A COMPARATIVE STUDY OF FIRE SAFETY PROVISIONS EFFECTING EVACUATION SAFETY IN A METRO TUNNEL

Andrew Purchase
Karl Fridolf
Daniel Rosberg

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Background

→ **Metro tunnels**

- Geometrically simple – a tube / box
- Aerodynamically complex – train movements, vent, winds, etc.

Source: https://upload.wikimedia.org/wikipedia/commons/e/e9/Stockholm_metrosystem_map.svg
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→ **Fires on trains in rail tunnels**

- Continue to the next station
- Not always possible to reach station
- Unlikely event, but generally credible enough to design for a train fire in a tunnel

Source: https://en.wikipedia.org/wiki/Tunnel#/media/File:A_crossover_on_the_south_side_of_Zhongxiao_Xinsheng_Station.JPG
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What are *'typical'* rail tunnel evacuation provisions?

- **Survey of tunnels around the world**
- **Some provisions are typical:**
  - Walkways with emergency lighting to assist with evacuation
  - Regular exits once tunnels are over a certain length
- **Some provisions vary:**
  - Longitudinal ventilation for smoke control
  - Walkway width: 0.7m – 1.5m
  - Walkway elevation: track or train floor level
  - Spacing of exits: 240m to >500m

Source: Author

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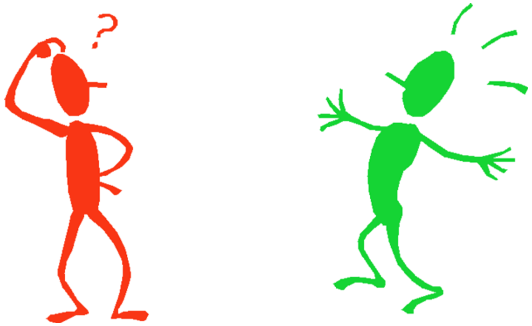
Why the variation in typical provisions?

→ **Many reasons, for example:**

- Standards for a particular jurisdiction
- Each system has it's own nuances
- Difference in opinion / perceptions of safety
- Driven by performance based design
- Maintaining a strategy within a wider system
- Stakeholder requirements, etc. etc.

→ **But, can be misleading / confusing when a provision is viewed in isolation**

- Question: "*Why do / don't we have this provision?*"
- Other disciplines may not appreciate the implications of a change



Purpose and use

→ ***What are you trying to achieve?***

Investigate a range of tunnel evacuation design configurations and the impact that these have on occupant safety. Focus on metro tunnels.

→ ***How do you do this?***

CFD and evacuation modelling with results compared on the basis of visibility and the accumulated FED regarding asphyxiates.

→ ***What are the limitations?***

Applies only to a specific set of inputs, assumptions and engineering simplifications.

→ ***How can I use this?***

Comparative set of results that can be used by fire safety designers when developing their own options for further assessment.

Source: Author

Source: WSP Stock Photo

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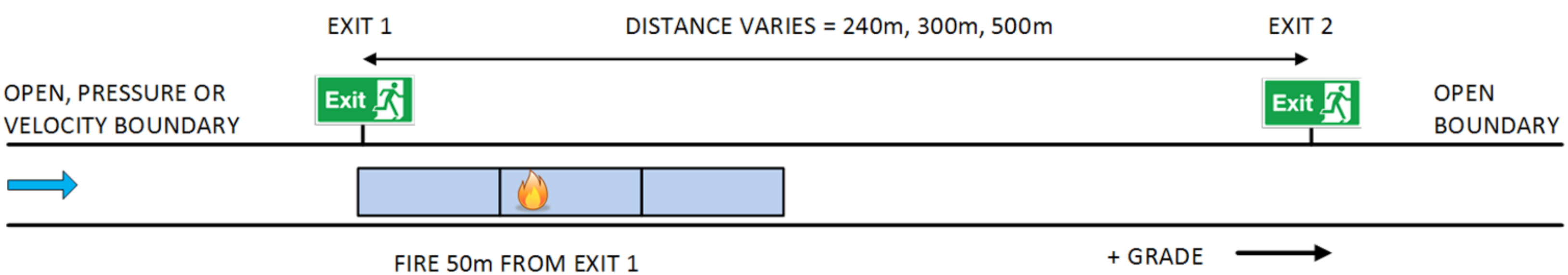
Scenario selection

→ **12 CFD simulations, 144 evacuation scenarios**

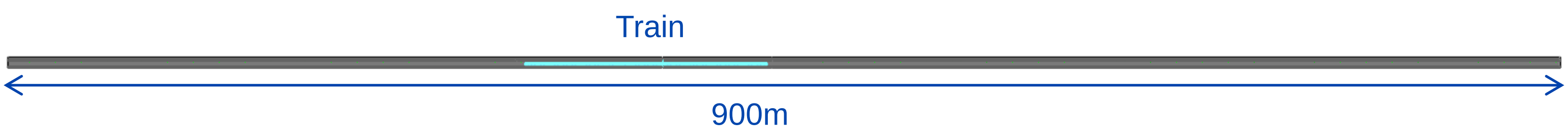
CFD Scenario Parameters				
Fire location in train	-	Front	*Middle*	Back
Fire size	MW	2	*5*	>10
Fire growth rate	kW/s^2	0.003	*0.012*	0.047
Tunnel grade	%	-4	*0*	*+4*
Tunnel velocity	-	*No velocity*	*2m/s wind*†	*Critical velocity*
Tunnel area	m^2	*22*	*28*	45‡
Evacuation Scenario Parameters				
Walkway width	m	<0.8	*0.8*	*1.2*
Pre-movement ◇	s	120	*240*	360
Occupant load	p	600	*900*	1200
Exit separation	m	*240*	*300*	*500*
Walkway elevation	-	*Track*	Semi	*Elevated*

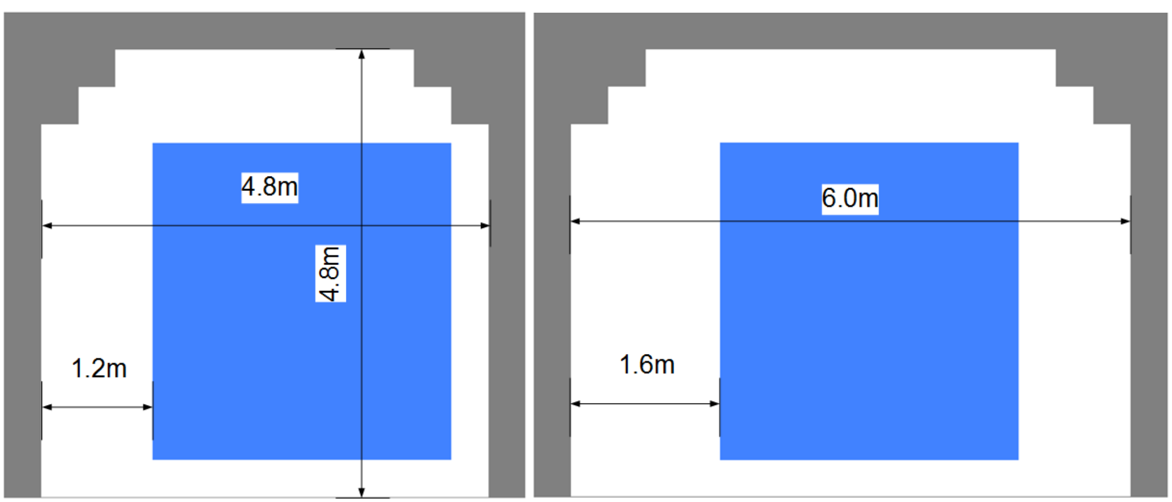
† Modeled as a pressure boundary ‡ Double track geometry
◇ Agents in the fire car, other agents have a pre-movement time of +120s

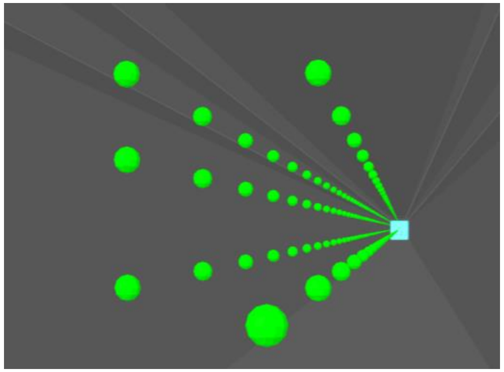


CFD modelling

- FDS Version 6
- 900m long tunnel allows for 140m long train and 500m(+) exits
- Two tunnel cross-sections: 22m^2 and 28m^2 free area
- Devices for tenability assessment – Visibility, temperature, etc.
- Visibility results interpreted as space (X) vs time (T) figures
- Snapshot of results in following slides



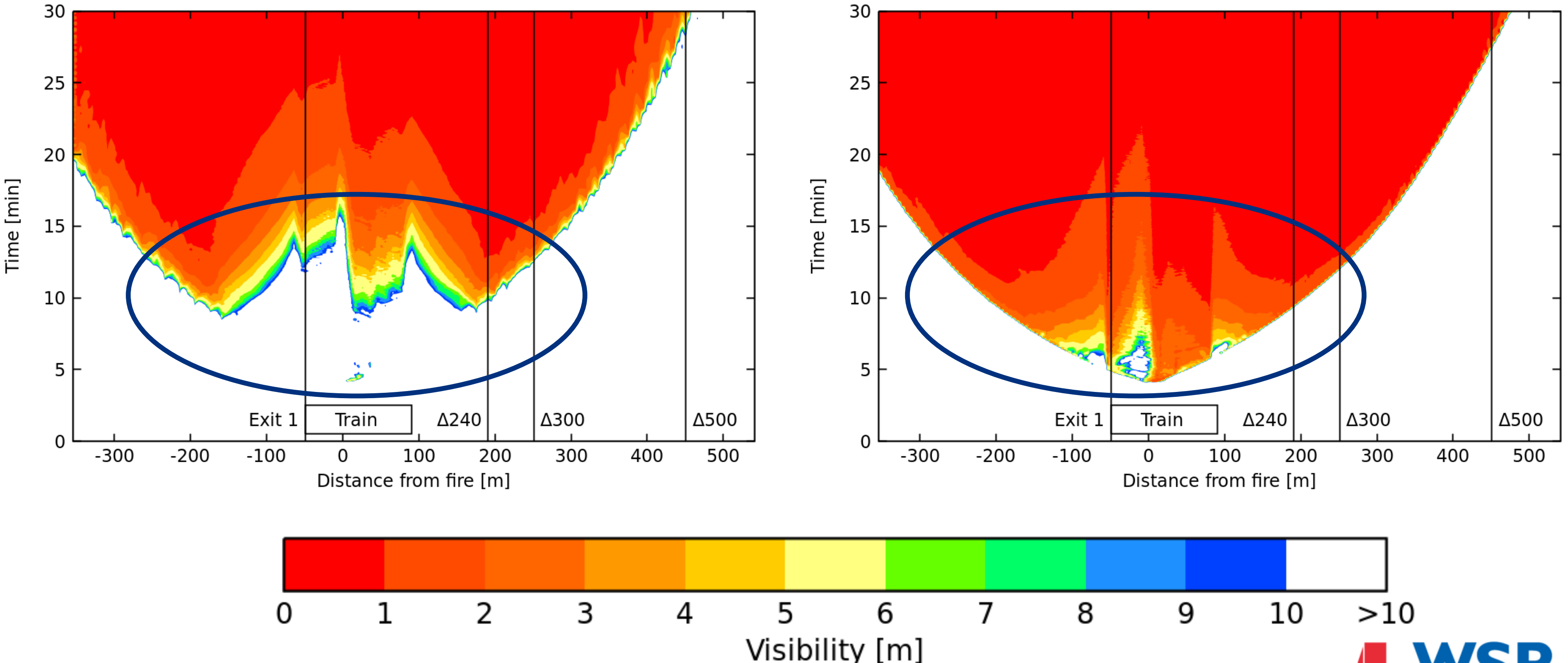




Visibility – walkway elevation

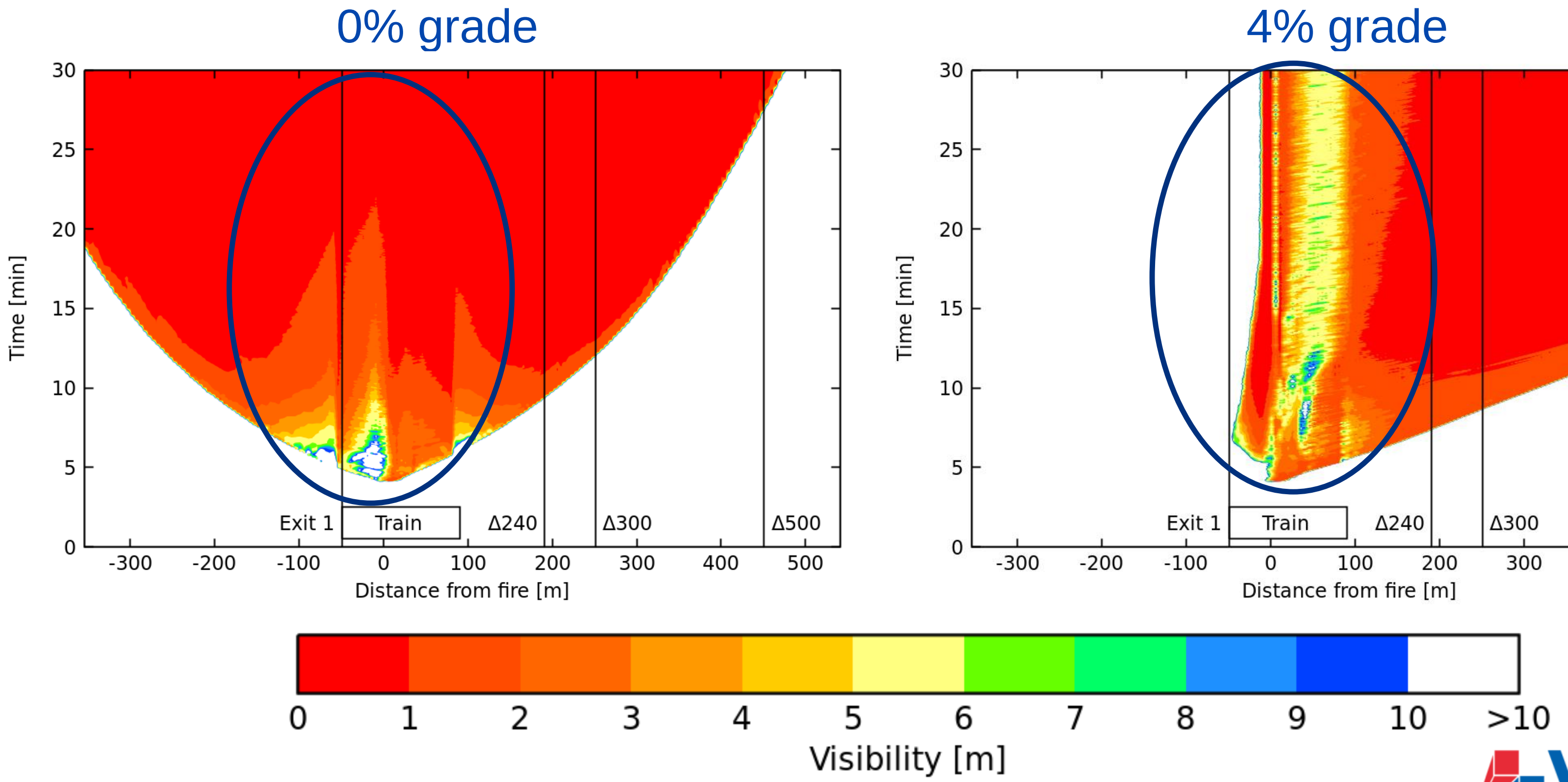
→ **22m² cross-sectional area, still air, 0% grade tunnel**

Track-level walkway — Elevated walkway



Visibility – variation in tunnel grade

→ **22m² cross sectional area, still air, elevated walkway**

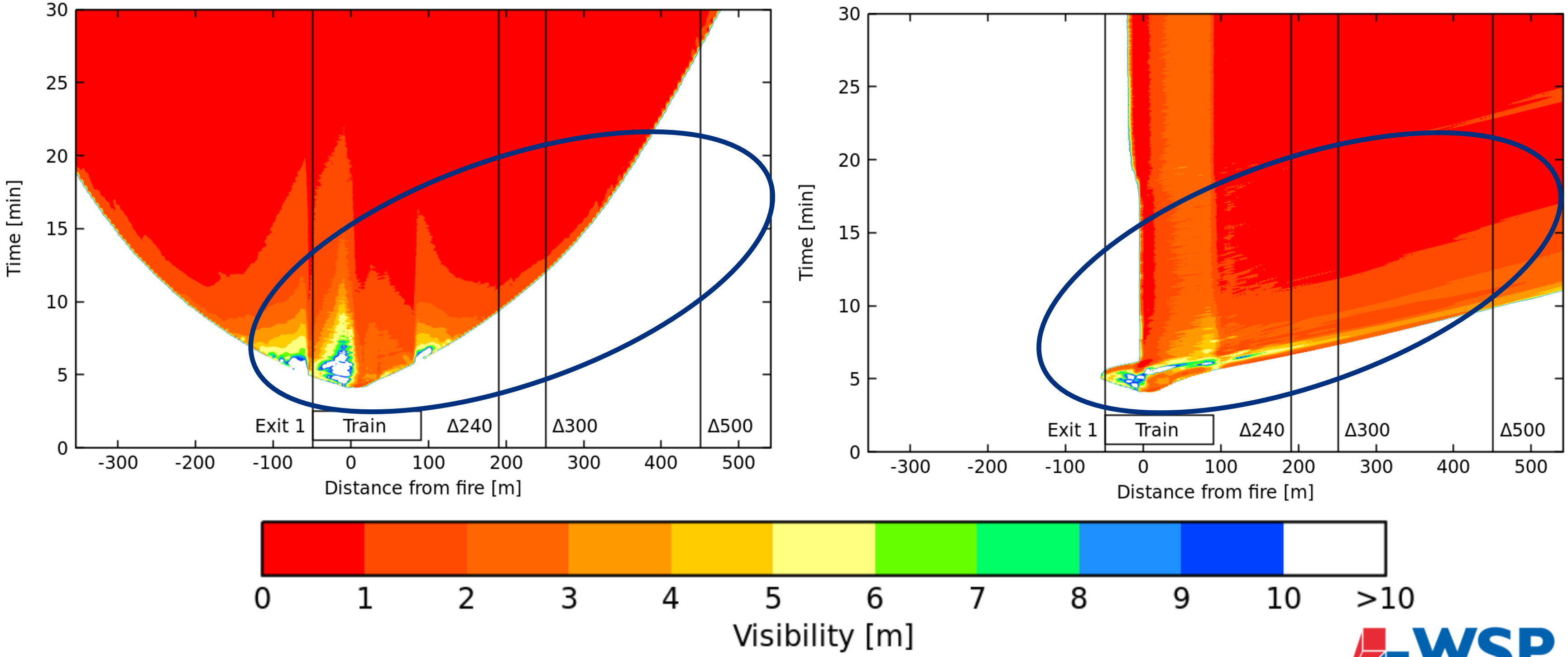


Visibility – longitudinal smoke control

→ **22m² cross sectional area, 0% grade, elevated walkway**

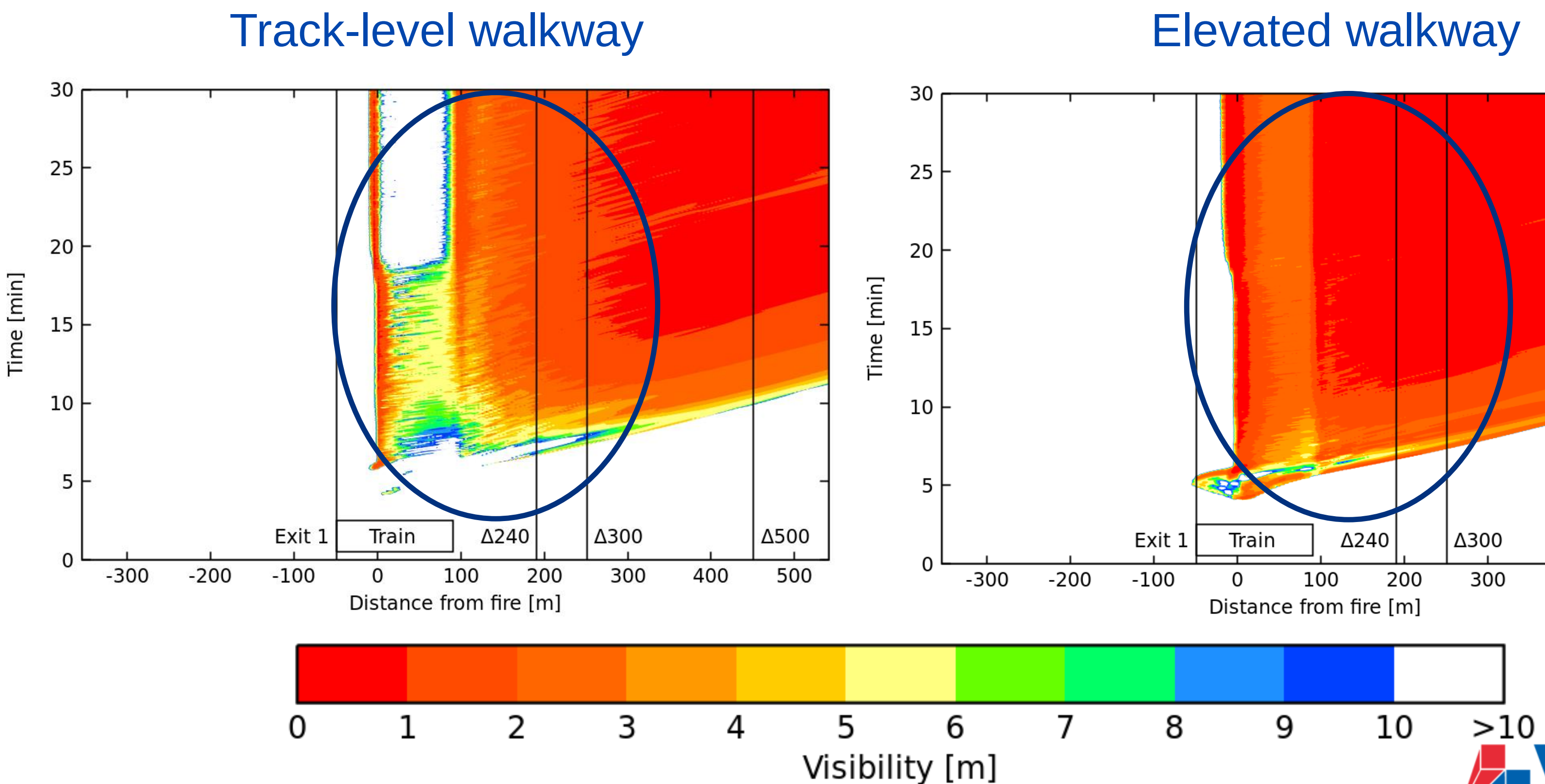
Still air (no smoke control)

Longitudinal smoke control



Visibility – walkway elevation, longitudinal smoke control

→ **22m² cross sectional area, 0% grade**



Evacuation modelling

- **1-D evacuation model**
  - Purpose-built for rail tunnel evacuation
  - Developed in Perl, allows for easy scripting
  - Allows reduction in walking speed with reduced visibility
- **Flow rate along walkway (Lundström et al.)**

$$Flow\ rate\ of\ people\ [p/s] = 1.27 \cdot walkway\ width[m] + 0.07$$

- **Flow rate along walkway with train (BBRAD)**

$$Flow\ rate\ of\ people\ [p/s] = 1.2 \cdot walkway\ width[m]$$

- **Walking speed in smoke (Fridolf et al.), x = extinction coefficient**

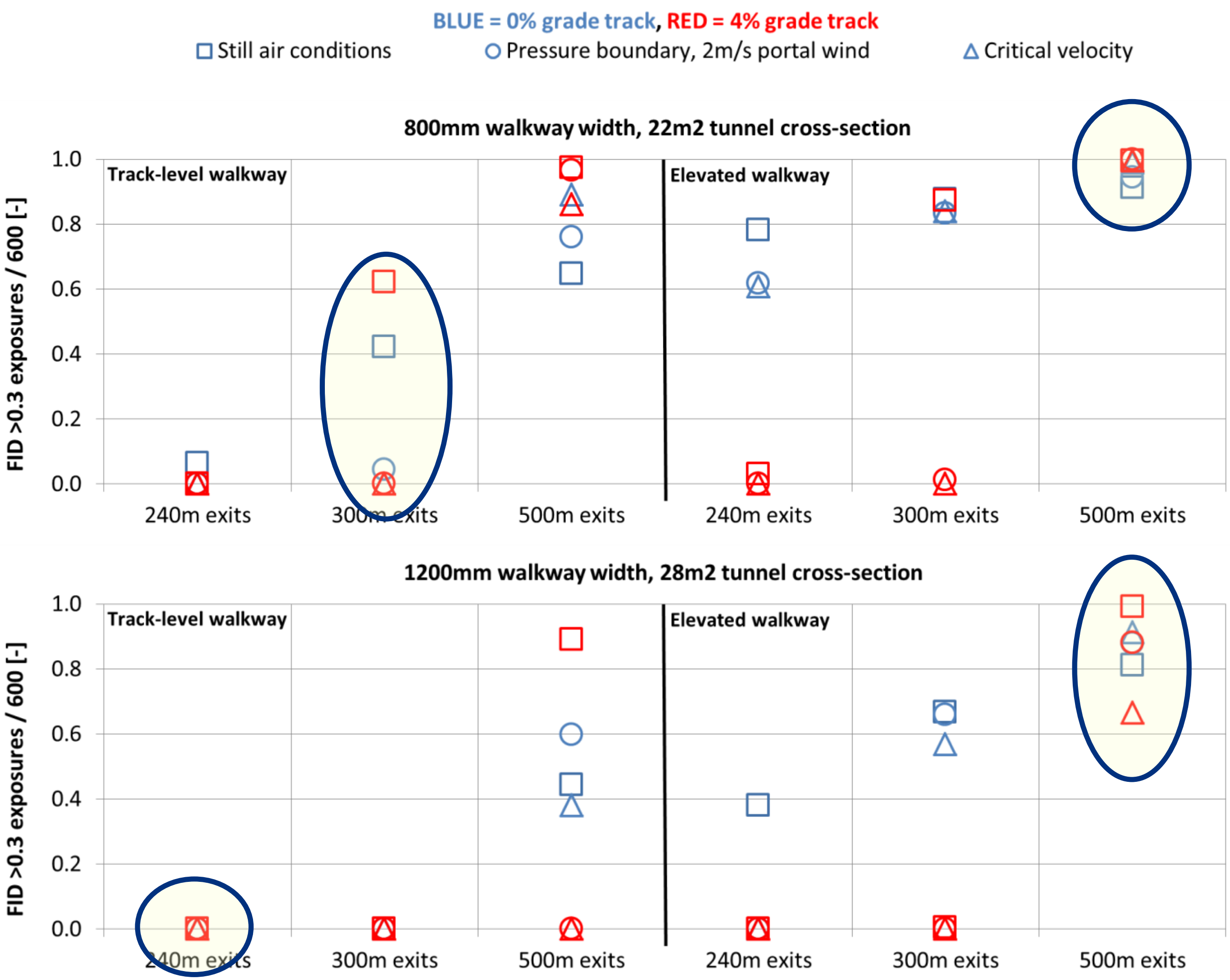
$$Walking\ speed\ [m/s] = -1.1423 \cdot x + 1.177$$

- **Walking speed = f(crowding, flow rate, visibility, agent characteristics)**
- **Snapshot of results – see paper for more**
  - $22m^2$ tunnel with 800mm walkway
  - $28m^2$ tunnel with 1200mm walkway

Maximum FIDs

- **Highest**
  - 500m exits
  - Elevated
  - $22m^2$ tunnel
- **Lowest:**
  - 240m exits
  - Track-level
  - $28m^2$ tunnel
- **Spread**
  - varies with grade, velocity conditions, area

Number of exposures to FID ≥ 0.3



- → **Highest**
  - 500m exits
  - Elevated
  - $22m^2$ tunnel
- → **Lowest:**
  - 240m exits
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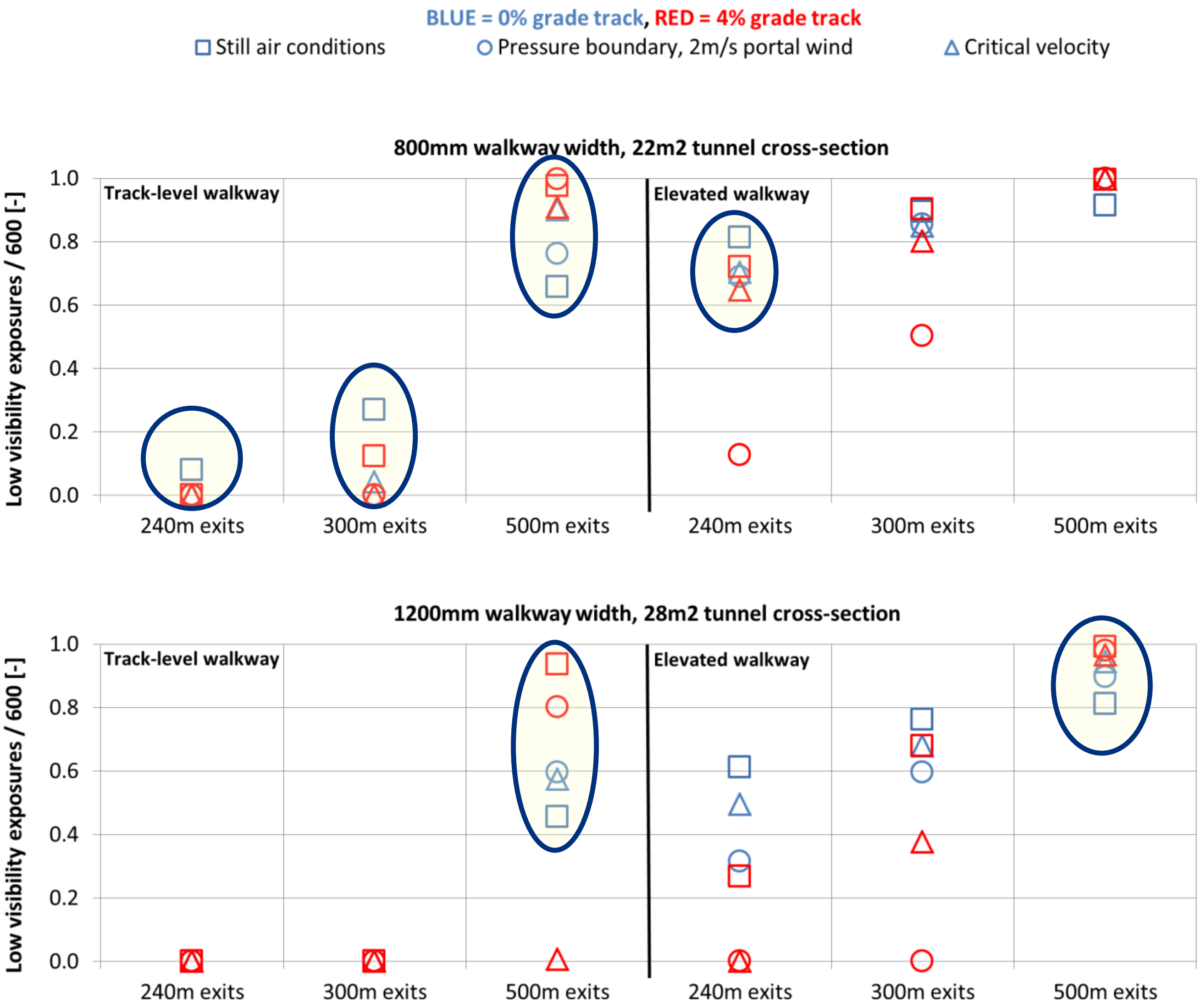
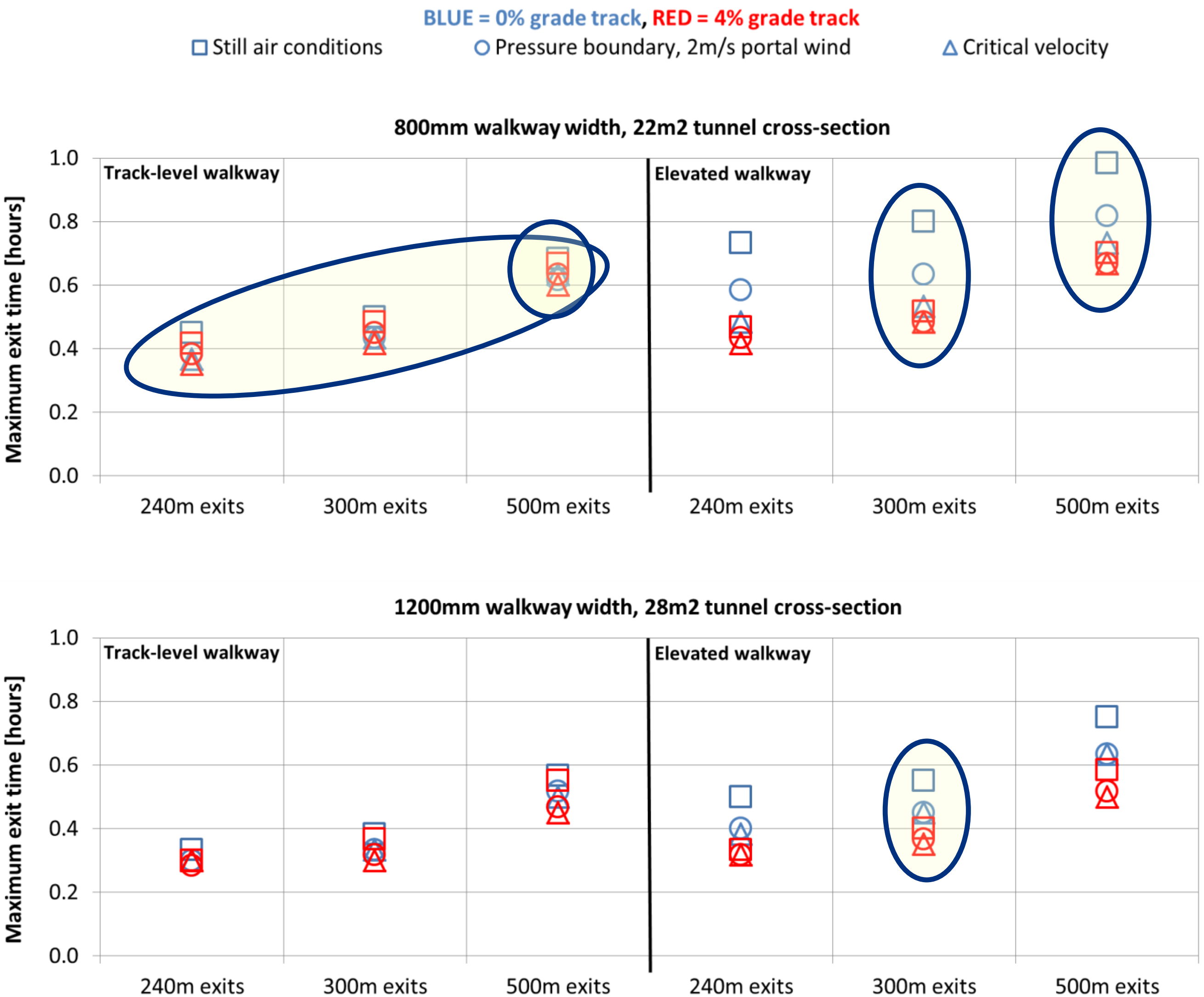
  - varies with grade, velocity conditions, area

Low visibility exposures (<5m for >10 minutes)



- → Outcomes not always clear with different velocity conditions
- → Still air generally worse for short exit distances
- → Airflow (forced or grade effect) generally worse for long exit distances

Total evacuation time



- Evacuation times increased with increasing exit spacing, reduced walkway width
- Longer times with elevated walkway due to reduced speed in lower visibility
- Improved with larger tunnel cross-section

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Conclusions

→ **Outcomes likely obvious to an experienced practitioner**
- Maybe not to stakeholders or other design disciplines

→ **In general, and specific to the modelling undertaken:**
- Increase exit spacing, reduce walkway width ~ reduces tenability
- Decrease exit spacing, wider / low-level walkway ~ increases tenability
- Tunnel grade and tunnel area have a noticeable effect
- Outcomes with different velocity conditions are not always obvious

→ **So what is the '*best*' configuration?**
- Depends on the specifics of a project
- Perspectives: Highest level of fire safety = cost effective? Probably not.

→ **Trade-offs to arrive at an optimal solution → value in modelling**

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Thank you!

andrew.purchase@wspgroup.se