULATION (EU) No 1303/2014

of 18 November 2014

concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the rail system of the European Union

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community [1], and in particular Article 6(1), second subparagraph, thereof,

Underground Railway Ventilation

Tunnel Ventilation Requirements

- Smoke control (*but* consider effect of enhancing fire)
- Air quality (dilution/purging of CO, NOx and particulate matter)
- Visibility
- Temperature
- Humidity

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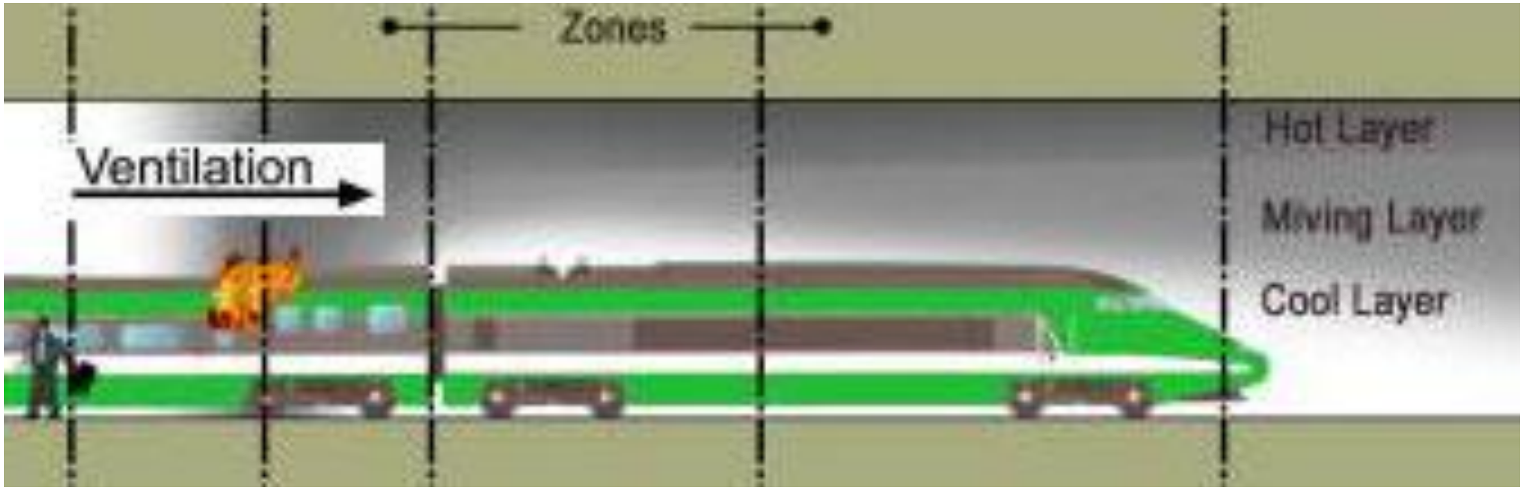
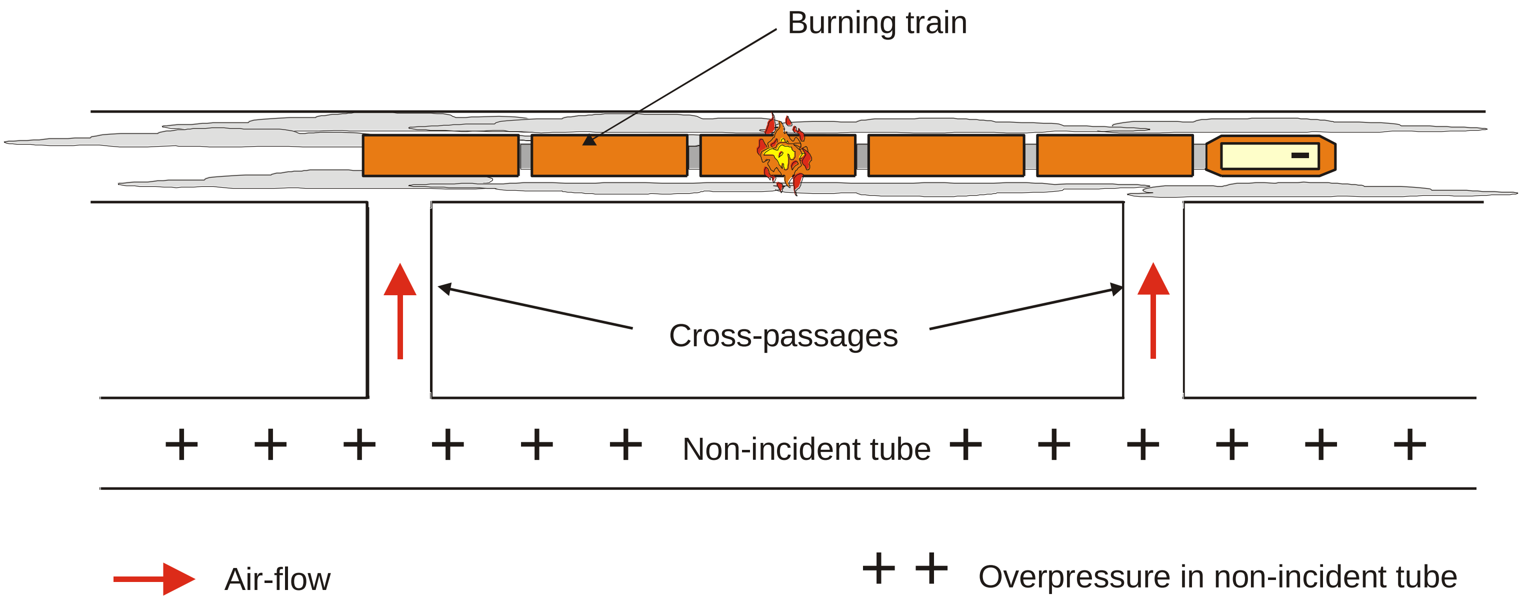
Critical Velocity for Smoke Control



Inertia of oncoming air > Thermal buoyancy of smoke

Smoke Control in Cross-Passages



- Pressurise non-incident tube
- Airflow towards incident tube

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Air Quality – CO & Visibility

TABLE 3 - DESIGN AND THRESHOLD VALUES FOR CO AND VISIBILITY/ EXTINCTION			
Traffic situation	**CO**	**Visibility**	
		Extinction coefficient K	**Transmission s (beam length: 100 m)**
	ppm	**10^{-3} m^{-1}**	**%**
Free flowing peak traffic 50 – 100 km/h	70	5	60
Daily congested traffic, stopped on all lanes	70	7	50
Exceptional congested traffic, stopped on all lanes	100	9	40
Planned maintenance work in a tunnel under traffic*	20	3	75
Threshold values for closing the tunnel**	200	12	30

* National workplace guidelines have to be considered

** The values given here are for tunnel operation only and not for determining ventilation capacities.

Air Quality – NO_x

- $NO_x = NO + NO_2$
- Health considerations dominated by NO_2
- World Road Association guidance: 1 ppm tunnel-average value at any one time for NO_2

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Temperature

- Train congestion: keep intake temperature for air-conditioning units below 45°C
- Tunnel fit-out: keep temperature below (ambient + 10 °C)
- In fire emergency: keep temperatures low enough to ensure tenability

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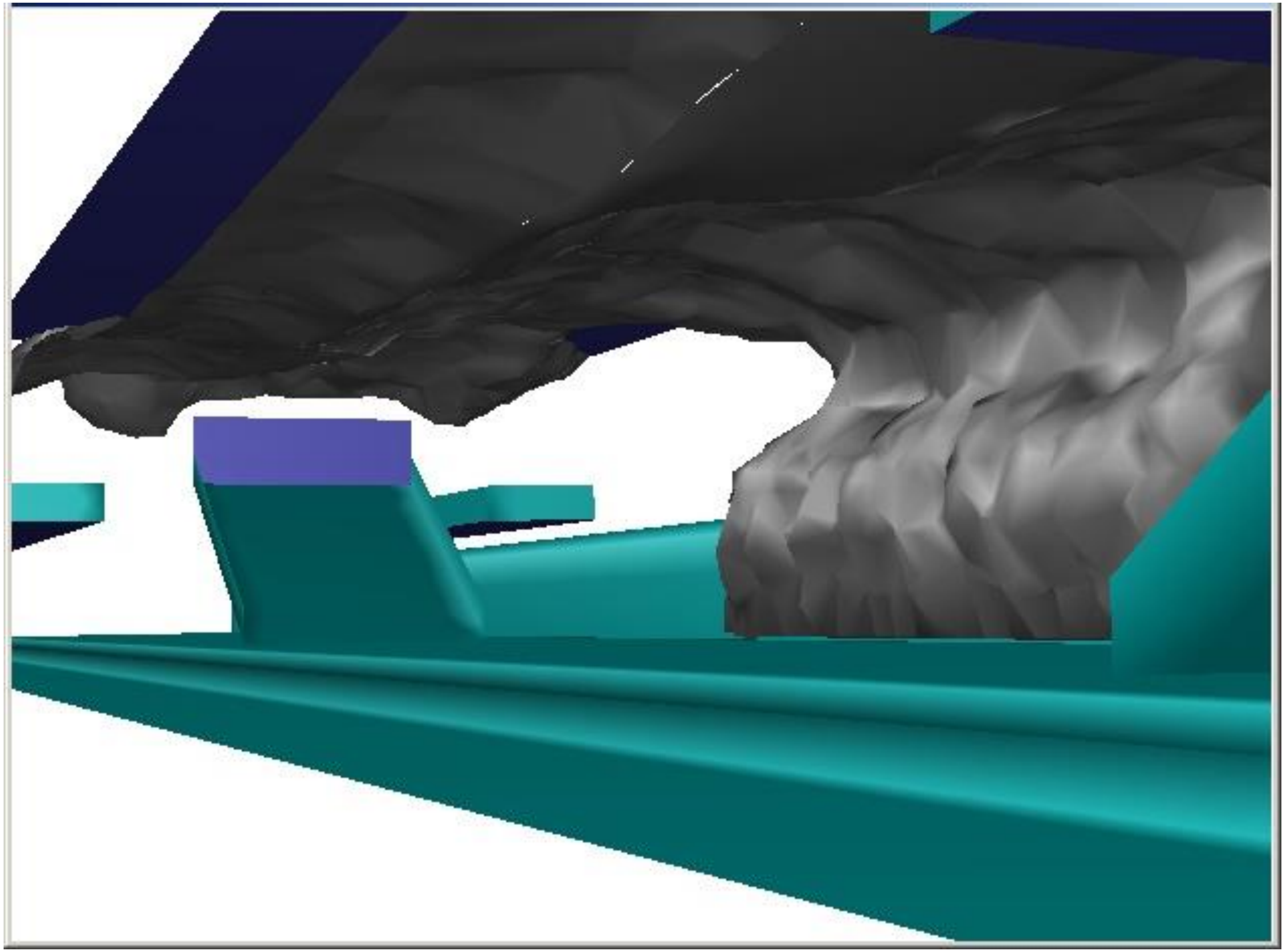
Station Smoke Ventilation



Smoke Purging

- Minimum of 9 air changes per hour
- Activated automatically by station fire alarm system
- Manual activation from fire command centre
- Exhaust fan to operate at 250°C for two hours

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Station – Tunnel Smoke Separation

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Metro Tunnel Ventilation Normal Design Criteria

To ensure A/C system can continue to operate normally:

- Normal operation: T < 40°C
- Congested operation: T < 45°C
- Online stabling start-up: T < 45°C

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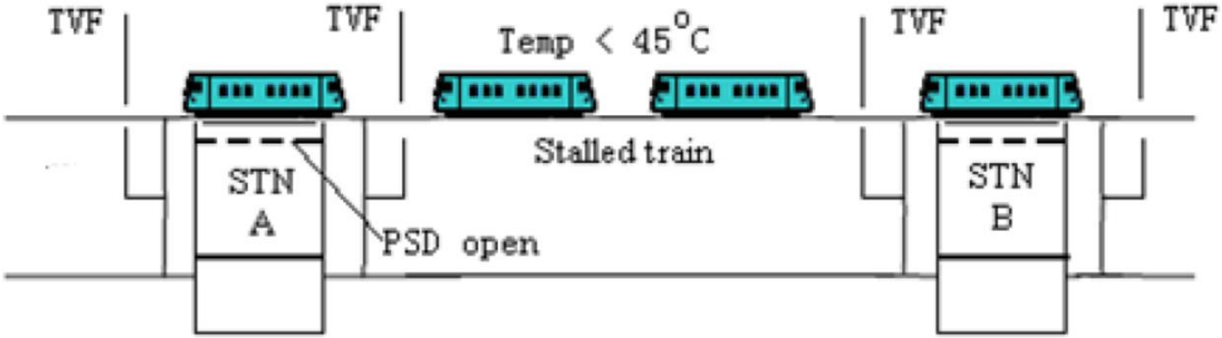
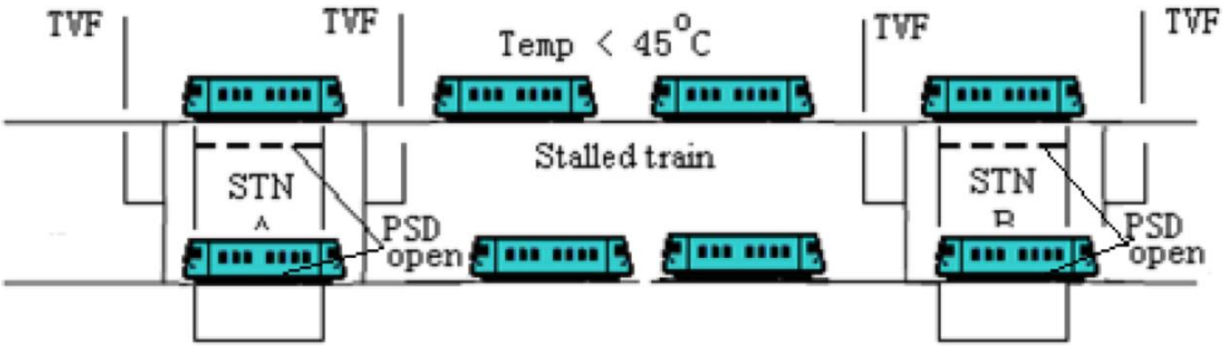
Train Congestion

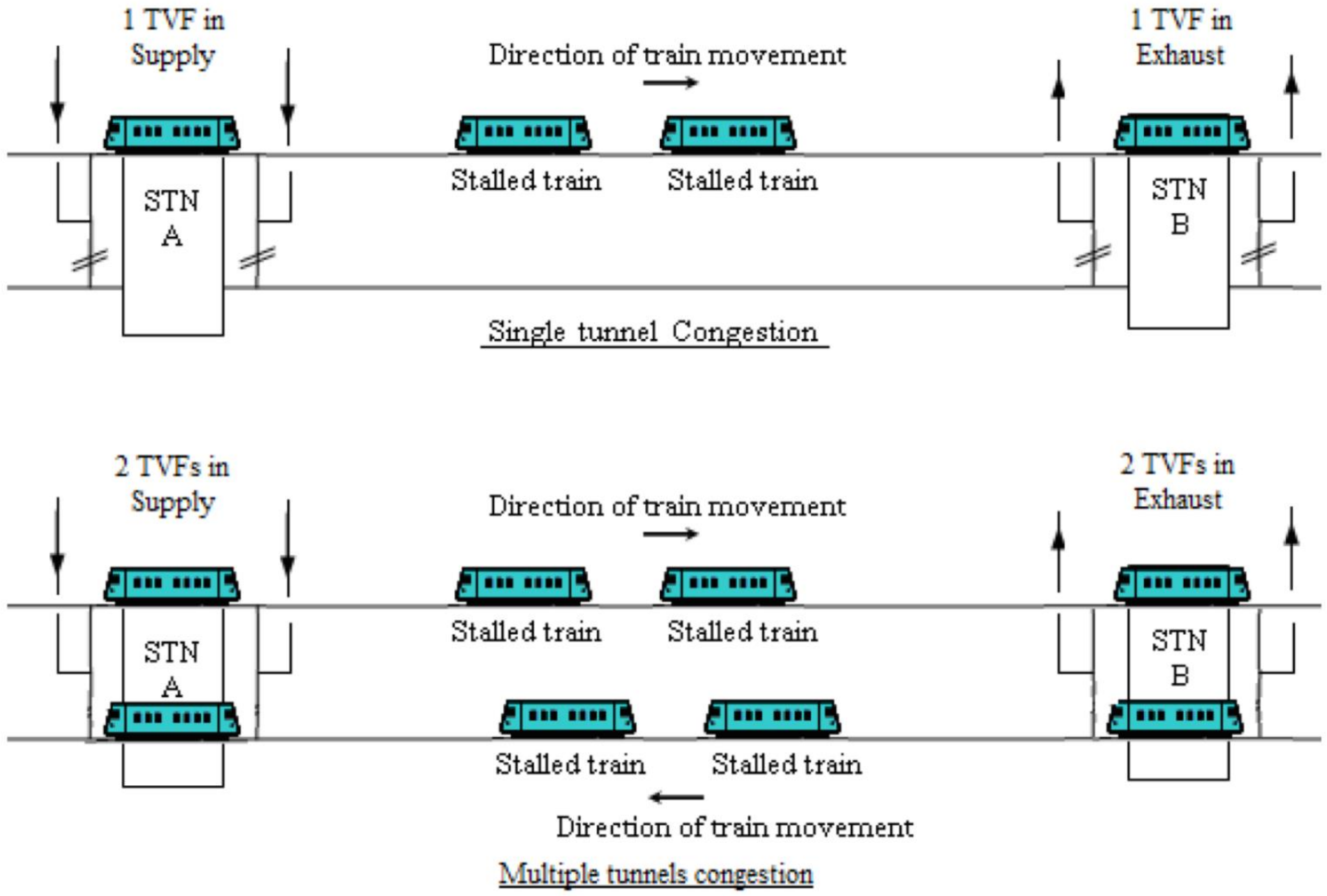


Single Tunnel Congestion



Multiple Tunnel Congestion

Congestion - Ventilation Arrangements



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Metro Tunnel Ventilation Emergency Design Criteria

8-20 MW fire heat release rate typically selected.

- Tenable environment along egress path
- Eliminate smoke back-layering (critical velocity)

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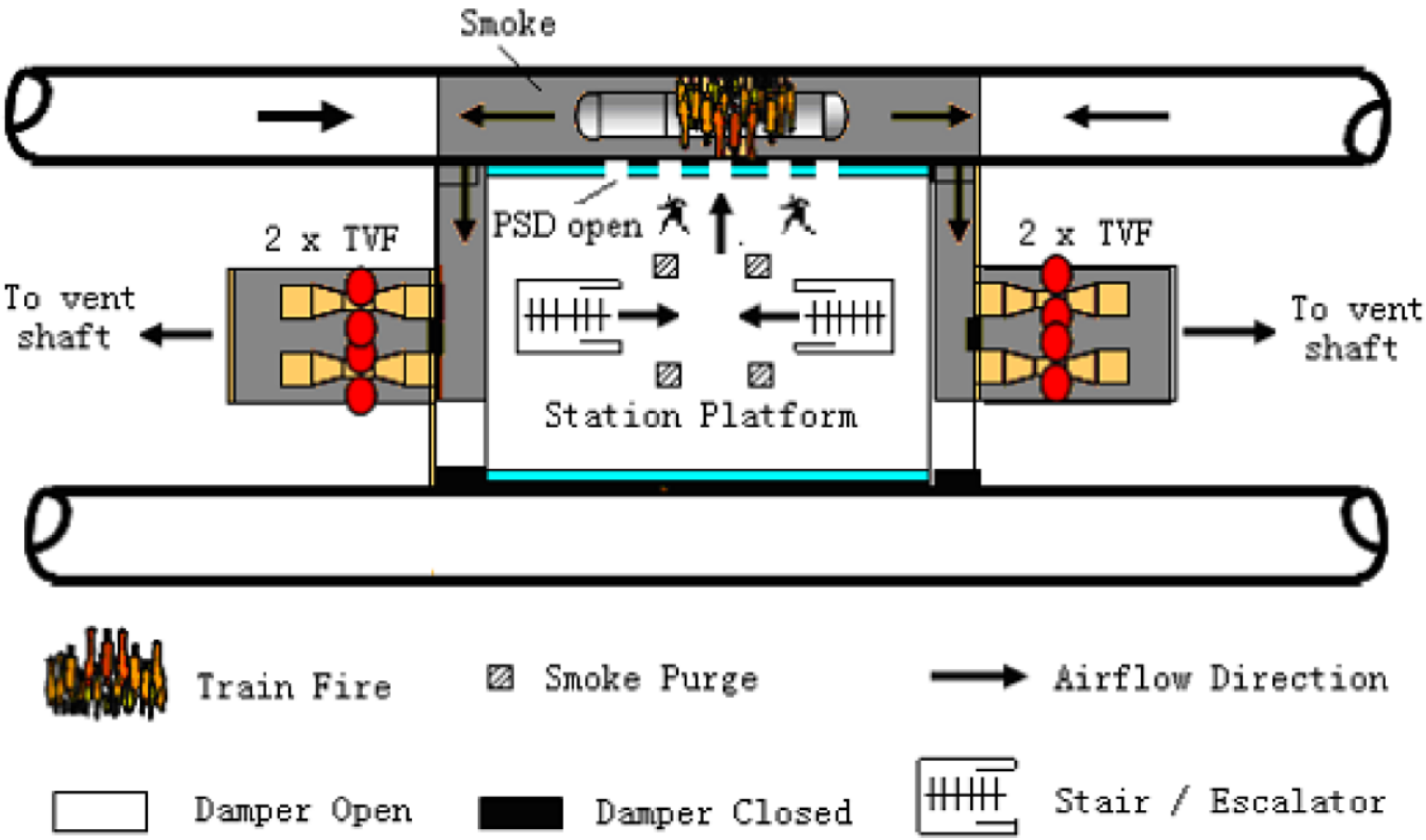
Train on Fire in a Station



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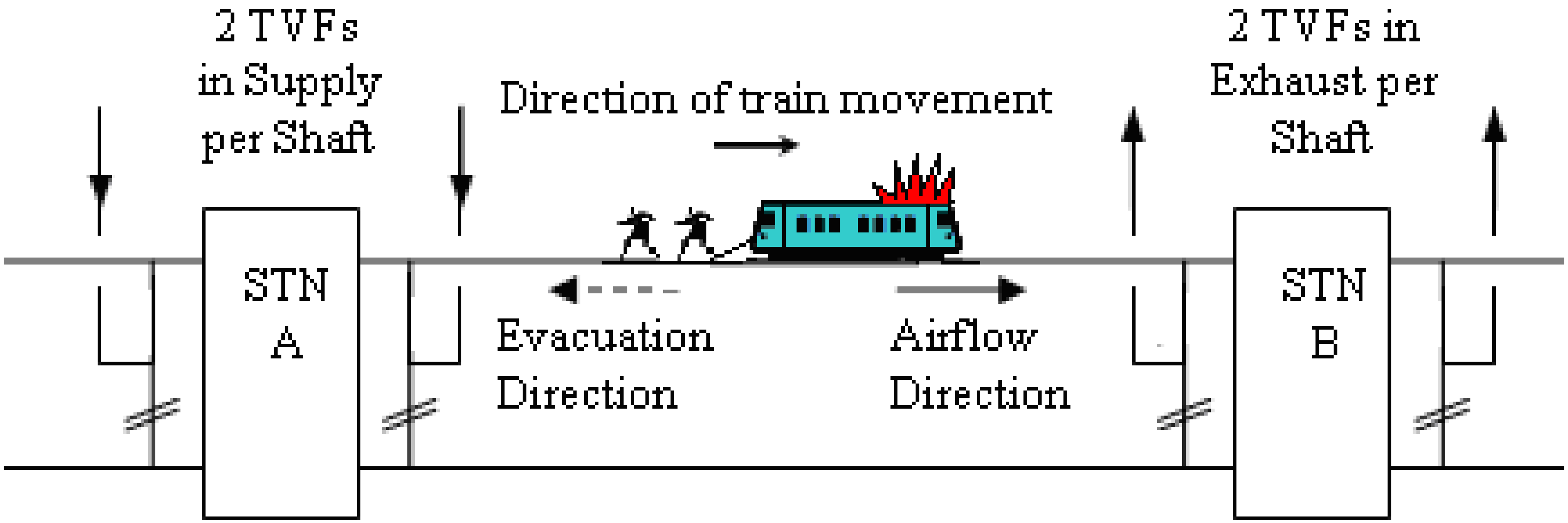
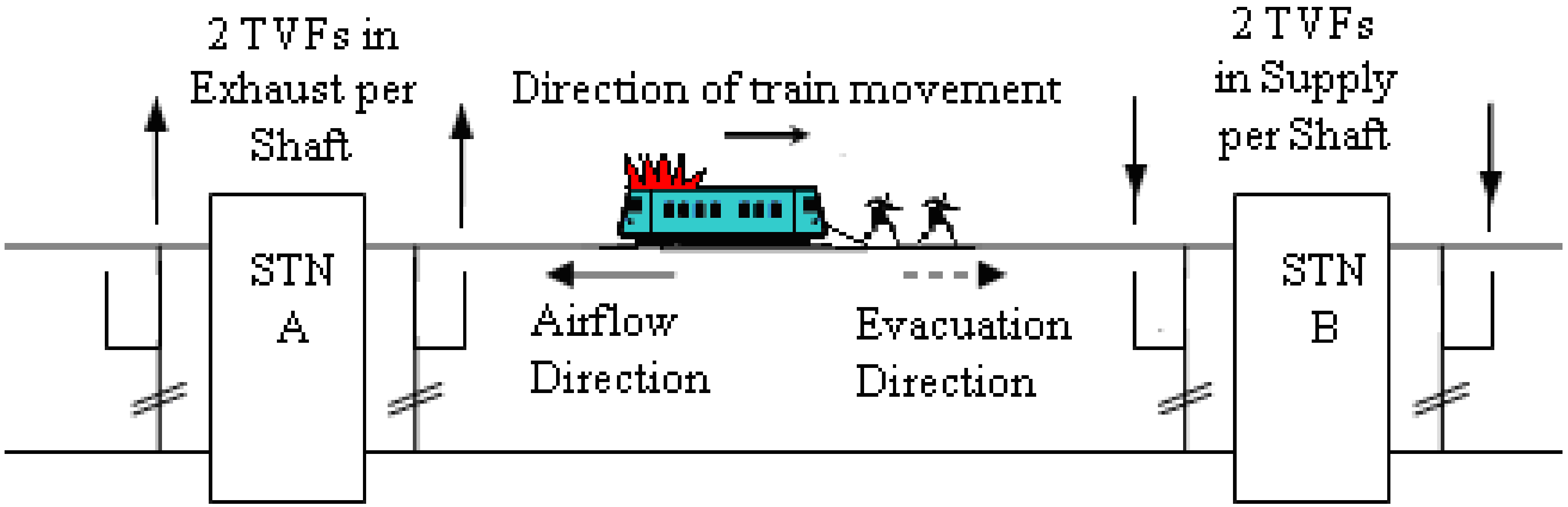
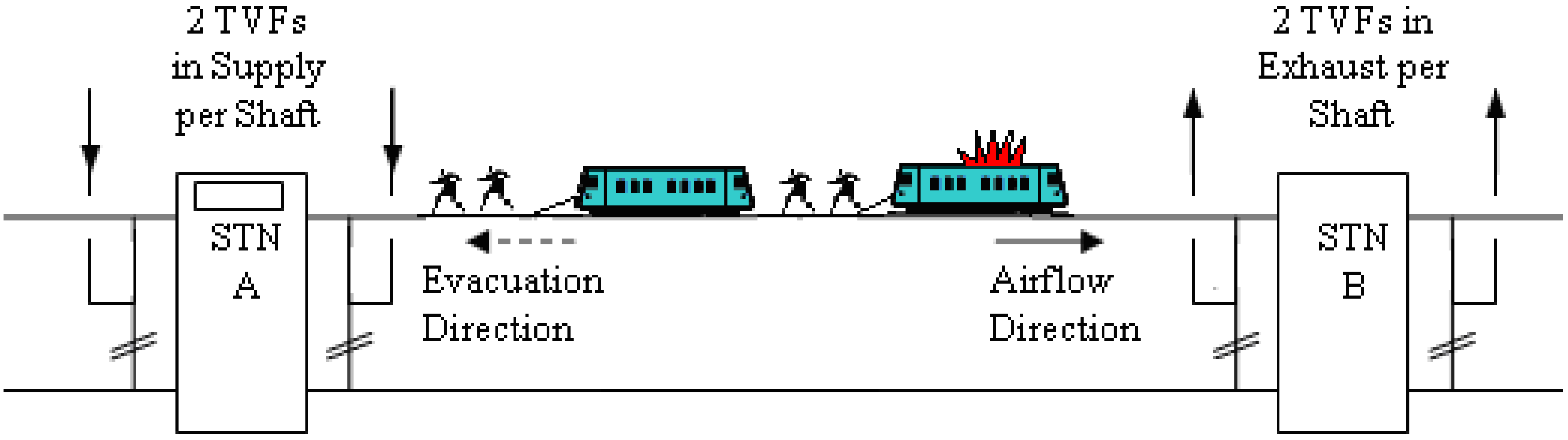
Train Fire in a Tunnel



Train Fire in a Tunnel (Reverse)



Train Fire, with Non-Incident Train



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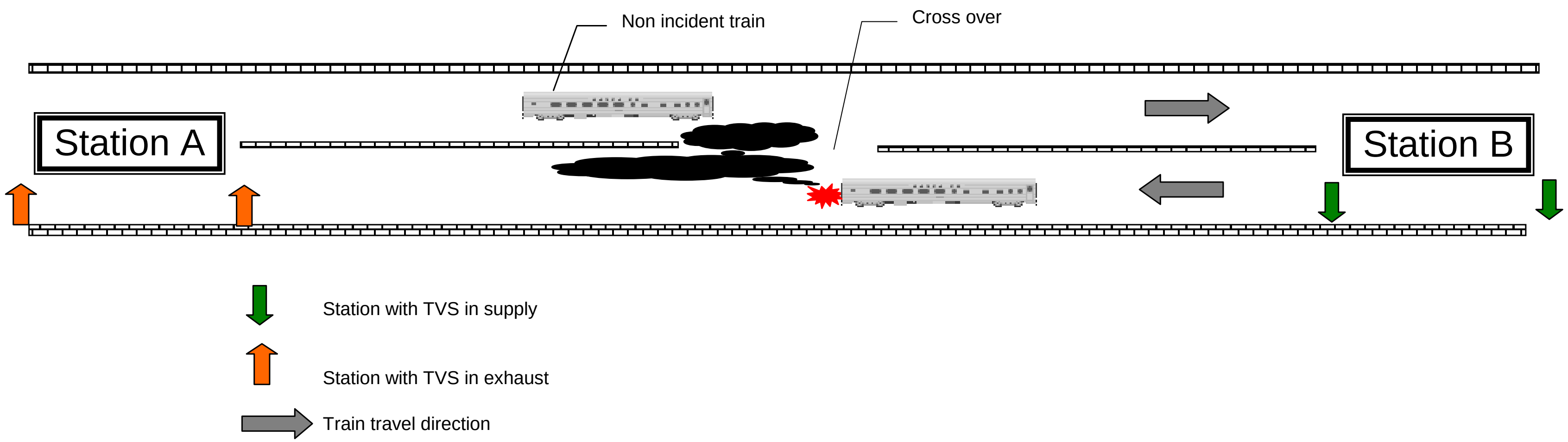
Train Fire in Vicinity of Cross-Over



- Critical velocity for smoke control may not be achieved.
- Tenable conditions to be maintained along escape paths and for non-incident train.

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Ventilation Redundancy

- Failure of one ventilation component (e.g. fan or damper) should not lead to failure of the system
- Design check as to which component is most critical

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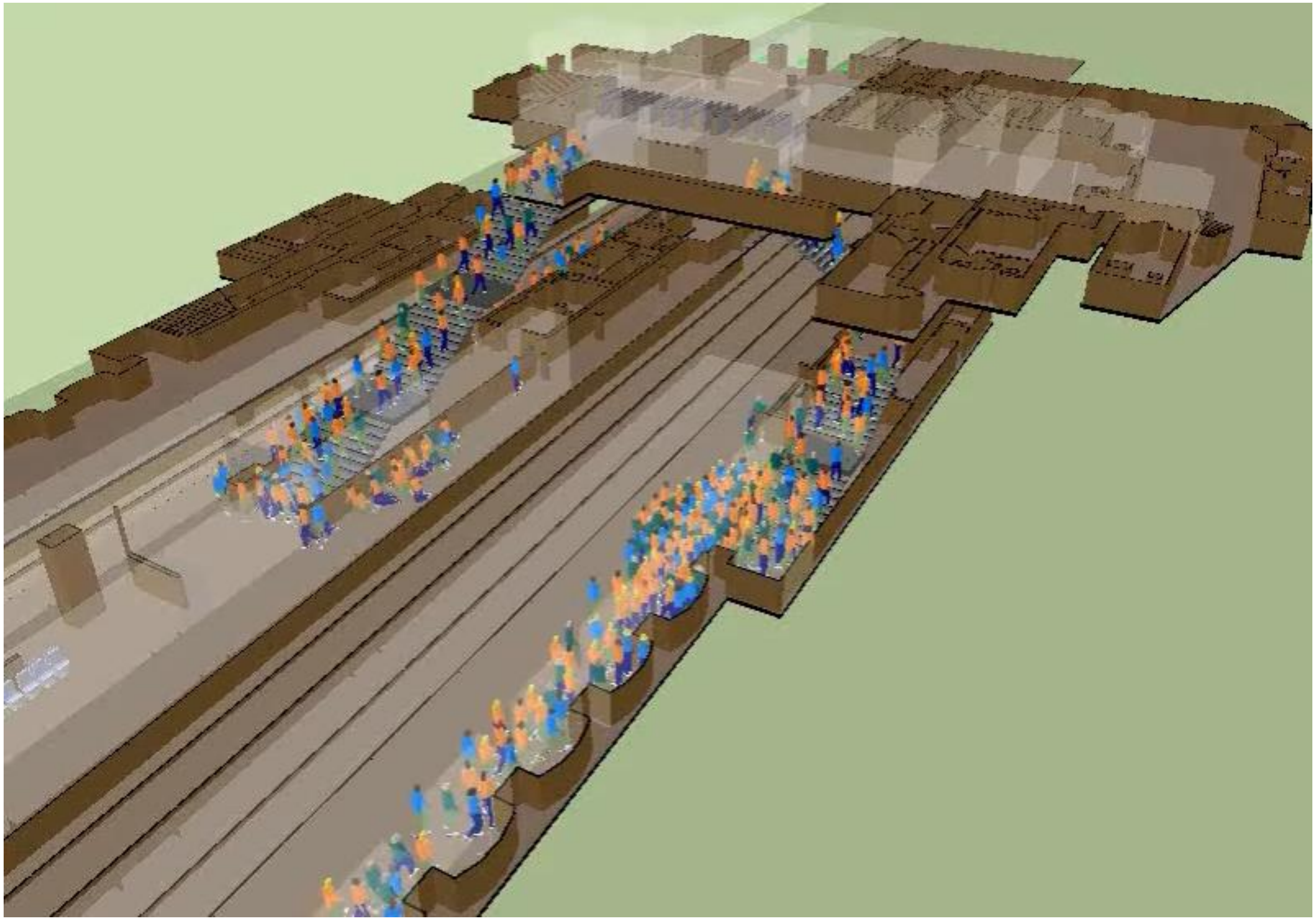
Fire evacuation strategies

Station Evacuation



Evacuation Strategy

- Train on fire should continue travelling to the next station if possible:
  - Evacuation via open platform screen doors and out of the station via escalators, staircases and exits
  - Ventilation system to hold back smoke from entering the platform and concourse
- Alternatively:
  - Evacuation along tunnels to adjacent station
  - Ventilation to provide tenable conditions along evacuation route

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Key Design Goals

- Clearance of platform: 4 minutes
- Clearance of station (or to "point of safety"): 6 minutes

Evacuation Scenarios

- Train on fire – key fire scenario
- Station on fire

Evacuation Load – Train on Fire

Number of passengers to be evacuated =

- Crush-loaded train +
- Peak link load x 2 train headways +
- Train load from adjoining platform +
- Link load for one train headway

Consider:

- AM and PM rush hours
- Each platform as "peak" direction
- Number of staff to be evacuated

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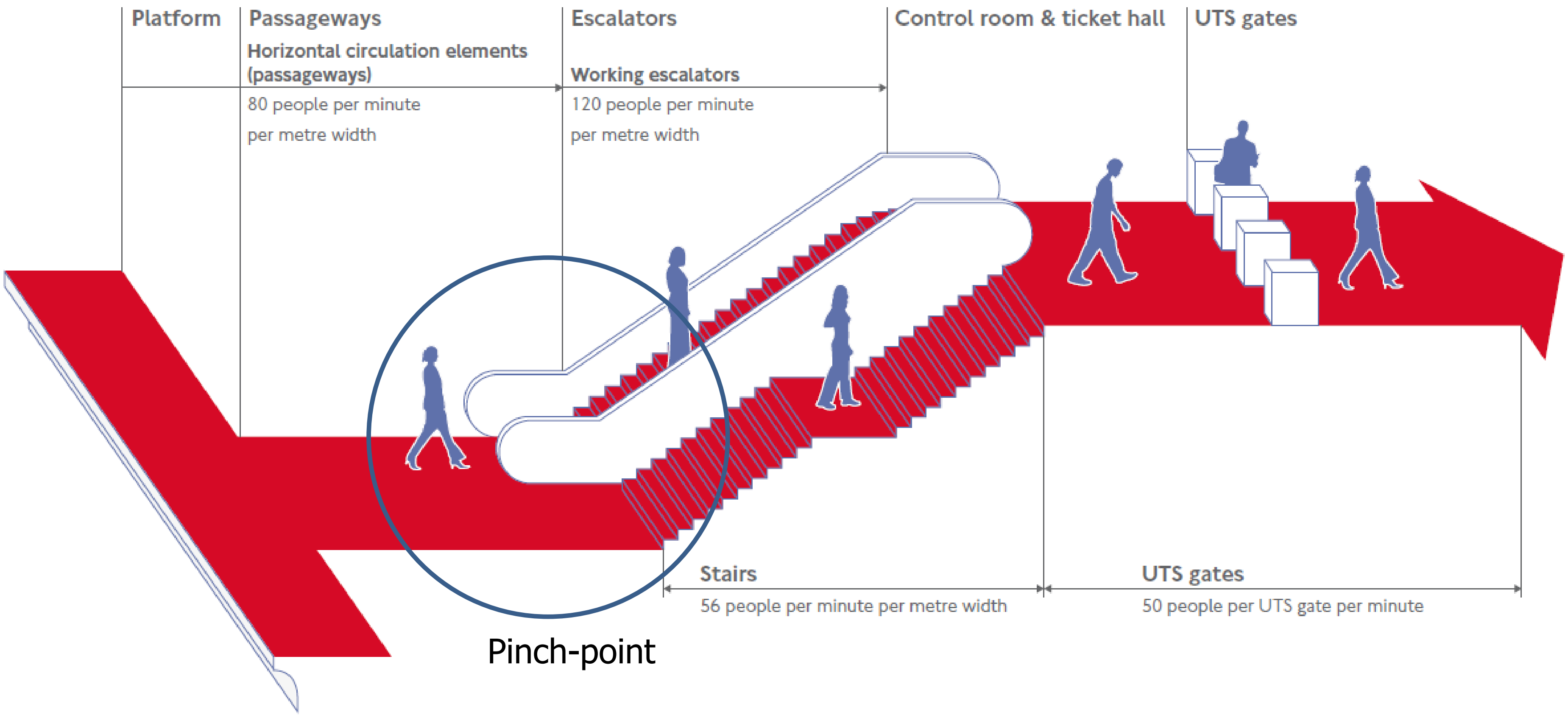
Evacuation Capacities



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Evacuation Time Calculation

- Evacuation time = Passenger load / evacuation capacity
- Sum times over all station elements (platform, escalator, staircase, ticket hall, gateline, concourse)
- Evacuation time = platform clearance time + pinch-point clearance time + free-flow walk time

Performance-Based Fire Safety Engineering

- ASET = Available safe egress time *(determined by smoke movement)*
- RSET = Required safe egress time (determined by evacuation routes)
- Need to ensure that ASET > RSET

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Safety Factors for Performance-Based Fire Safety Engineering

Singapore Fire Safety Engineering Guideline (2015):

- Base case ≥ 2 Safety Factor (ASET/RSET)
- Sensitivity analysis ≥ 1.2 Safety Factor (ASET/RSET)

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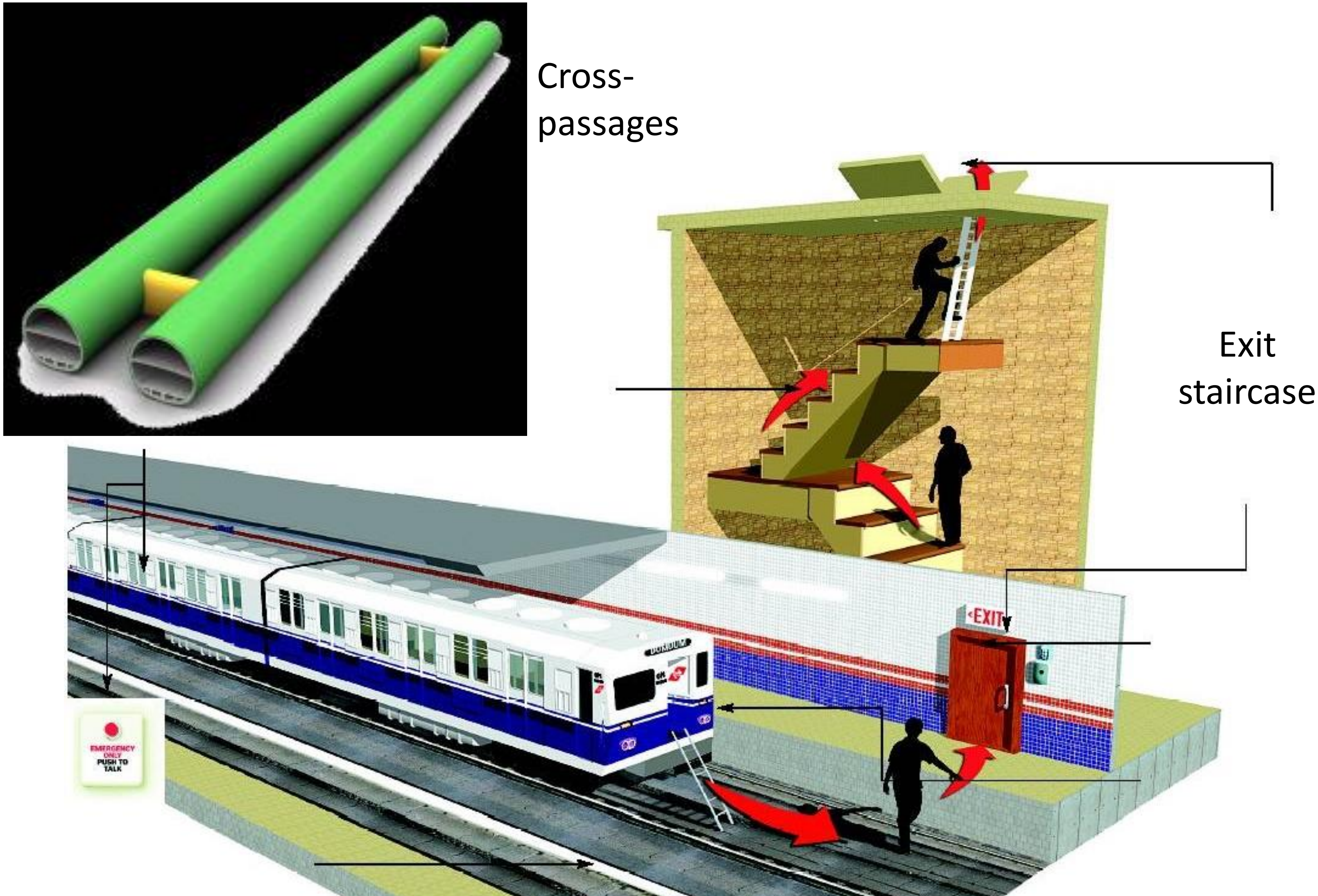
Metro Tunnel Evacuation & Fire-Fighting Access



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Maximum Allowable Travel Distances (Singapore)

- Single running tunnel: 760m between exit staircases; <u>or</u>
- Dual running tunnels with 2-hour fire resistance between tunnels:
  - 500m between cross-passages & exit staircase or platform
  - 250m between cross-passages; 500m between cross-passages straddling cross-over

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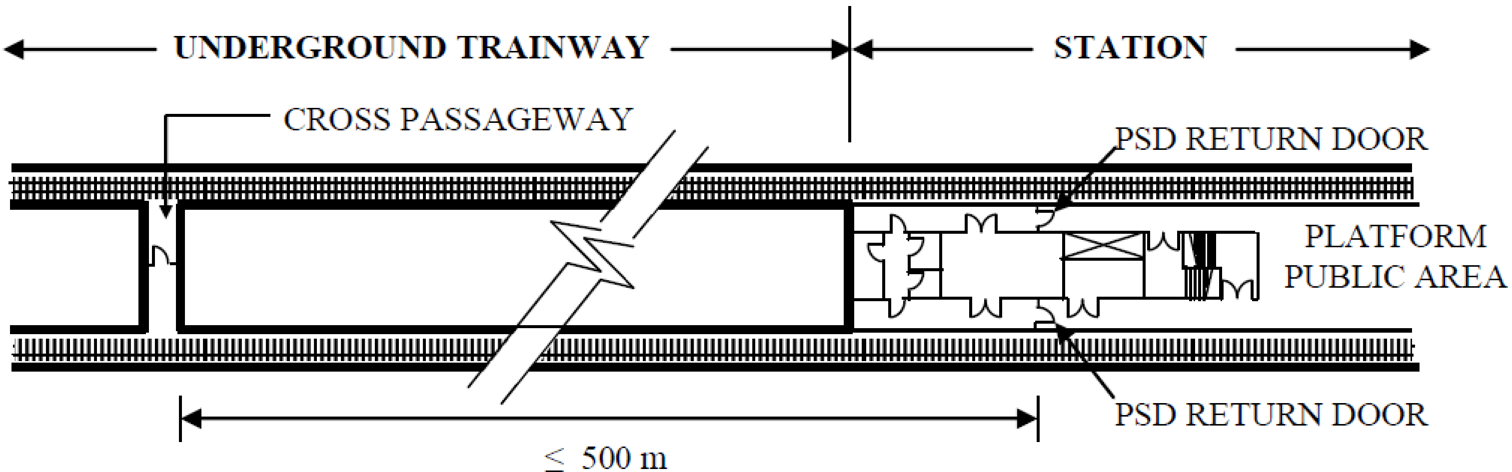
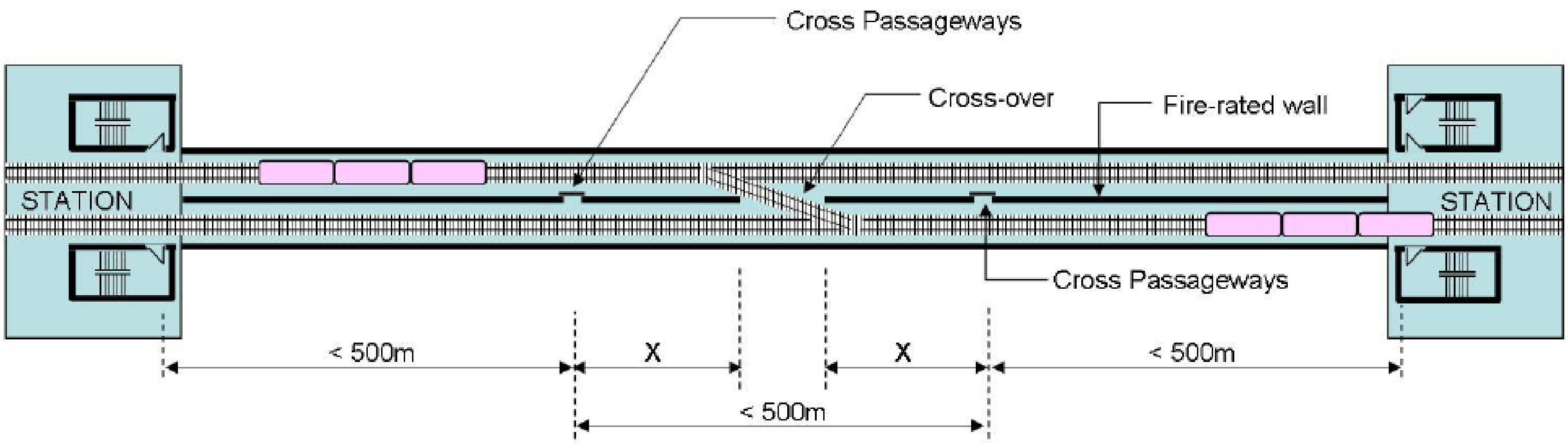
Maximum Allowable Travel Distances – (Singapore)





Q & A Session

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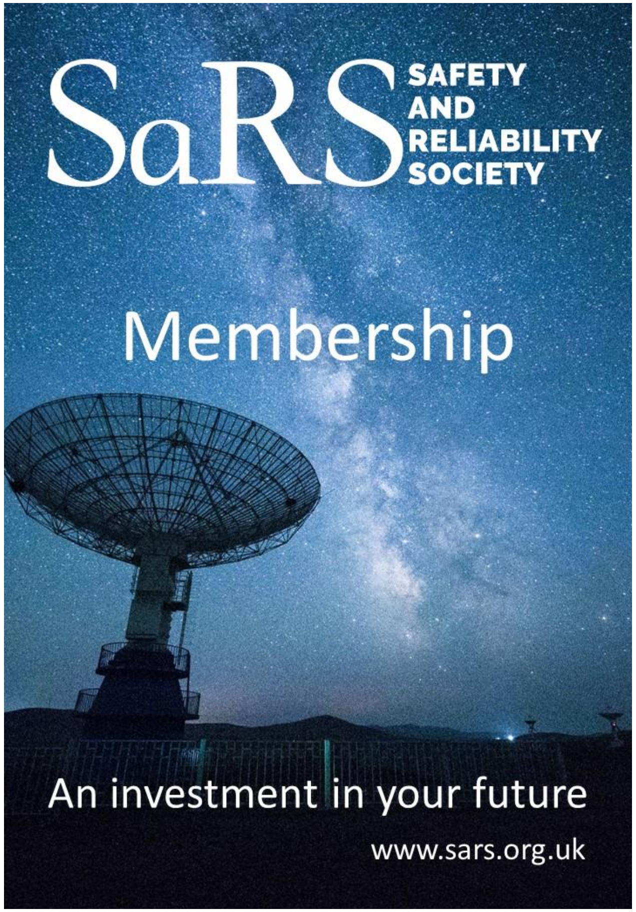

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