

TUNNEL SAFETY AND VENTILATION – GRAZ 2020

PERMISSIBILITY OF DANGEROUS GOODS THROUGH AN URBAN RAILWAY TUNNEL

A Risk Study by

Slobodan Rosić, IŽS Railway Infrastructure

Branislav Bošković, University of Belgrade

Florian Diernhofer, ILF Consulting Engineers

Oliver Heger, ILF Consulting Engineers

Regina Schmidt, ILF Consulting Engineers

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QUIZ



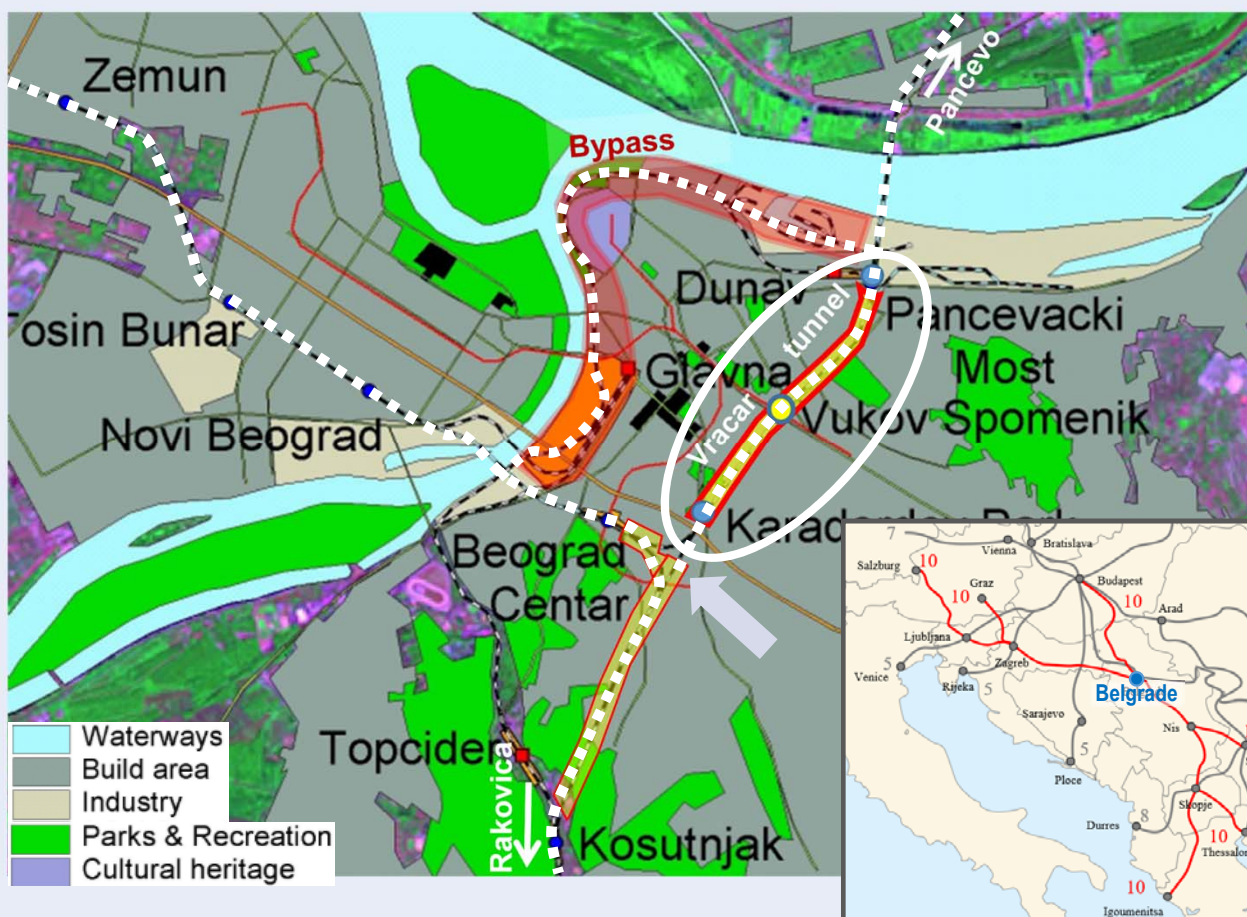
▪ WHICH CAPITAL?

BELGRADE



OVERVIEW

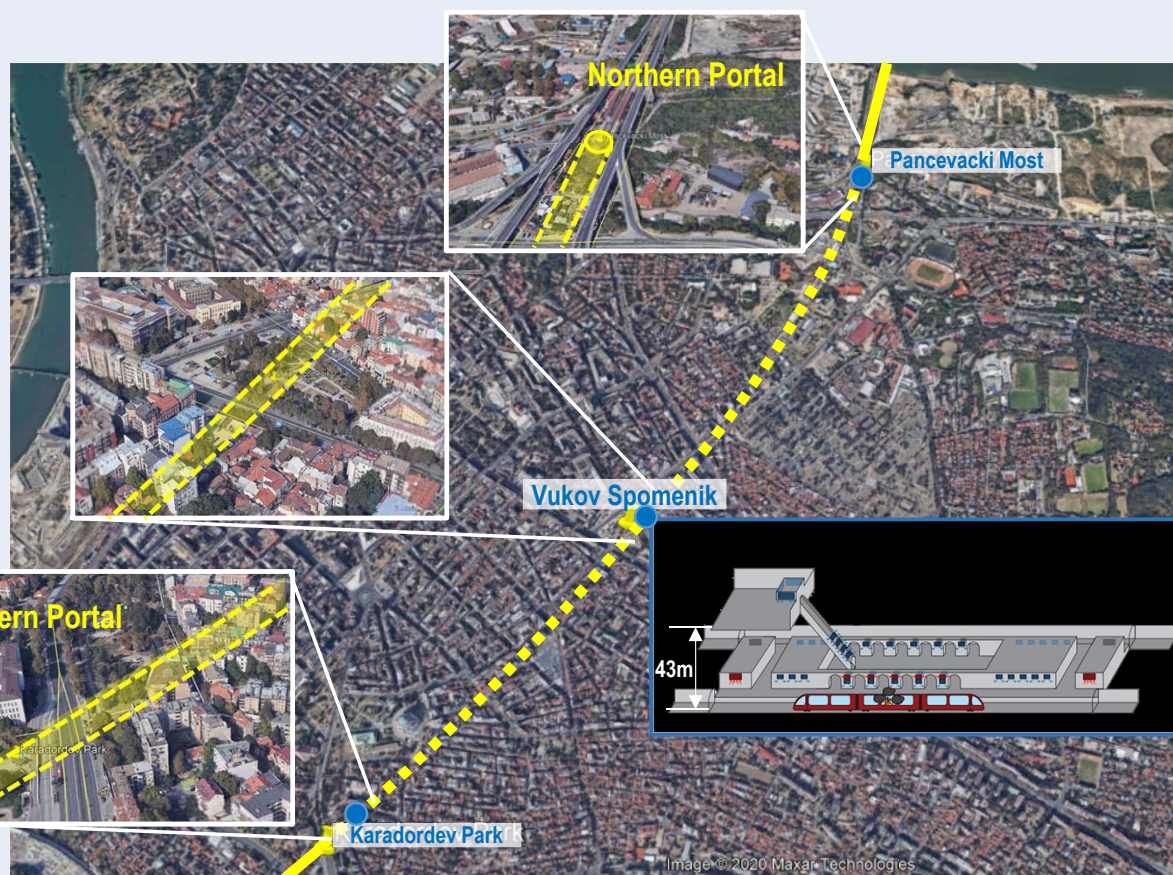
▪ BELGRADE RAILWAY JUNCTION



- After the fall of the iron curtain the former „Yugoslavia“ planned new district railway lines with the idea of a **central underground junction** in the heart of Belgrade.
- Linked to the junction are the **Vračar tunnel (3.5 km)** and the south Dedinje tunnel (6.2 km), which provide a double-track fast connection in all directions as part of corridor 10 of the TERN.
- The idea also included a **bypass** to separate freight / DG trains and route them along the Save banks which connects the industrial city Panceco in the north with southern regions.

OVERVIEW

▪ VRAČAR TUNNEL & VUKOV SPOMENIK STATION



- **Vračar tunnel:**
 - 3.54-km-long urban railroad tunnel (2 single-track tubes, no crosscuts)
 - underground station “Vukov Spomenik” approx. in the tunnel middle
- **Present regulations:**
 - Diesel traction at least during the night (00:00 – 04:00 when station closed)
 - DG are basically not permitted; but since the closure of the bypass there is no useful alternative
- **Need for risk analysis:**
 - approval of necessity (effectivity) for risk-diminishing measures

QUESTIONS TO ANSWER



- **PERMISSIBILITY OF DANGEROUS GOODS?**
- **RISK LEVEL FOR CURRENT & FORECAST SITUATION?**
 - **FREQUENCY ANALYSIS**
 - **CONSEQUENCE ANALYSIS**
- **NEED OF SAFETY & RISK MITIGATION MEASURES?**
 - **ASSESSMENT OF EFFICIENCY**
 - **OVERALL SAFETY CONCEPT**
- **HOW TO ENSURE SAFETY?**
 - **OVERALL SAFETY CONCEPT & OPERATION RULES**

RISK ANALYSIS



Frequency Analysis

Identifying
Initial Events

Development
of Event Trees

Determination
of Probabilities

Consequence Analysis

Consequence
Models

Flow
Measurements

Determination
of Fatalities

Risk Values

- Reference Variant
- Standard Variant
- Risk Mitigation Measures

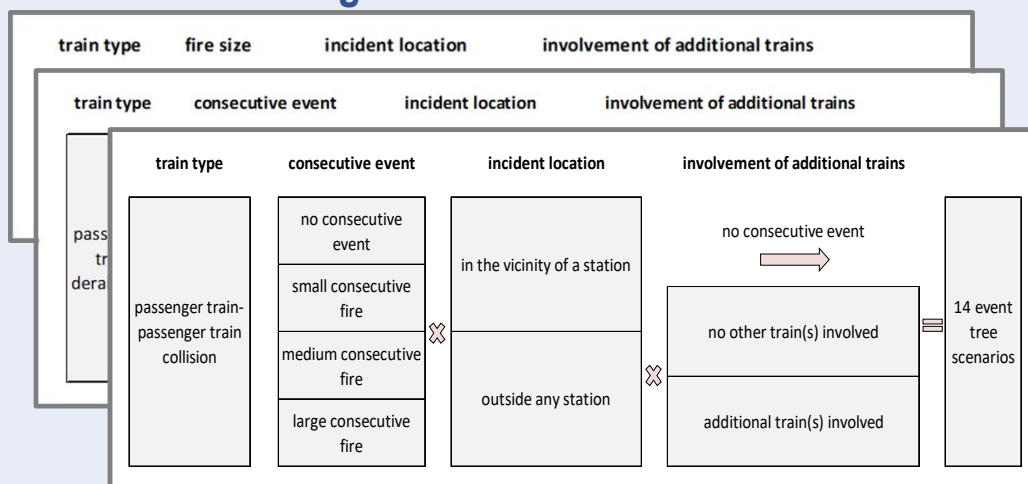
FREQUENCY ANALYSIS



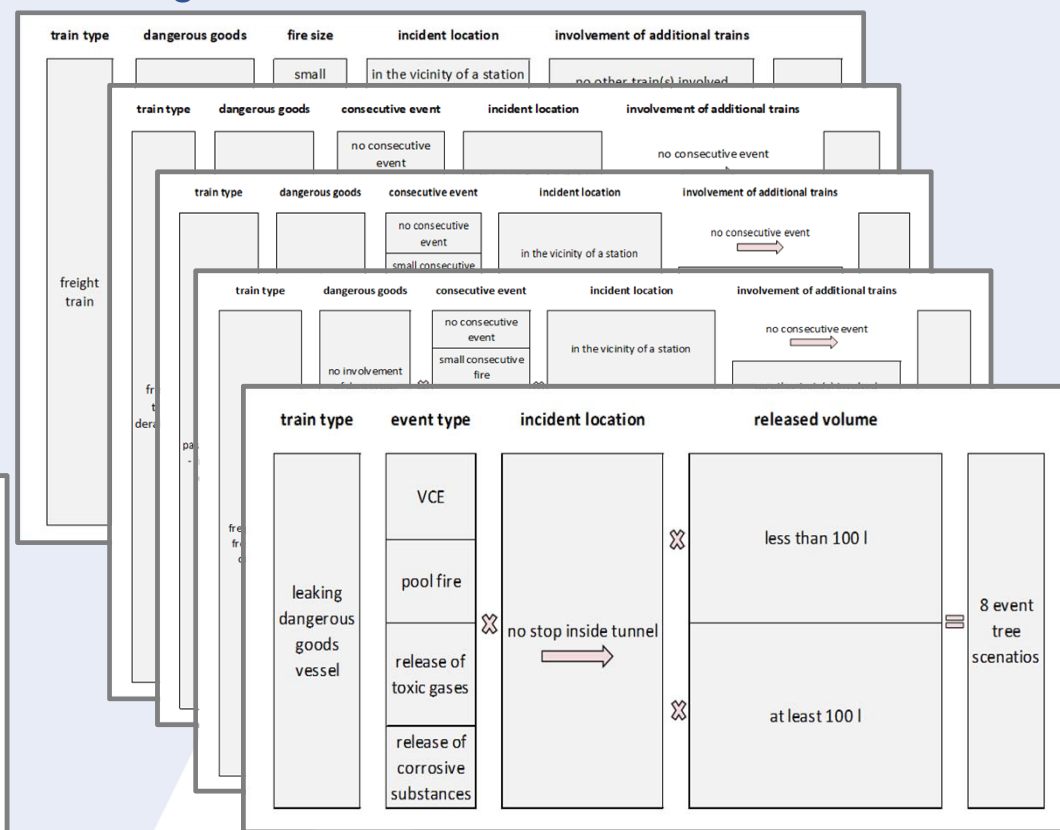
Initial Events

- Train fires (with and without dangerous goods)
- Derailments (with and without dangerous goods)
- Collisions (with and without dangerous goods)
- Release of dangerous goods due to leaking vessels

Passenger Train Event Trees



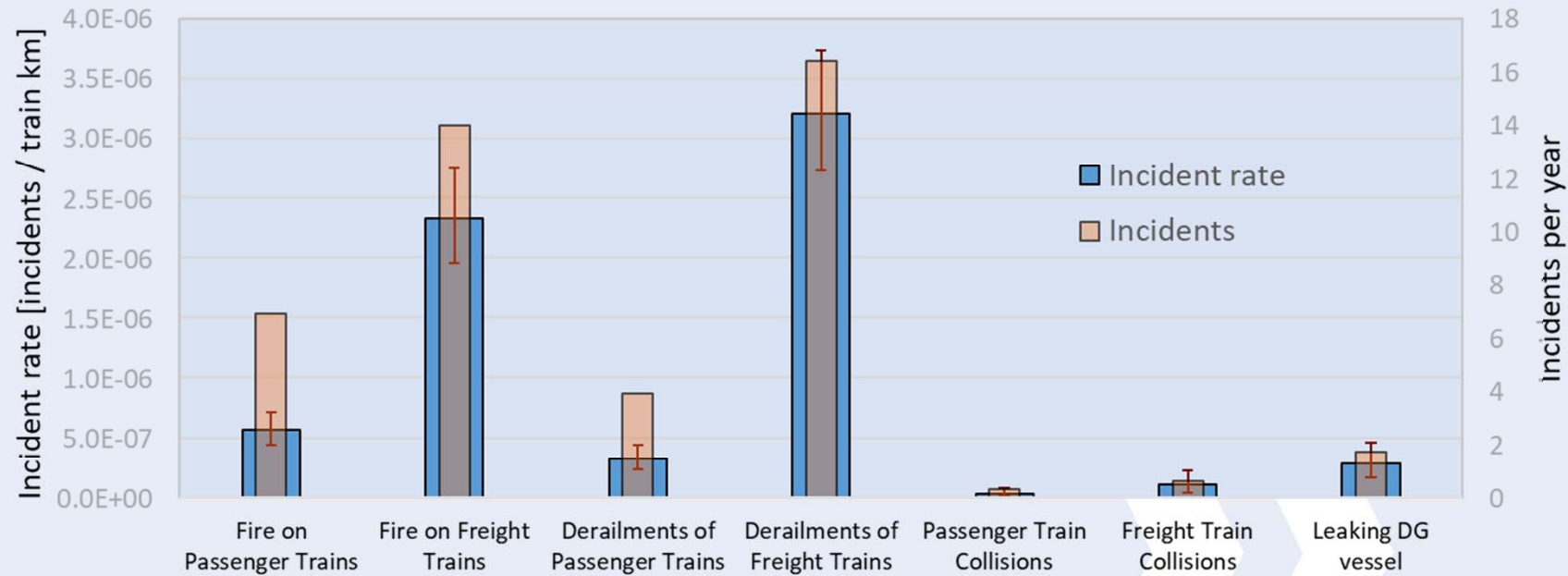
Freight Train Event Trees



FREQUENCY ANALYSIS



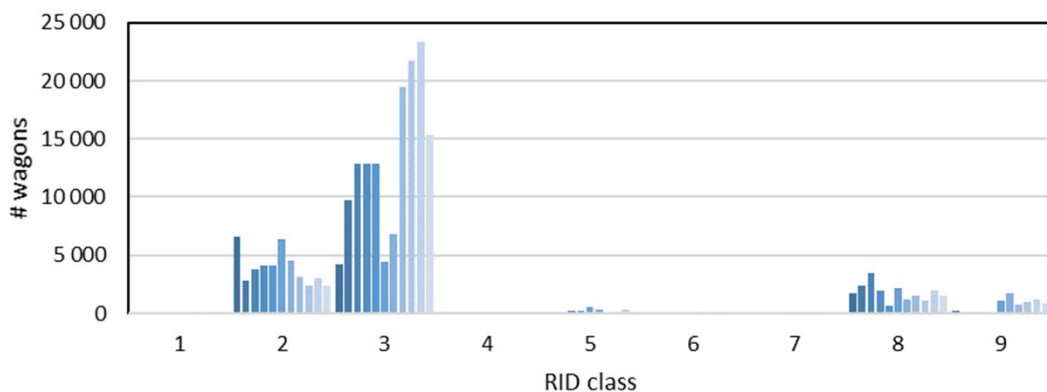
Incident Statistics IŽS



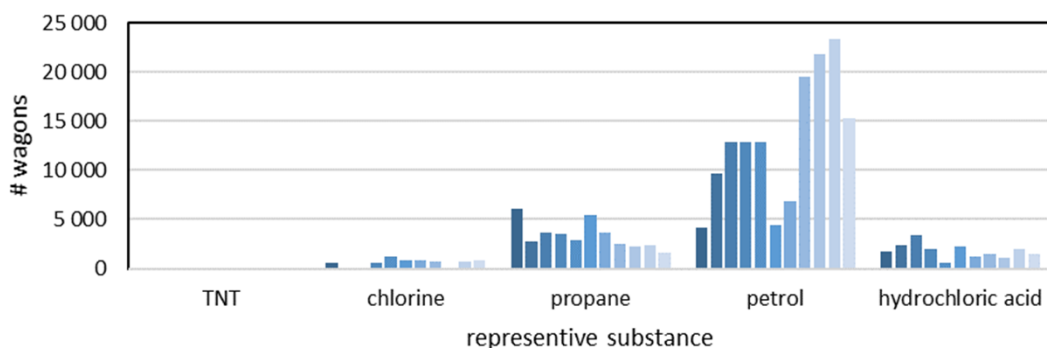
Incidents per year and resulting incident rate on the IŽS railway network 2007 - 2017

CONSEQUENCE ANALYSIS

RID class transport distribution via bypass






distribution of representative substance transport via bypass



■ 2008 ■ 2009 ■ 2010 ■ 2011 ■ 2012 ■ 2013 ■ 2014 ■ 2015 ■ 2016 ■ 2017 ■ 2018*

DANGEROUS GOODS SCENARIOS

- TNT → explosive scenario → 
- Chlorine → toxic gas scenario → 
- Propane → VCE & BLEVE scenario → 
- Petrol → pool fire → 
- hydrochloride acid → corrosive substance ... neglected

CONVENTIONAL SCENARIOS

- train fire
- train derailment
- train collision
- » in station & outside station

CONSEQUENCE ANALYSIS

CONSEQUENCE MODELS FOR EXPLOSIVE SCENARIOS

- **Consequences due to pressure wave**
- **Consequences due to fire ball**
 - » Consequences depend on involved mass, time delay between initial event and explosion and distance to Vukov Spomenik station

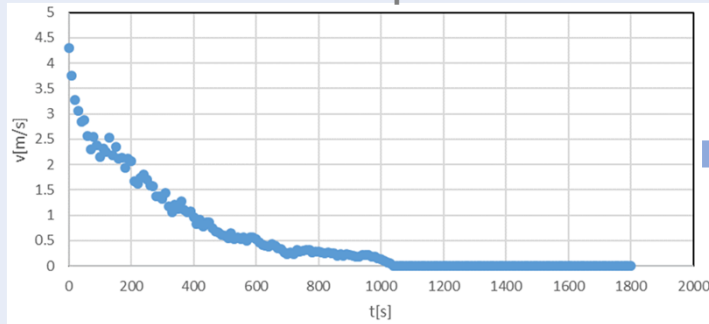
CONSEQUENCE MODEL FOR TOXIC GAS

- **Consequences due to lethal chlorine dosage (3000 ppm min \equiv LC_{50})**
 - » Consequences depend on involved mass, airflow conditions and delay between detection of event and chlorine cloud arrival at Vukov Spomenik station

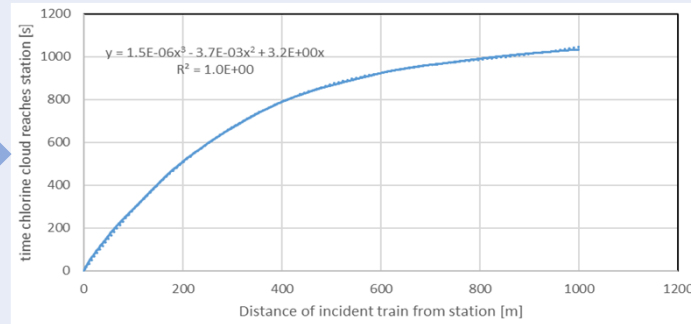
CONSEQUENCE ANALYSIS

CHLORINE INCIDENT OUTSIDE STATION

Airflow development



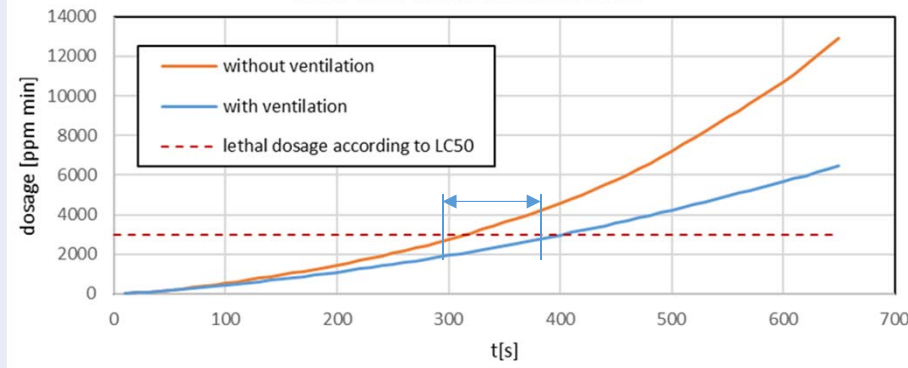
Time till chloride cloud arrives at station



- Full chloride tank in tunnel leads to delayed fatalities
- Empty chloride tank in tunnel leads to non-lethal concentrations at station

CHLORINE INCIDENT IN STATION

chlorine concentration progress with and without ventilation



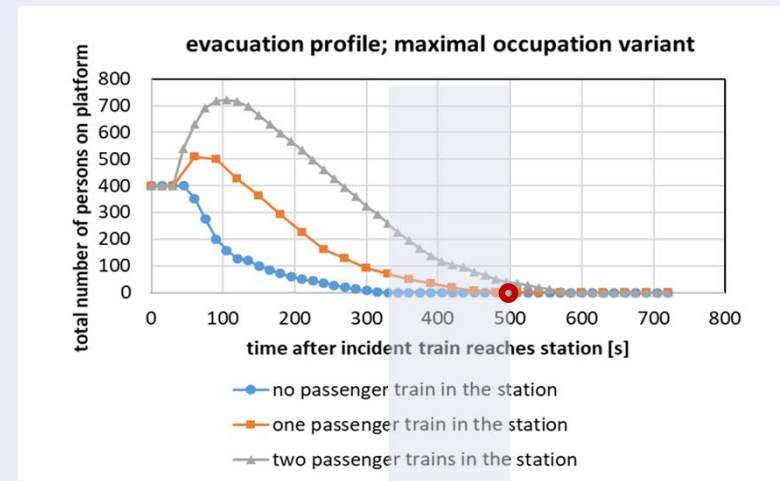
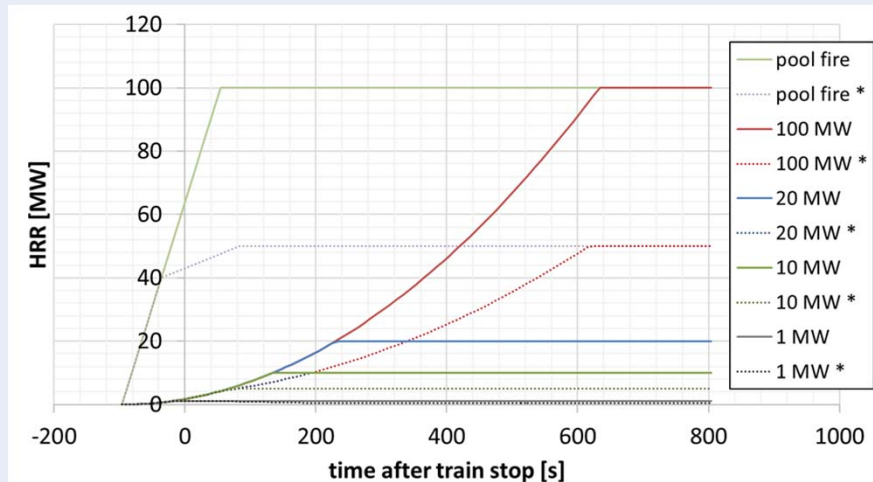
- Full chloride tank in station leads to immediate fatalities
- Empty chloride tank in station leads to delayed fatalities

CONSEQUENCE ANALYSIS

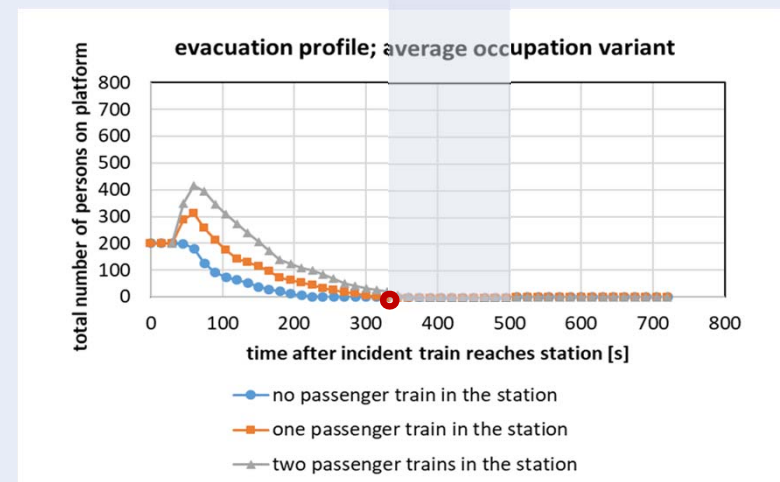


CONSEQUENCE MODELS FOR FIRE SCENARIOS

- Consequences due to heat and toxic combustion products
 - » Consequences depend on fire development, smoke distribution and egress time for evacuation

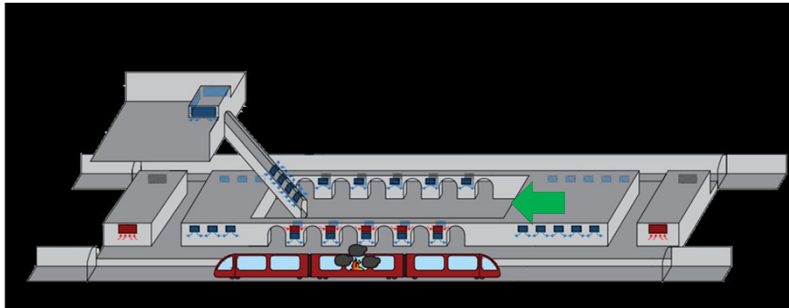


400 people on platform +300 people per train



200 people on platform +150 people per train

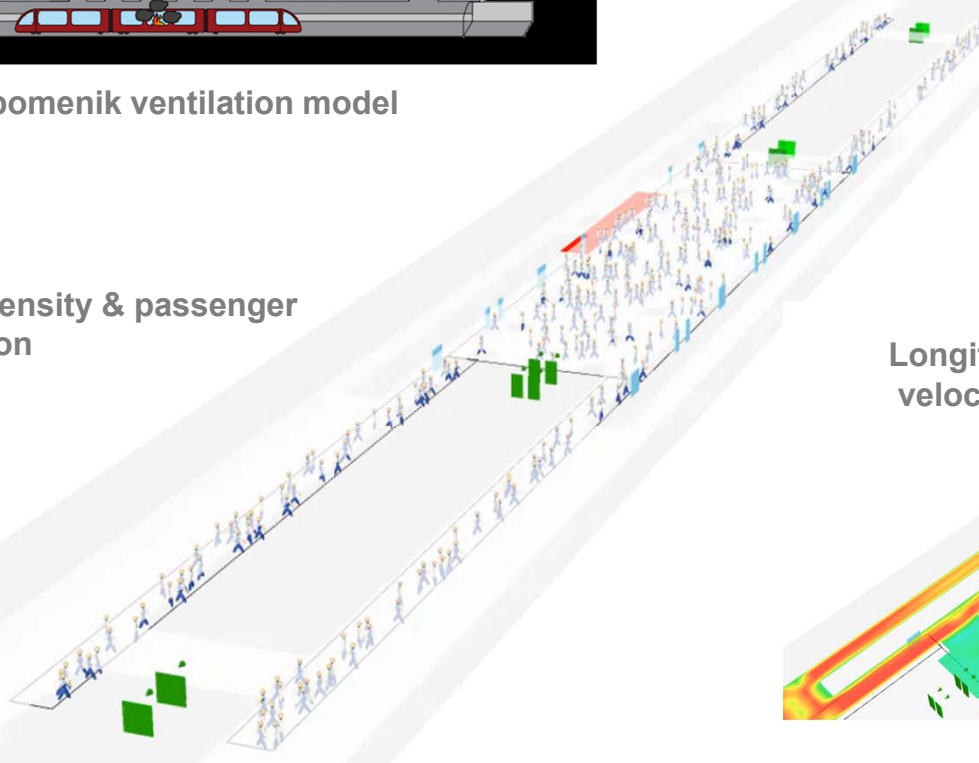
CONSEQUENCE ANALYSIS



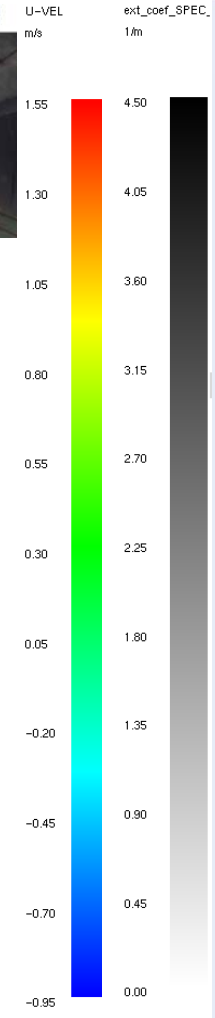
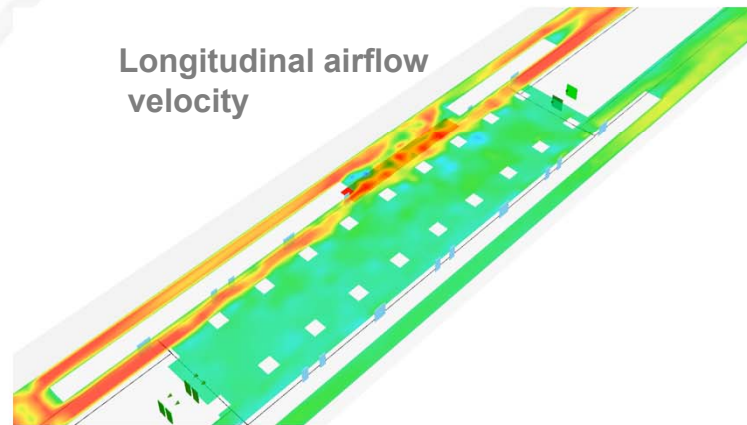
Vukov Spomenik ventilation model



Smoke density & passenger evacuation



Longitudinal airflow velocity



RISK ASSESSMENT

INVESTIGATED VARIANTS

- **Reference Variant (Ref)**
- Standard Variant (Standard)
- Operational Measure Variant I (Op I)
- Operational Measure Variant II (Op II)
- Guard Rails Variant (GRail)
- Hot Axle Boxes Variant (HotAB)
- Lighted Escape Way Variant (Escape Way)
- Emergency Exit Variant (EE)

„...the Reference Variant resembles the tunnel in its **current design** and train numbers but **without DG** wagons...”

Train type	Trains per day
Passenger trains	74
Non-DG freight trains	15
DG freight trains	0

RISK ASSESSMENT

INVESTIGATED VARIANTS

- Reference Variant (Ref)
- **Standard Variant (Standard)**
- Operational Measure Variant I (Op I)
- Operational Measure Variant II (Op II)
- Guard Rails Variant (GRail)
- Hot Axle Boxes Variant (HotAB)
- Lighted Escape Way Variant (Escape Way)
- Emergency Exit Variant (EE)

„... the Standard Variant resembles the tunnel in its **current design including the DG** traffic of the former bypass...“

Train type	Trains per day
Passenger trains	74
Non-DG freight trains	7
DG freight trains	8

RISK ASSESSMENT

INVESTIGATED VARIANTS

- Reference Variant (Ref)
- Standard Variant (Standard)
- **Operational Measure Variant I (Op I)**
- Operational Measure Variant II (Op II)
- Guard Rails Variant (GRail)
- Hot Axle Boxes Variant (HotAB)
- Lighted Escape Way Variant (Escape Way)
- Emergency Exit Variant (EE)

„...Operational Measure Variant I resembles the Standard Variant but with **restricting DG trains exclusively to night hours** where no passenger trains enter the tunnel and no passengers are present at the tunnel stations...“



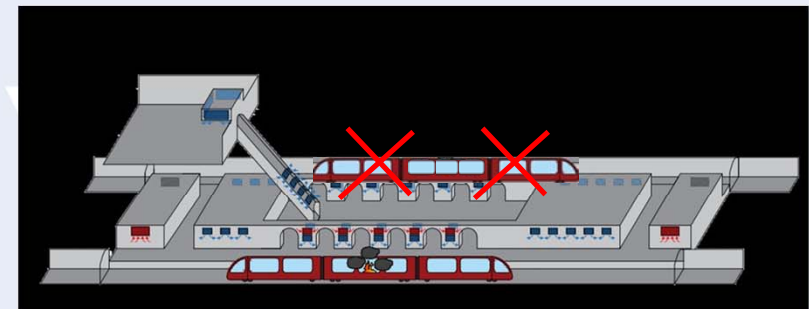
Closed 00:00 – 04:00

RISK ASSESSMENT

INVESTIGATED VARIANTS

- Reference Variant (Ref)
- Standard Variant (Standard)
- Operational Measure Variant I (Op I)
- **Operational Measure Variant II (Op II)**
- Guard Rails Variant (GRail)
- Hot Axle Boxes Variant (HotAB)
- Lighted Escape Way Variant (Escape Way)
- Emergency Exit Variant (EE)

„...Operational Measure Variant II resembles the Operational Measure Variant I but with the **additional restriction for passenger trains to omit stops at tunnel stations** if an incident is already detected in the opposite tunnel tube...“



RISK ASSESSMENT

INVESTIGATED VARIANTS

- Reference Variant (Ref)
- Standard Variant (Standard)
- Operational Measure Variant I (Op I)
- Operational Measure Variant II (Op II)
- **Guard Rails Variant (GRail)**
- Hot Axle Boxes Variant (HotAB)
- Lighted Escape Way Variant (Escape Way)
- Emergency Exit Variant (EE)

„...Guard Rails Variant resembles the Operational Measure Variant II with **additional Guard Rails located in the vicinity of all switches...**“



RISK ASSESSMENT

INVESTIGATED VARIANTS

- Reference Variant (Ref)
- Standard Variant (Standard)
- Operational Measure Variant I (Op I)
- Operational Measure Variant II (Op II)
- Guard Rails Variant (GRail)
- **Hot Axle Boxes Variant (HotAB)**
- Lighted Escape Way Variant (Escape Way)
- Emergency Exit Variant (EE)

„...Hot Axle Boxes Variant resembles the Operational Measure Variant II with **additional Hot Axle Boxes** installed... “



RISK ASSESSMENT

INVESTIGATED VARIANTS

- Reference Variant (Ref)
- Standard Variant (Standard)
- Operational Measure Variant I (Op I)
- Operational Measure Variant II (Op II)
- Guard Rails Variant (GRail)
- Hot Axle Boxes Variant (HotAB)
- **Lighted Escape Way Variant (Escape Way)**
- Emergency Exit Variant (EE)

„...Lighted Emergency Walk Way Variant resembles the Operational Measure Variant II where a **continuous escape way equipped with orientation lighting** is considered along the whole tunnel....“



RISK ASSESSMENT

INVESTIGATED VARIANTS

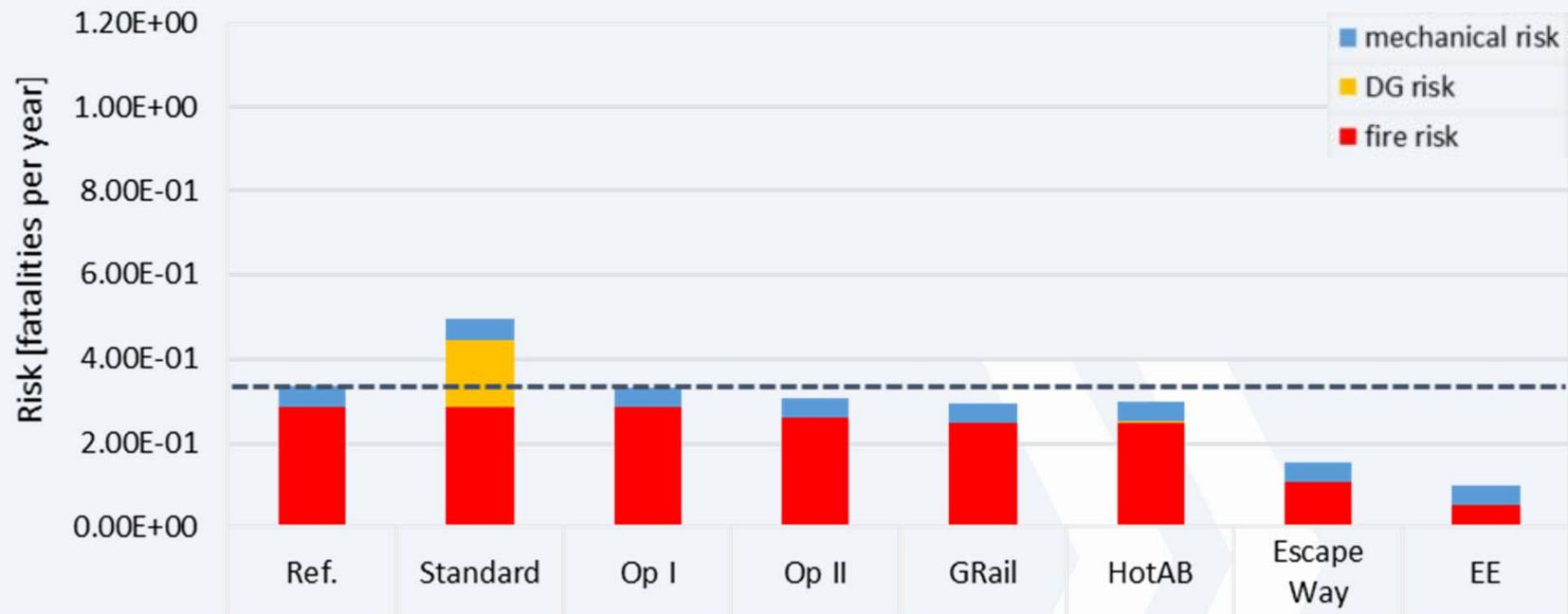
- Reference Variant (Ref)
- Standard Variant (Standard)
- Operational Measure Variant I (Op I)
- Operational Measure Variant II (Op II)
- Guard Rails Variant (GRail)
- Hot Axle Boxes Variant (HotAB)
- Lighted Escape Way Variant (Escape Way)
- **Emergency Exit Variant (EE)**

„...Emergency Exit Variant resembles the **Lighted Escape Way Variant with additional cross-cuts every 500 m** serving as emergency exits to the parallel tube...”



RESULTS

Comparison of design variants - current traffic
maximal passenger occupation



CONCLUSIONS



- **Fire- and DG-incidents** constitute the major part of the risk profile of the Vračar tunnel
- **Without** any measures the DG-traffic leads to an **increase of the total risk (+32%)**
- The **separation of DG-traffic and passengers** showed to be a very effective measure
- **Operational measures** (Op I & OP II) showed to be sufficient to **fulfill legal obligations**
- The residual tunnel risk mainly arises from **passenger train fires aside the station**;
if a **further risk reduction** is to be achieved, the lever must be set at the implementation of safety measures specially effective for evacuation aside the station
(→ lighted escape way and emergency exits)

THANK YOU FOR YOUR ATTENTION!

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