Probabilistic Temperature Assessment of Railway Tunnel Fires

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Introduction

❑ Problem statement

Extreme fire events in tunnels may have **catastrophic consequences**, including loss of lives, structural damage, and major socioeconomic impacts. One of the primary factors that influences the level of damage is the **demand fire scenario** in a tunnel. A few standard hydrocarbon fire temperature-time curves exist, but they are idealized curves that do not consider the actual fire duration and fire spread inside the tunnel. **Risk-based decision-making frameworks** and **performance-based design** of tunnel linings require a more **realistic set of fire scenarios compared to the standard fire curves**.

❑ Motivation

Consequences of four historic rail fire events:

Tunnel fires can have **extremely high consequences**, especially for those events that include **fire spreading** between train cars.

Historic rail fire events:

Real Events	The Baku fire (1995)	Channel Tunnel fire (1996)	Leinebusch Tunnel fire (1999)	Howard Street Tunnel fire (2001)
Location	Azerbaijan	France/UK	Germany	Baltimore
Tunnel Type	Metro	Railway	Railway	Railway
Major Source of Fuel	Linoleum floor/ foam seats/plastic covers	Frozen fat/ clothing	Paper/ cellulose	Flammable liquid chemical
Cars Involved	Two railcars	10 HGVs	A freight wagon	Three or four railcars
Estimated Peak HRR	100MW	370MW	Not available	50MW

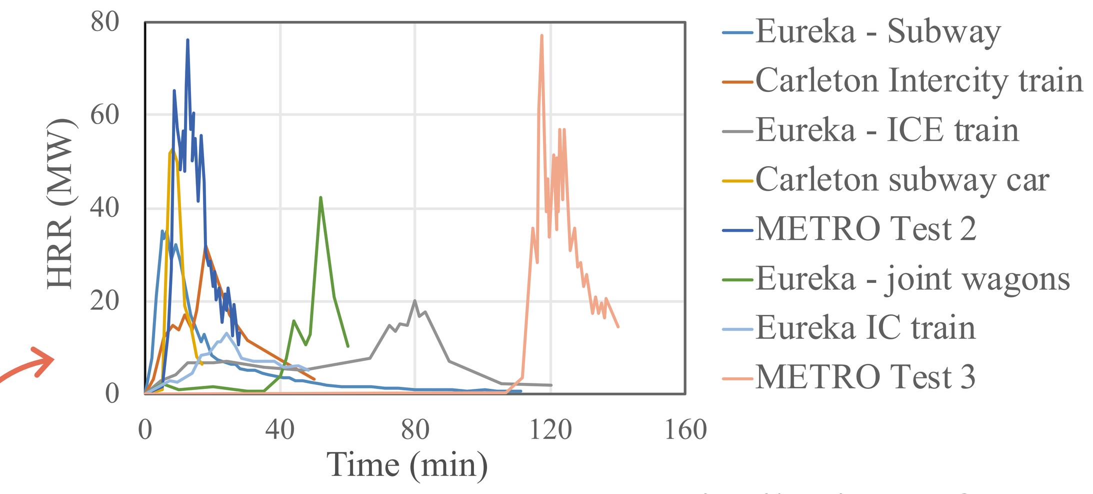
Objective

The outcome of this work will be used to establish guidelines for **temperature demands in the design of concrete tunnel linings within risk-based frameworks** to **minimize economic losses** in railway tunnel fire events.

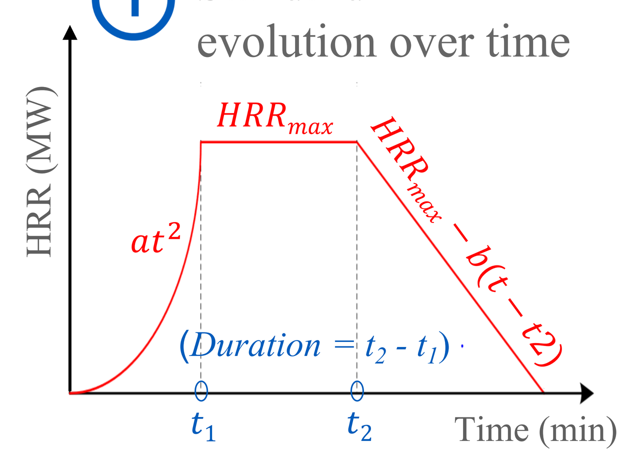
Methodology

❑ Heat release rate of a passenger railcar

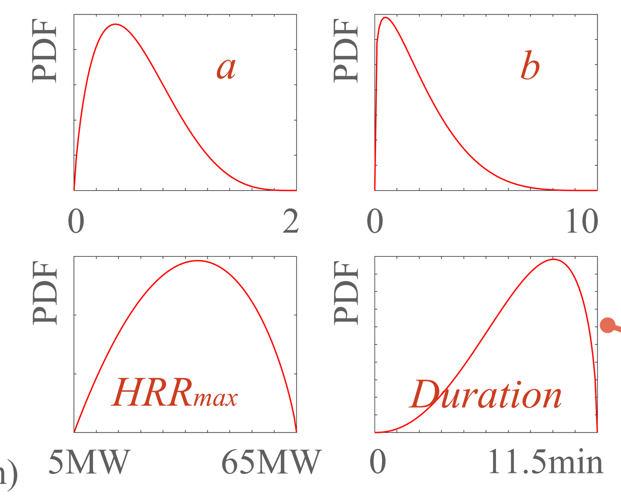
② Full-scale experimental data



① Standard HRR evolution over time

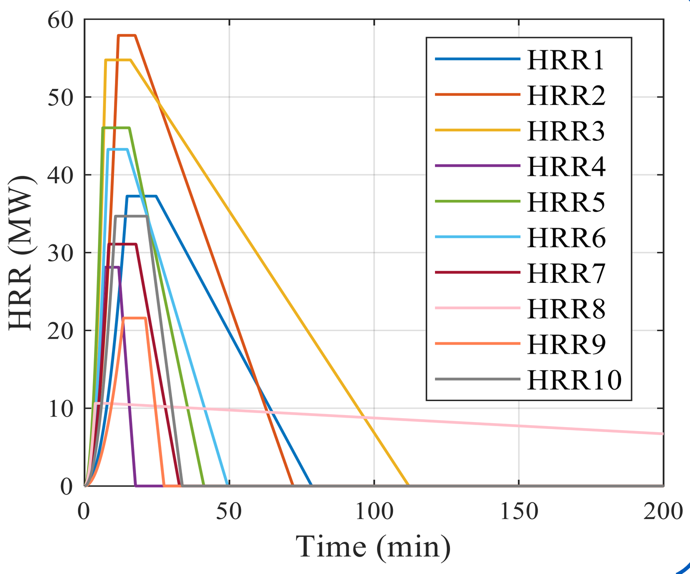


③ Distributions of HRR parameters



④ HRR demand

Ten HRR curves are randomly generated from passenger train car HRR distributions using Latin Hypercube Sampling (③).

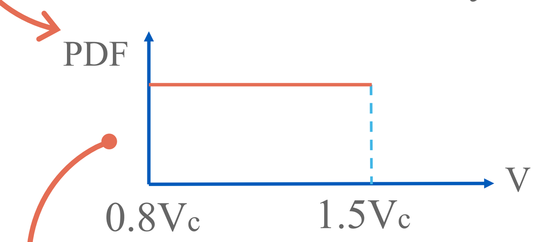


❑ Ventilation velocity

Critical velocity (V_c): The minimum steady-state velocity of the ventilation airflow moving toward the fire, within a tunnel or passageway, that is required to prevent backlayering at the fire site (*NFPA-502-2017*).

Assume fans installed along tunnel will be turned on to create a ventilation velocity around or larger than Vc.

A uniform distribution of ventilation velocity:



Critical velocity prediction model (Li, 2010):

$$V_C^* = \begin{cases} 0.63Q^{*1/3}, & Q^* \le 0.15 \\ 0.33, & Q^* > 0.15 \end{cases}$$

➡ V_c = 2.67m/s

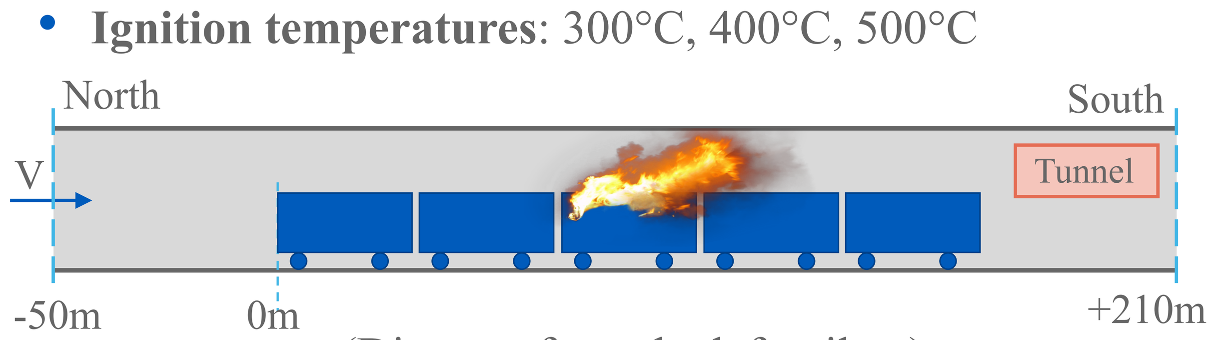
Ventilation velocity demand:
V_1 = 2.45 (m/s), V_2 = 3.08 (m/s), V_3 = 3.70 (m/s)

❑ Traveling fire scenarios of a railway tunnel

- **Train car sizes** (Amtrak "Superliner" railcar) :

Train type	Length	Height	Width
Passenger railcar (Amtrak)	25.9m	4.9m	3.1m

- **Total number of railcars**: Five
- **Ignition point**: Third car
- **Ignition temperatures**: 300°C, 400°C, 500°C

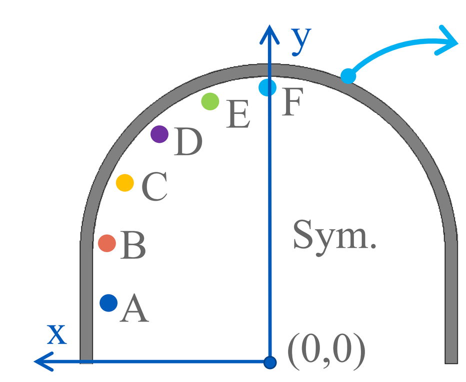


(Distance from the left railcar)

Results

❑ Gas temperature measurement

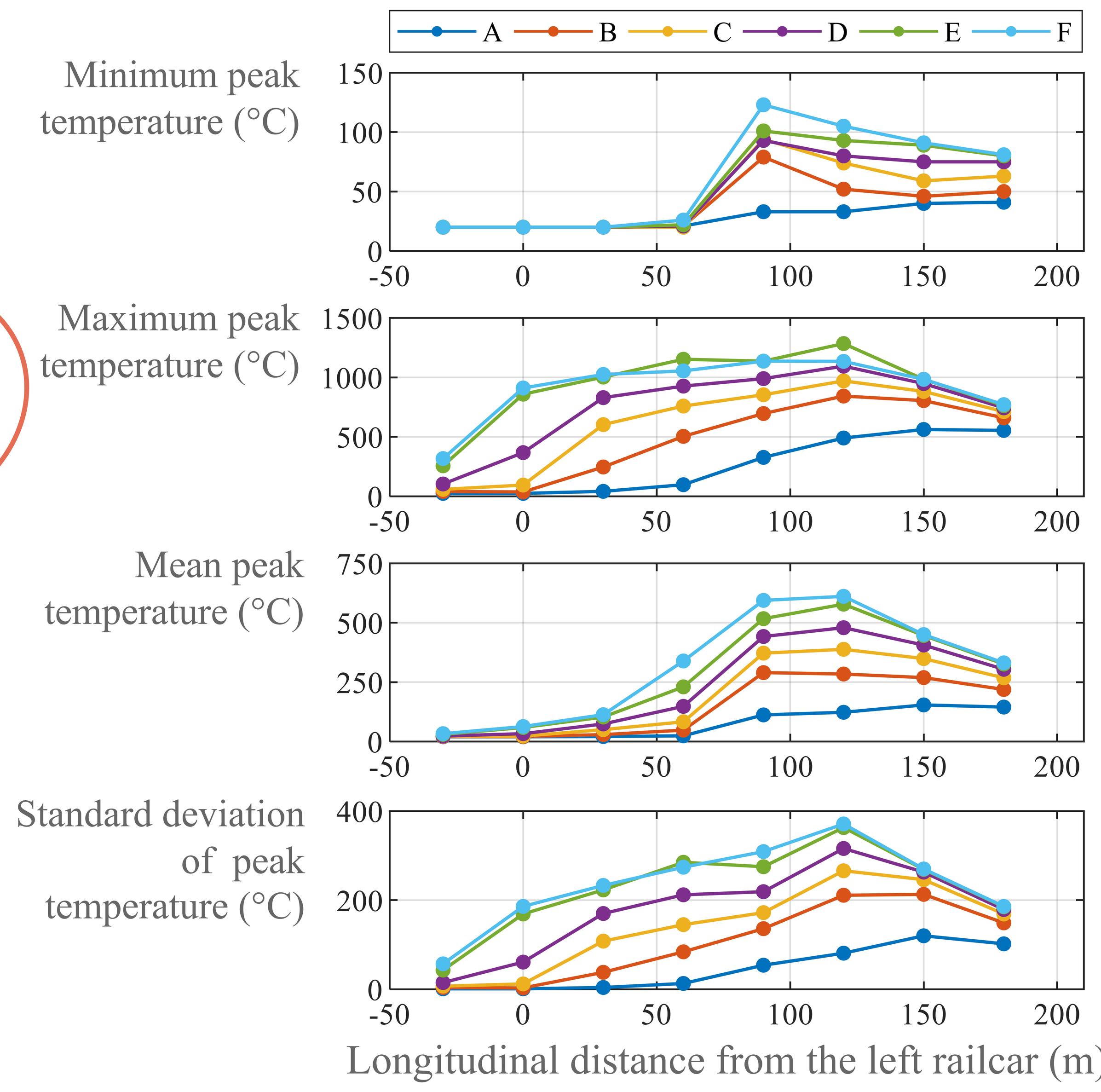
Location of measurement points



Tunnel cross-sections at -30m, 0, +30m, +60m, +90m, +120m, +150m and +180m.

A (3.9m, 1.3m), B (3.9m, 2.6m),
C (3.4m, 3.9m), D (2.9m, 4.9m),
E (1.9m, 5.9m), F (0, 6.4m).

Summary of peak temperatures of 90 FDS simulations (10 HRRs, three ventilation velocities and three ignition temperatures):



Conclusions

- **Probabilistic HRR demand** of a passenger railcar is established from full-scale experimental data.
- A **traveling fire** methodology for railway tunnels is proposed, which considers fire spread between railcars.
- This work establishes **temperature demands** by investigating 90 traveling fire scenarios with varying HRR, ventilation velocity and ignition criteria for fire spread.

Selected References

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6. NFPA 502. (2017). Standard for Road Tunnels, Bridges, and Other Limited Access Highways, National Fire Protection Association, Annex D, Quincy, MA.

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