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Framework for Fire Risk Assessment of Bridges

Structures in Fire Forum May 2024

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Commercial experience

United Kingdom

- 7 – 8 bridge projects
- Bridge spans 0.5 to 6 km
- 2 to 8 lanes of traffic
- Cycling and pedestrian use
- Wide range of design fires including vehicle, boat, train, wildfire, dangerous goods, and industrial activity fires assessed.

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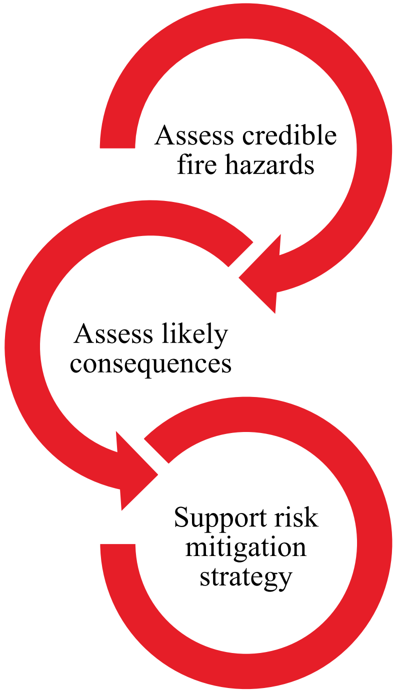
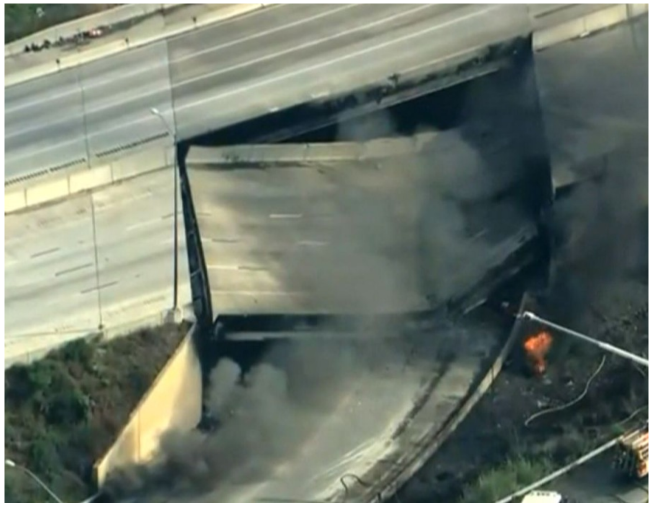
Core objectives



Hazard: *Road tanker fire under bridge deck (I79, Philadelphia, 2023)*



Consequences: *Structural collapse and major operational disturbance*

Fire Risk Appraisal Process

Method overview

- Establish client brief
- Stage #1 Credible hazards assessment
- Stage #2 Thermal impact assessment
- Stage #3 Consequence frequency assessment
- Stage #4 Mitigation strategy assessment

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Client brief

Method overview

- Scope of risks
- Scope of risk appraisal stages
- Regulatory and contractual framework
- Any client risk tolerability parameters
- Project deliverables and deadlines

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#1 Credible hazards assessment

Examples

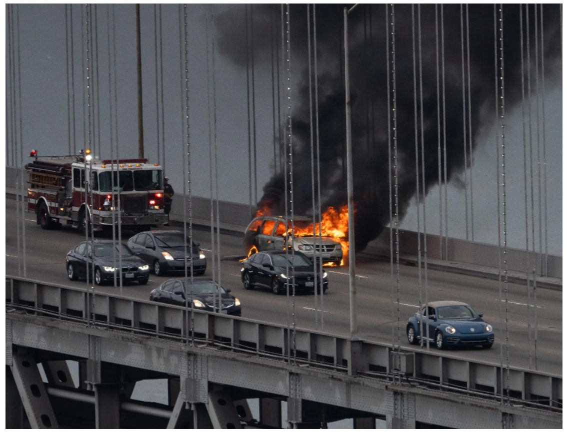
HGV fire on bridge deck

Pool fire on bridge deck

BLEVE on bridge deck

Industrial fire below the bridge deck

Wildfire in the vicinity of the bridge



Passenger car fire

#1 Credible hazards assessment

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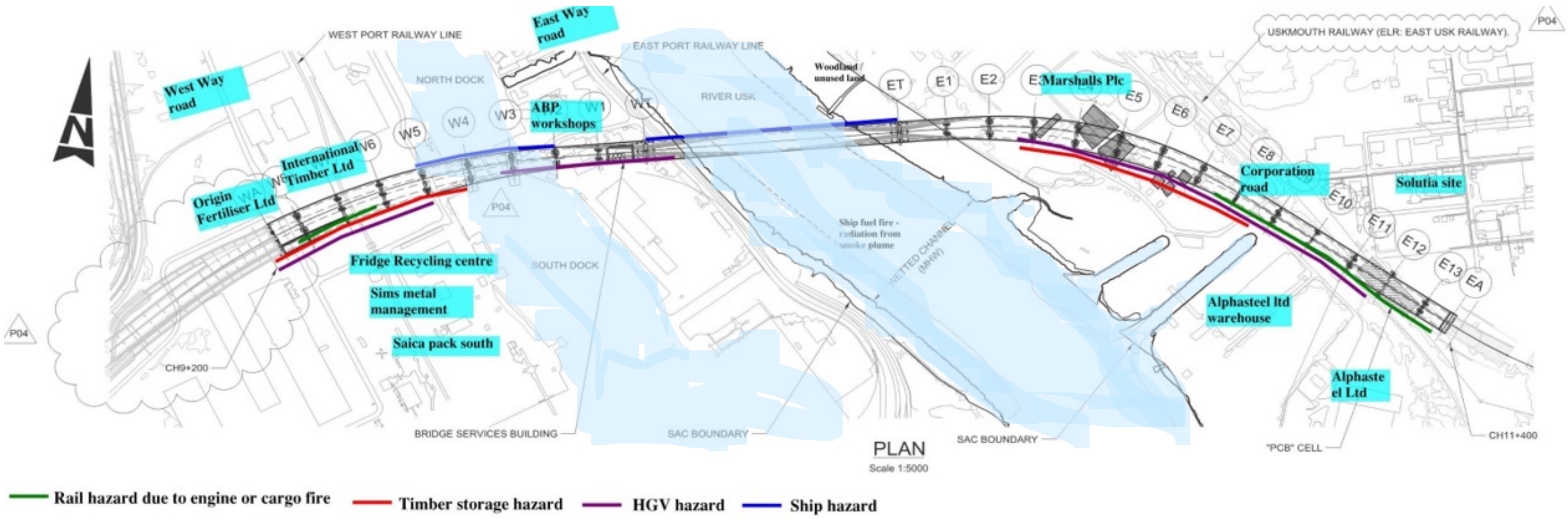
Hazard location mapping



#1 Credible hazards assessment

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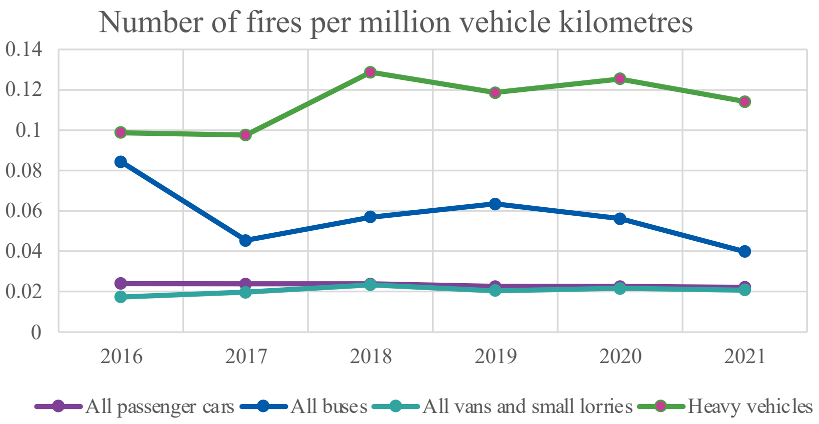
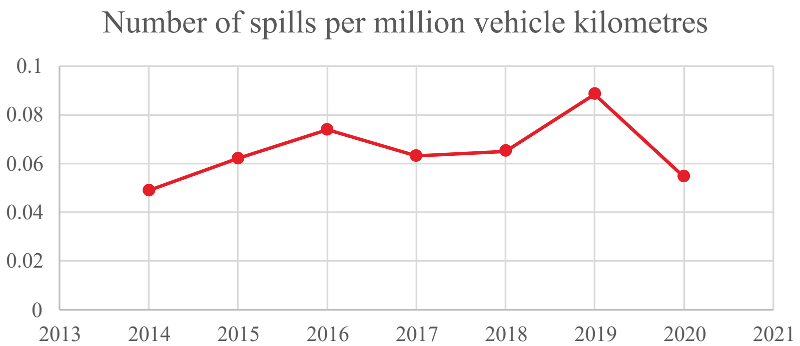
Quantified statistical analysis





$$P_{ig} = \lambda f L$$

P_{ig}: probability of ignition
λ: annual base rate
f: annual traffic frequency
L: credible threat zone

Fire hazard	Probability of ignition	
	Annual frequency	Mean return period (years)
Passenger car	1.1E-01	9
Small lorry	3.5E-02	29
Bus	5.0E-02	20
HGV	1.4E-01	7
HGV Flammable Goods	1.2E-04	8702
Road tanker	2.5E-04	3996
Liquid spill	2.3E-04	4440
Gas tanker jet	2.6E-04	4258

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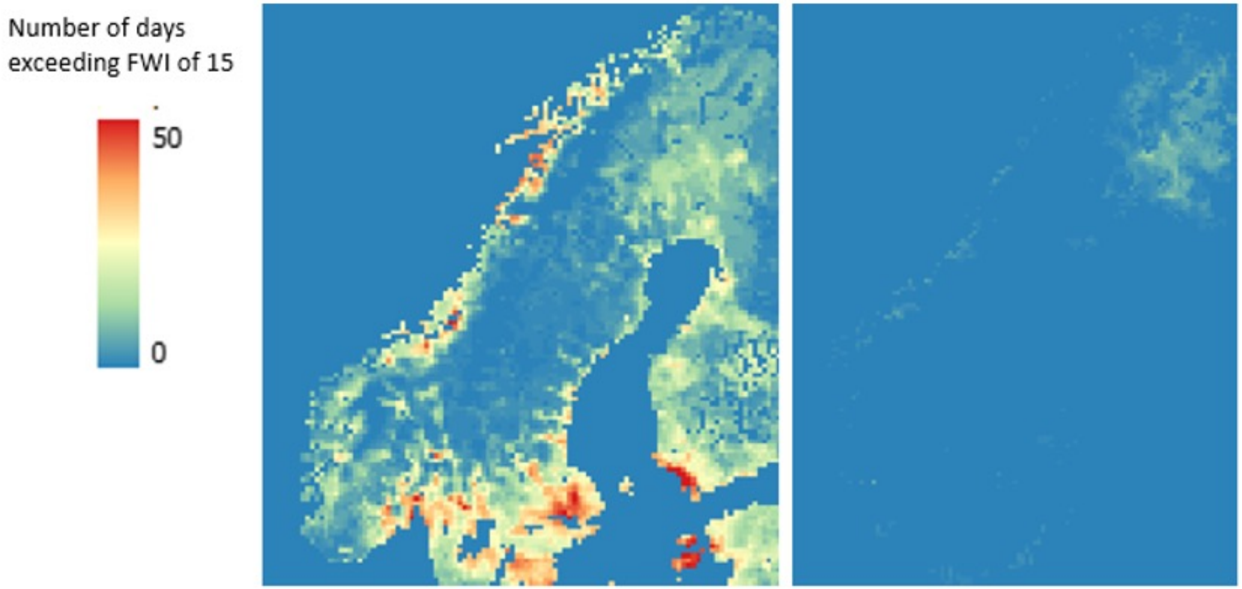
#1 Credible hazards assessment

Quantified statistical analysis



Fire weather index projections for 2060.
Left: emissions continue to rise without intervention (RCP 8.5).
Right: emissions decline after 2020 (RCP 2.5)

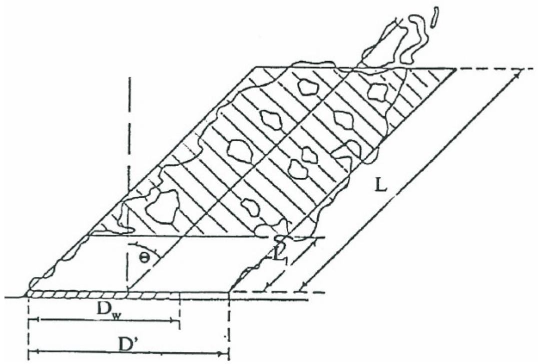
Wildfire hazards assessed based on

- Past local incidents
- Local fire weather index projections
- Carbon emission trajectories (RCPs)

#2 Thermal impact assessment

Analytical and numerical model approximations

Real life photograph of tanker fire



Design fire approximation

Establish key fire parameters:

- Footprint area
- Heat release rate
- Burnout time
- Flame temperature
- Flame height
- Emissive power

#2 Thermal impact assessment

Appreciation of different escalation scenarios from root hazard

Fire contained within the tank

Fuel spilled on road deck

BLEVE and/or fireball + explosion risk

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#2 Thermal impact assessment

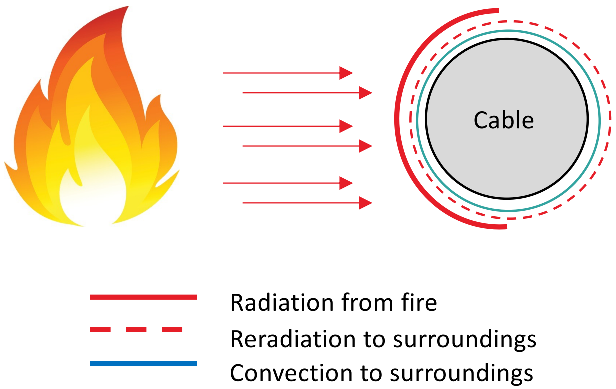
Design fires review

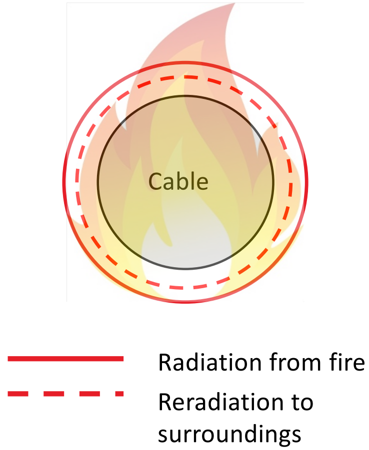
Design fire scenario description	Heat release rate (MW)	Burnout time (min)	Fire footprint size (m)	Growth to peak HRR (min)
Passenger car	3 - 6	15- 30	3x1.8 - 6x2.2	4 - 6
Small lorry	6 - 20	30 - 60	6x2.2 – 10x2.2	6 - 11
Bus	10 - 30	30 - 60	7x2.55 – 13x2.55	8 - 13
Heavy goods vehicle (HGV)	30 - 100	240 - 300	7x2.55 – 14.5x2.55	7 – 24
Fuel contained within the tanker (tanker fire)	50 – 70	238 – 273	8x2.55 m – 11x2.55 m (tanker footprint)	Instantaneous
Instantaneous spill	~ 11,000	1.7 (101 s)	75 m (pool diameter)	Instantaneous
Continuous spill from 80 mm to 100 mm diameter hole	136 – 290	30 – 34	8.4 m – 12 m (pool diameter)	Instantaneous
LPG at operating conditions (20 °C @ 863 kPa)	10 – 93	208 – 1,878 (HRR dependant)	1.1 – 3.5	Instantaneous
LPG at elevated temperature conditions (70 °C @ 2,482 kPa)	28 – 256	76 – 685 (HRR dependant)	1.2 – 3.5	Instantaneous

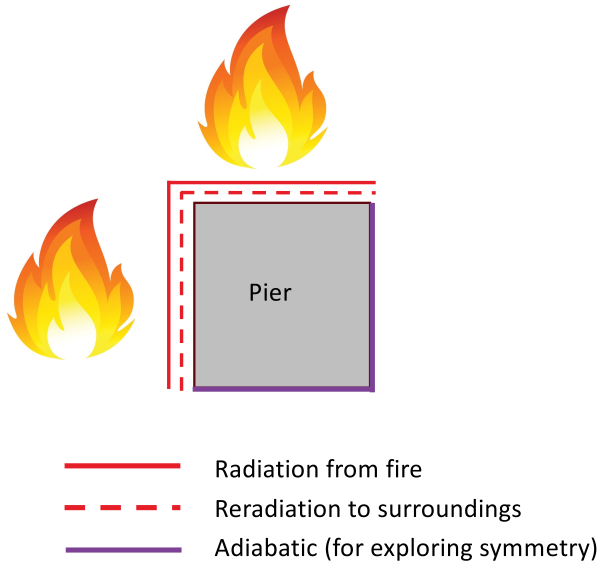
#2 Thermal impact assessment

Analytical and numerical model approximations

- Heat transfer to key bridge components usually assessed on a single element basis





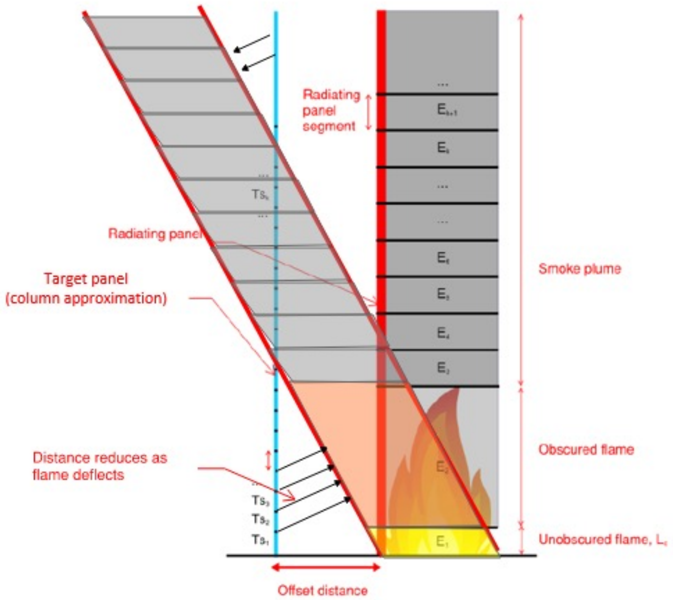


Typical first pass critical temperatures:
300 ºC – main cables
550 ºC – secondary steel elements
500 ºC – concrete piers

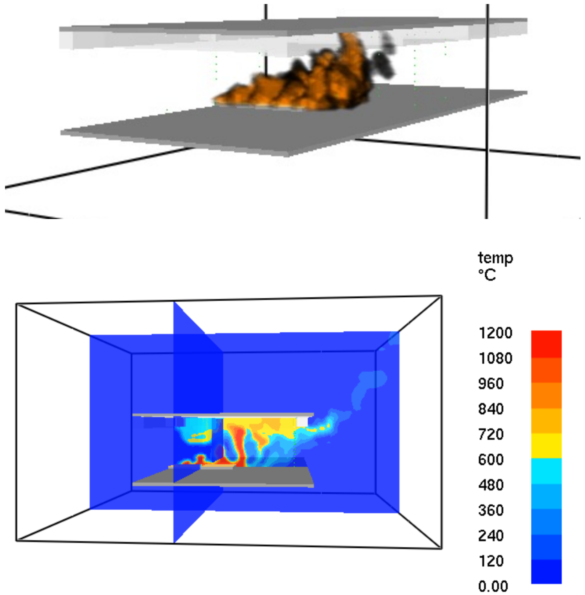
#2 Thermal impact assessment

Use of numeircal tools

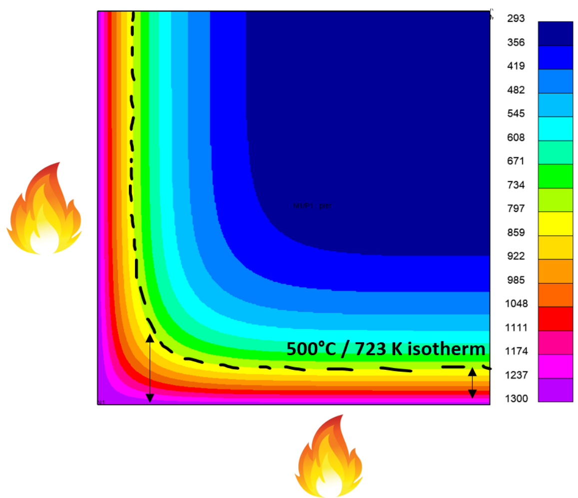
- Thermal impact problem can be solved with numerical tools of various degree of complexity
- Observe consistent level of crudeness
- Initially, quick models with numerous trials favoured over computationally inside ones



Radiation panel model



Computational fluid dynamics modelling



Heat transfer finite element analysis

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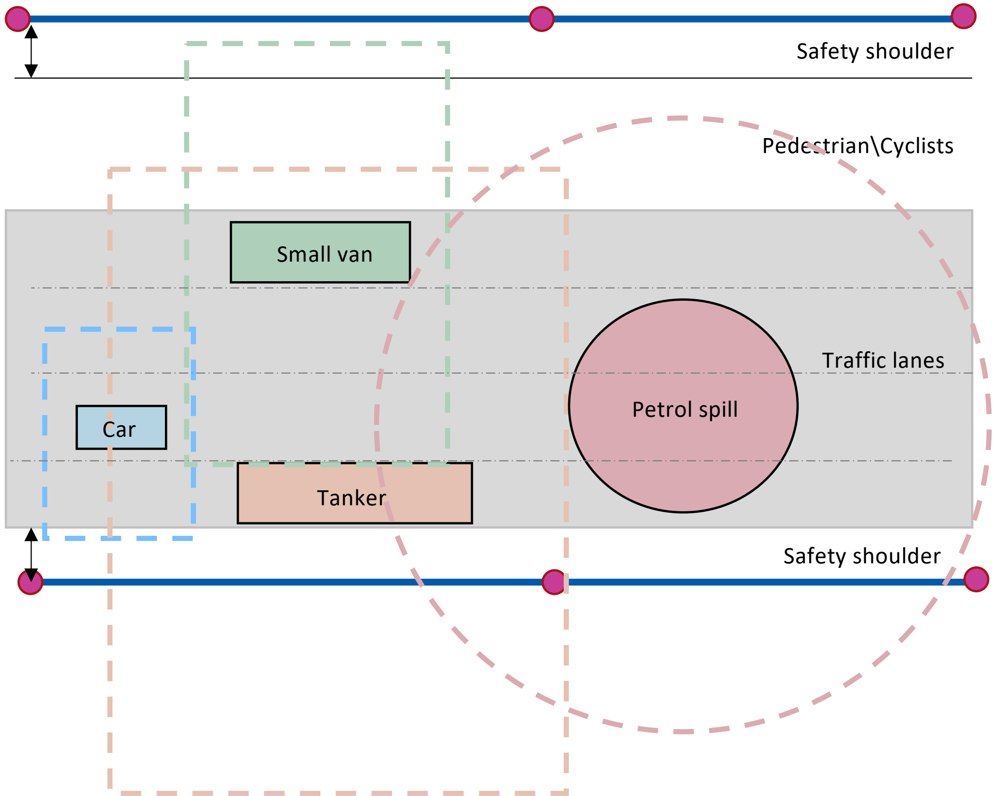
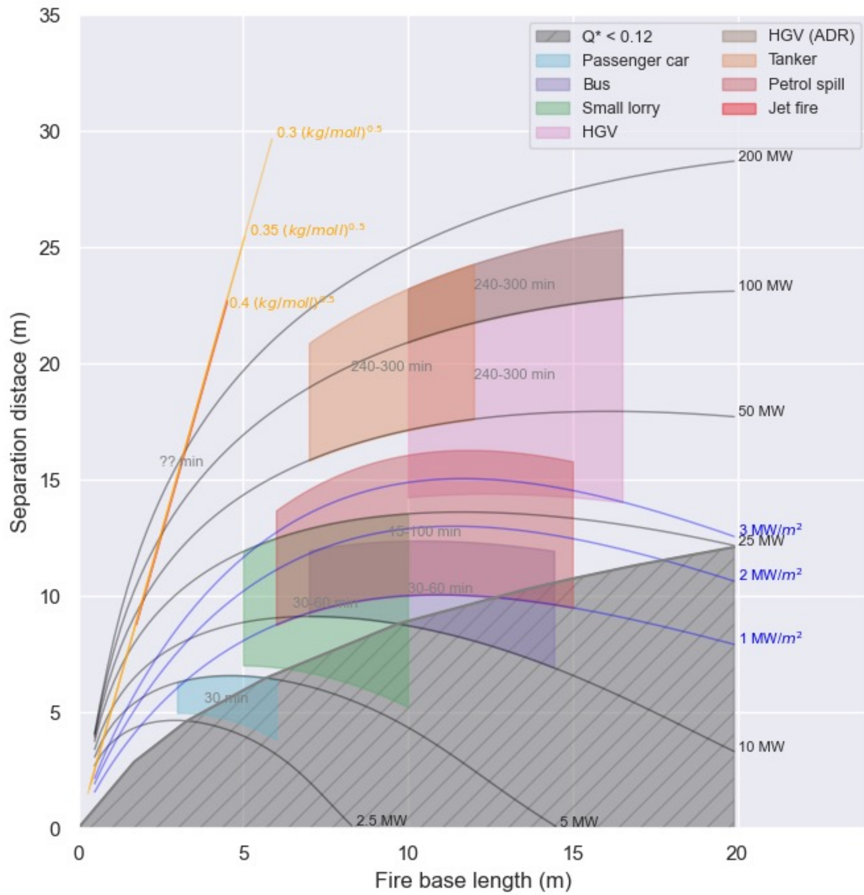
#2 Thermal impact assessment

Parametric study – results presentation





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#2 Thermal impact assessment

Probabilistic study

Estimation of confidence intervals for each hazard considering the variable nature of input parameters:

- Wind conditions
- Traffic
- Incident location
- Fire severity

#3 Consequence frequency assessment

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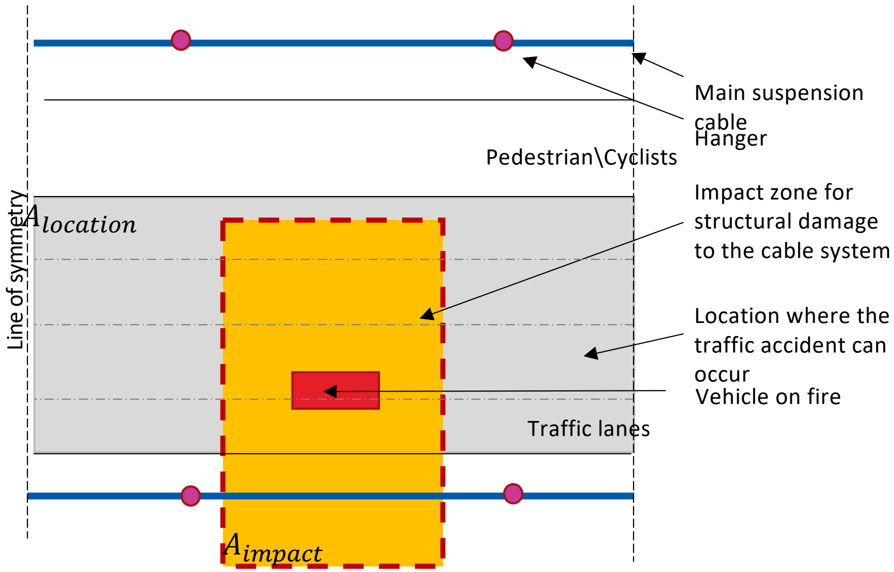
$m \propto A_{impact}/A_{location}$

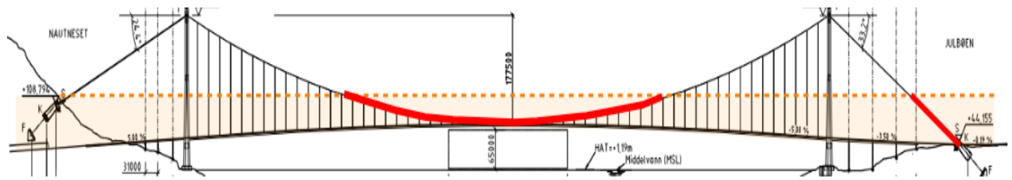


$$P_c = mP_{ig}$$

P_c: consequence probability

P_{ig}: probability of ignition

m: consequence factor



Incident location where impact on main hanger is likely (red) given hazard thermal impact zone (orange)

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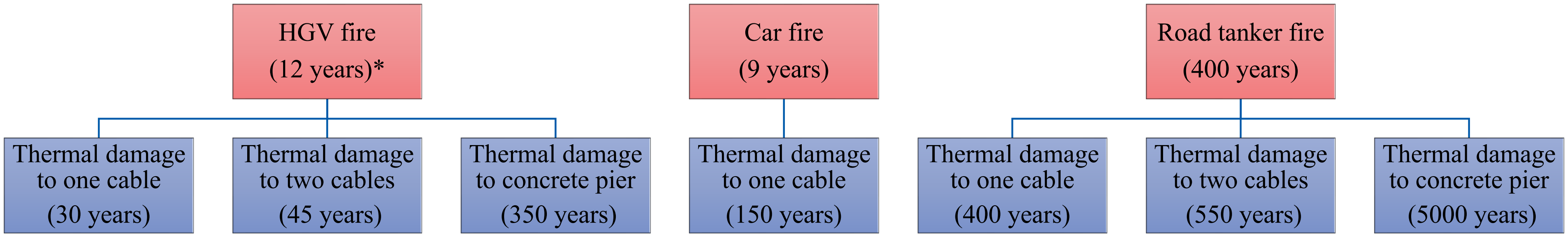
#3 Consequence risk assessment



**event mean annual return period*

Fire hazard

Consequence

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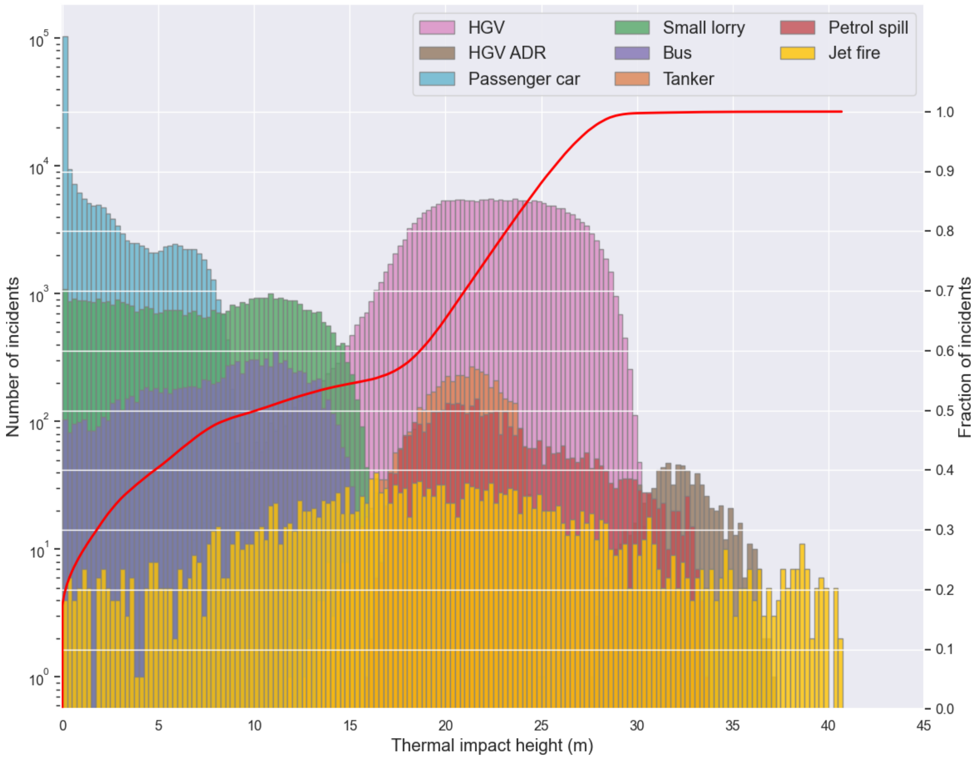
#3 Consequence risk assessment



Combined distribution of all investigated hazards informing the likely impact height from 100,000 different incidents.

Assess relative contribution of each hazard to the overall risk profile

#4 Risk mitigation strategy

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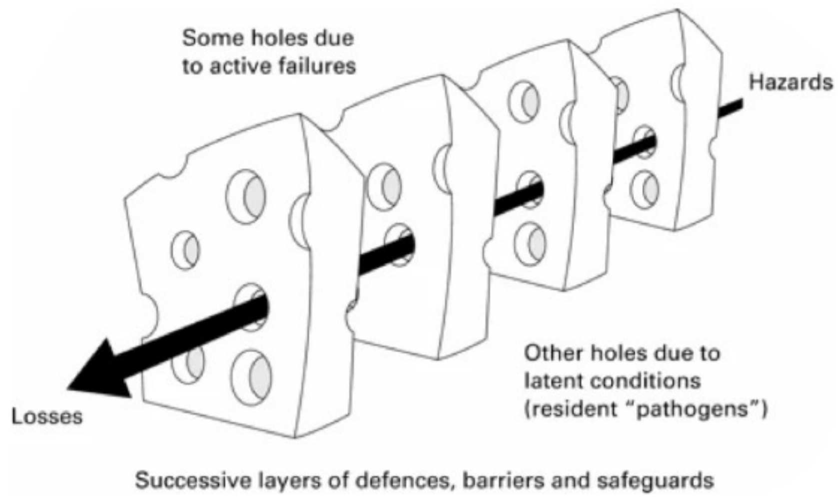
Design risk mitigation strategy
- Operational/Management
- Design features
- Passive fire protection system
- Active fire intervention



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Research and development

Arup University

Scientific Paper

Reliability-based Fire Protection of Structural Cables due to Deck Fires on Cable Supported Bridges

Panagiotis Kotsovinos (Dr, Eng.), Yavor Panev (Eng.), Heikki Lilja (Eng.), Atte Mikkonen (Eng.), Alberto Carlucci (Eng.) & Peter Woodburn (Dr, Eng.)

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Invest in Arup – Global Research

Quantifying the fire performance of structural cables: knowledge gaps and R&D

THE UNIVERSITY of EDINBURGH

'An investigation of the correlation between centreline temperature of large hydrocarbon fires and wind speed.'

by

Katarzyna Jaworska

Supervised by Dr Ricky Carvel

Analysis of the Thermomechanical Response of Structural Cables Subject to Fire

Panagiotis Kotsovinos, Ove Arup & Partners, London, UK

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Fire Performance of Structural Cables: Current Understanding, Knowledge Gaps, and Proposed Research Agenda

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