Risk assessment of zero-flow ventilation strategy for fires in bi-directional tunnels with longitudinal ventilation

Ichiro Nakahori and Toshiaki Sakaguchi, Sohatsu Systems Laboratory Inc.
Bernhard Kohl and Christoph Forster, ILF Consulting Engineers
Alan Vardy, University of Dundee

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EXPERTS IN FLUID ENGINEERING

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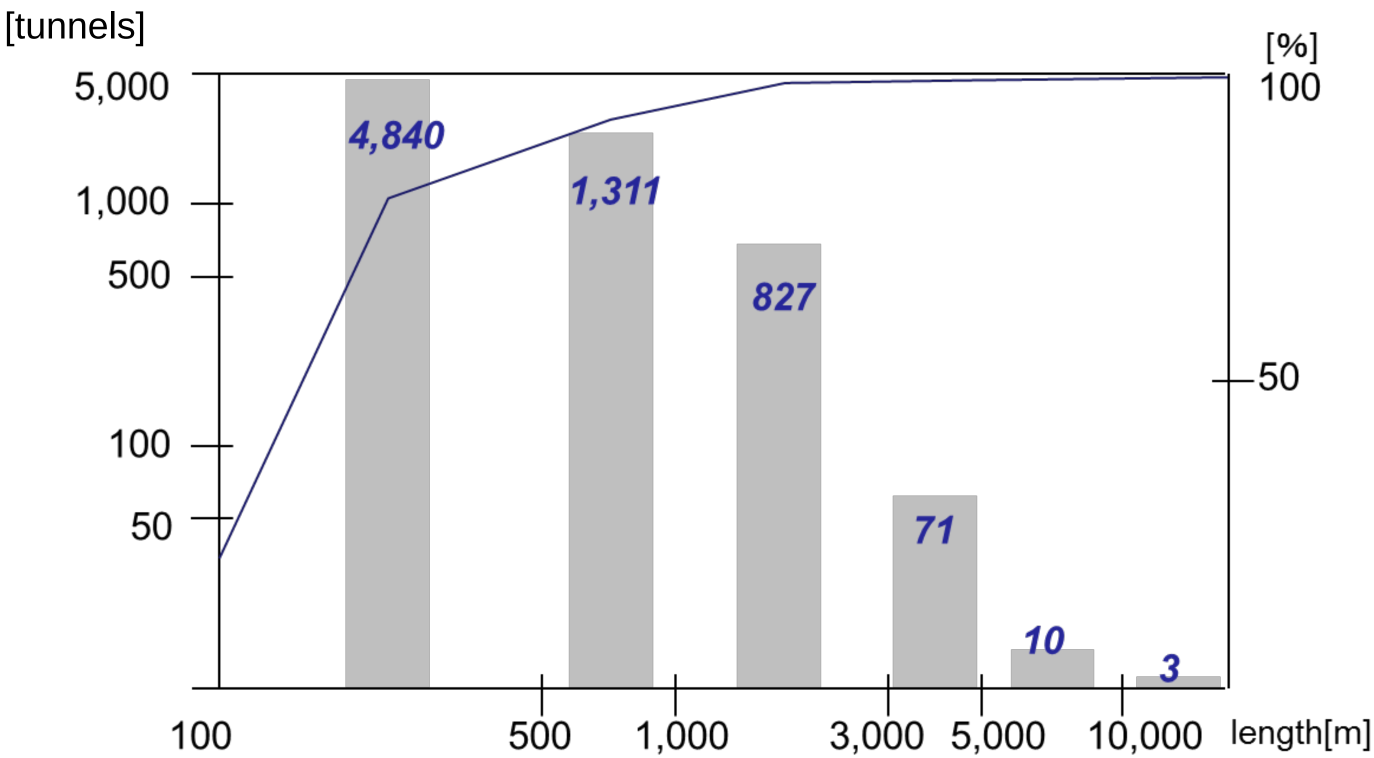
Tunnels in Japan



Distribution map over tunnel length

Background

- In **single tube** tunnels with **bidirectional** operation & **longitudinal** ventilation, fires can be especially dangerous
- **Cars will queue on both sides of the fire**. No option for smoke management will avoid endangering people
- In this situation, the **fire operation mode of the longitudinal ventilation** will strongly influence self-rescue opportunities
- **Two main strategies** are used: 1. blow smoke in a controlled direction at low speed; 2. switch off the ventilation system

Objectives of paper

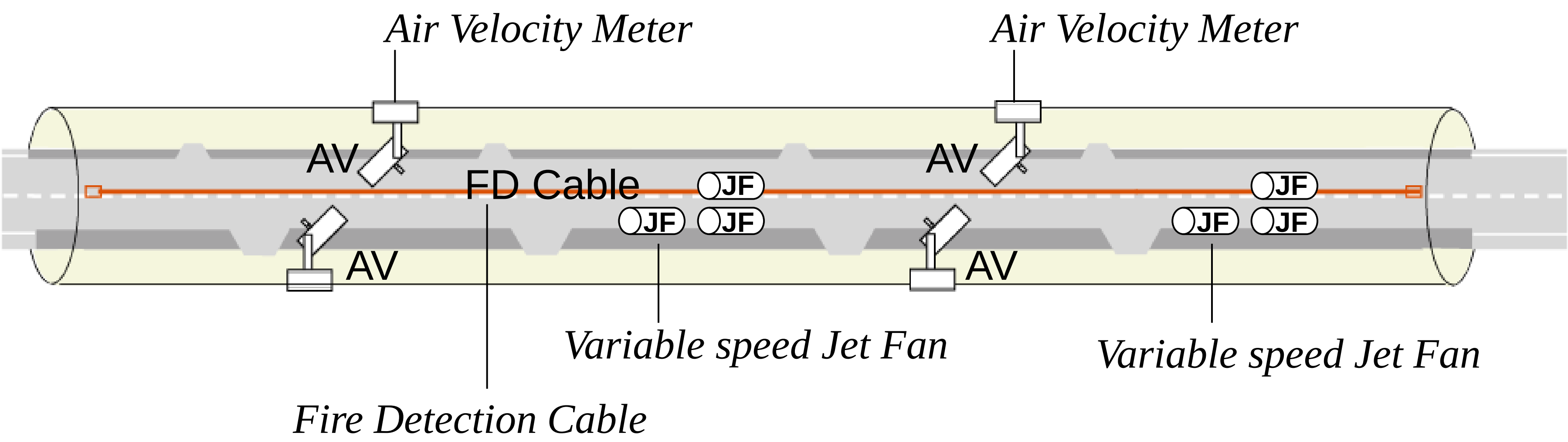
- Use **risk-assessment** to assess the merits of **zero-flow control** as a ventilation strategy in fire emergencies
- **Two methods of risk assessment** are proposed and applied to a bi-directional, longitudinally-ventilated tunnel in Japan:

  1) deterministic; 2) probabilistic [TuRisMo2]

Zero-flow control strategy in tunnel fires

- Zero-flow control was **first applied in the Kan-etsu Tunnel** in Japan (1985 BHR)
- Few subsequent applications because of **difficulty in achieving stable zero-flow conditions** with old technology
- Modern speed control eliminates this drawback – e.g. **inverter-driven jet-fans** for speed control (2009 BHR)

Realization of zero-flow control at the Yoka Tunnel



Equipment for zero-flow response to fire

Realization of zero-flow control at the Yoka Tunnel

Inverter Panels for the Yoka Tunnel

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Methodical approaches

- **Deterministic scenario-based approach** common in Japan
  - select and simulate **specific fire scenarios**
    assess results as **“safe”** or **“fatal”**
- **Probabilistic, system-based approach** used in several European countries (e.g. Austrian Tunnel Risk Model)
  - develop and assess a representative set of scenarios
    simulate **a standard set of fire scenarios**
    calculate overall risk (**expected risk value**)

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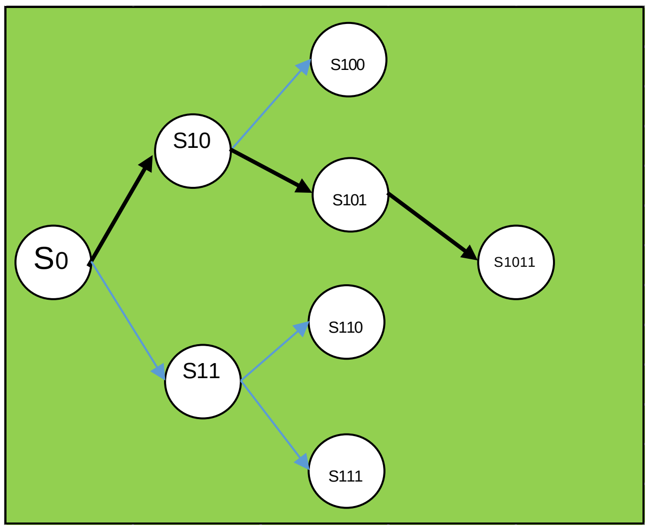
Methodical approaches – 1

Scenario-based approach: select and assess specific scenarios

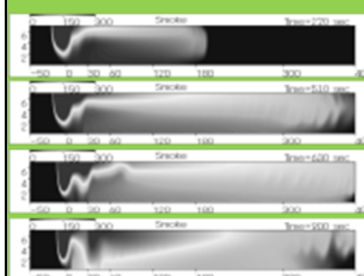
Scenario analysis -
Fire scale, Fire location, Natural wind, Traffic flow, Vehicle speed, Traffic congestion

Consequence analysis:
Worst scenario

Results



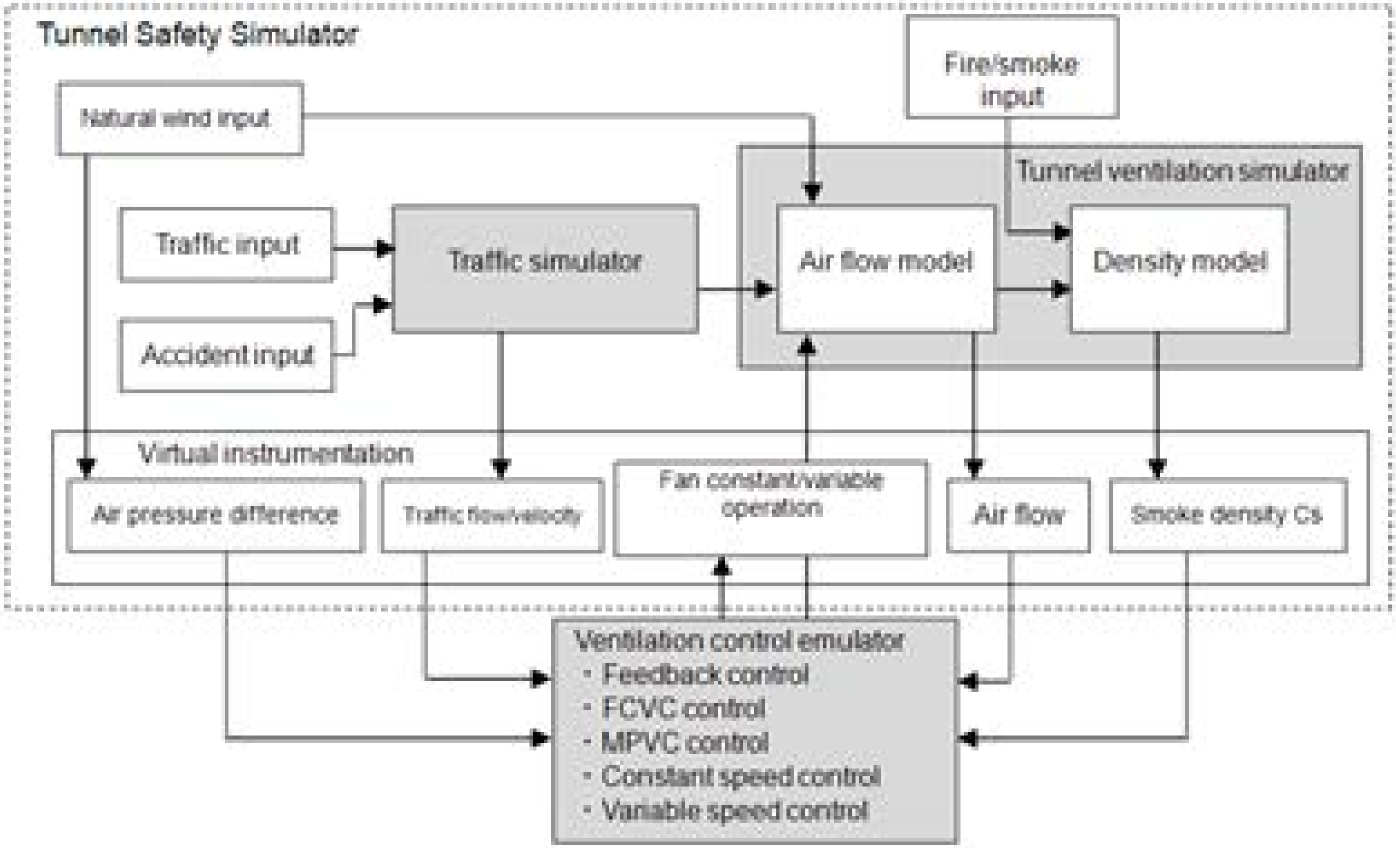
Smoke density propgation



SAFE

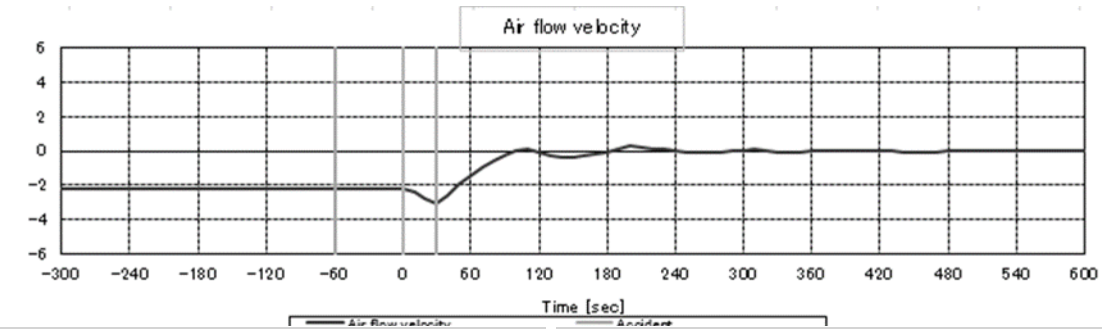
FATAL

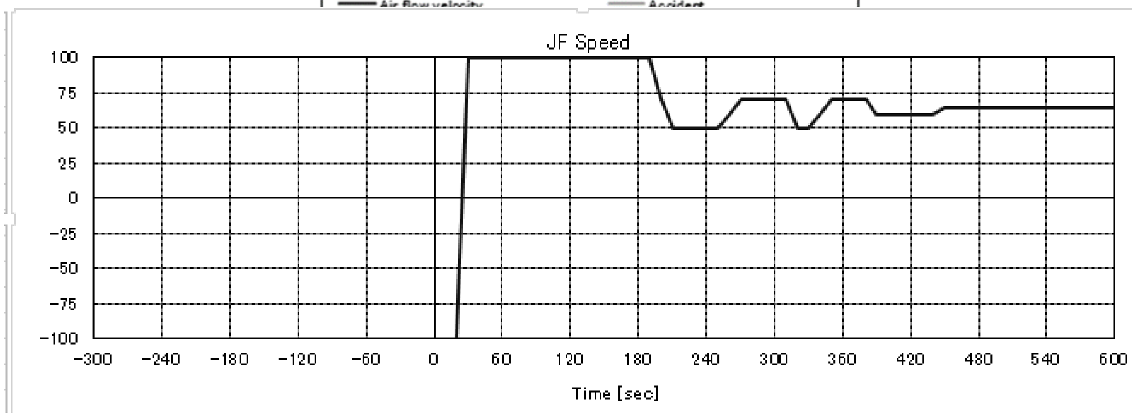
Methodical approaches – 1



Results of assessment in a typical tunnel

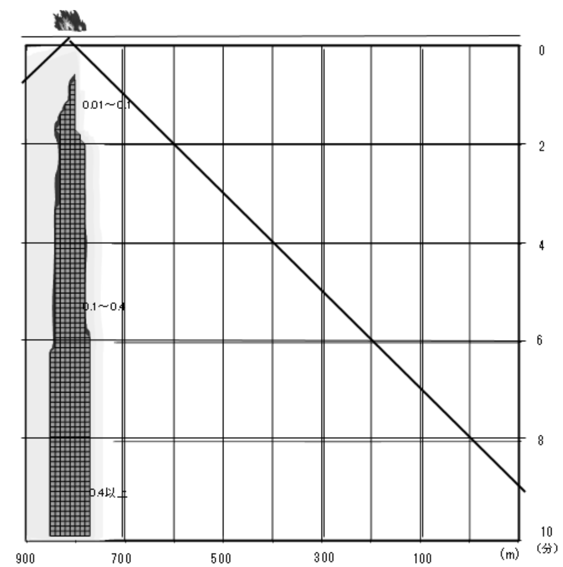
Evolution of air-flow velocity and jet-fan output in deterministic method



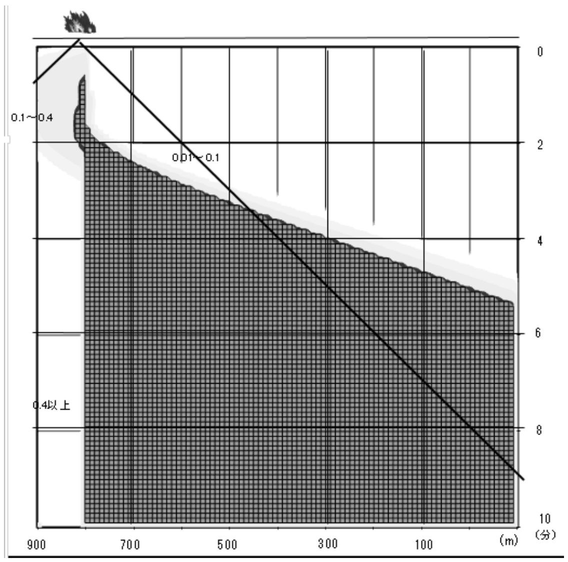


Results of assessment in a typical tunnel

Smoke density evolution and path of escapee in deterministic method



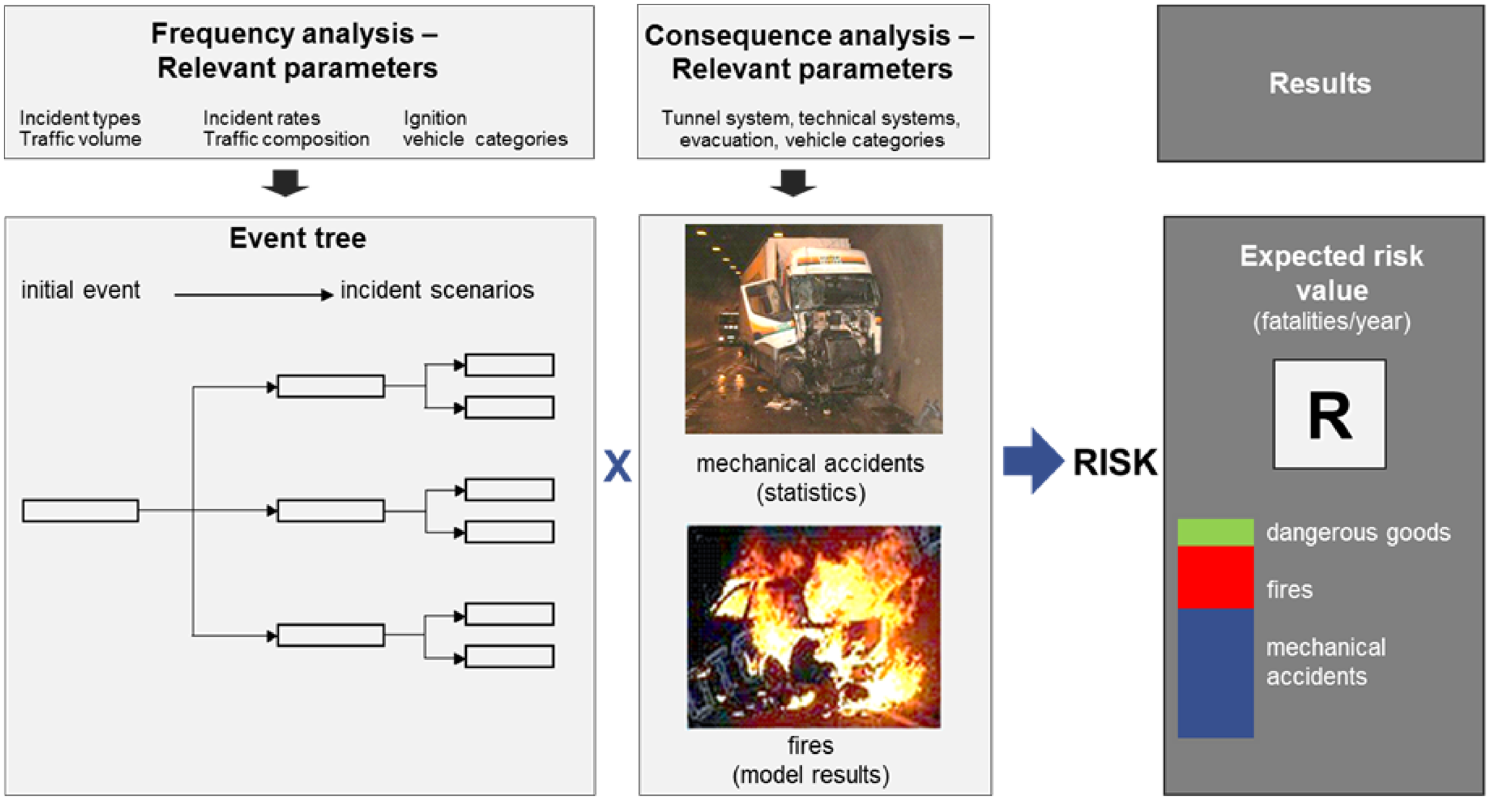
Zero-flow



Shutdown

Method 2: System-based approach

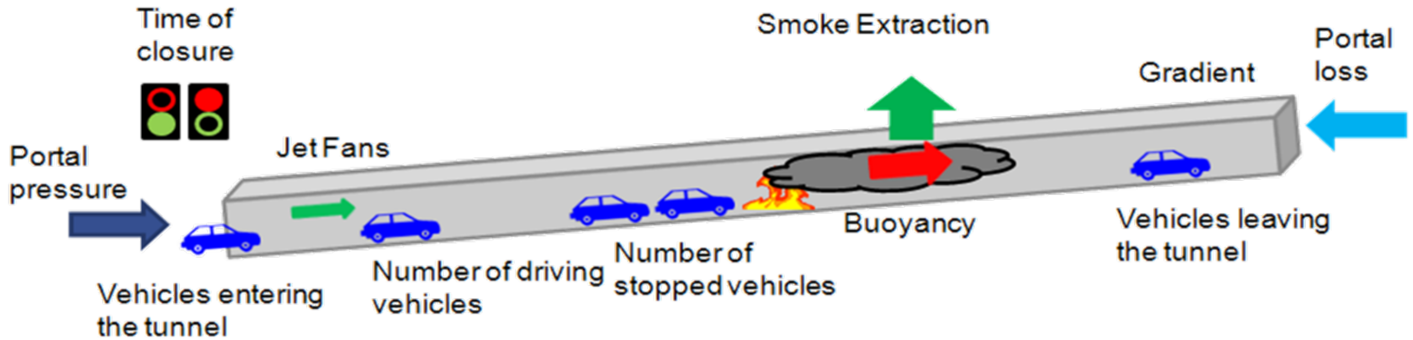
integrated, holistic assessment of the whole tunnel system



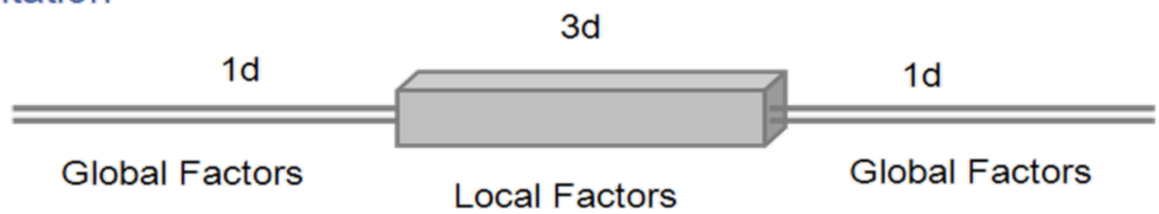
TuRisMo consequence analysis: smoke propagation

Combined unsteady 1D/3D Simulations

Influencing Factors



Implementation

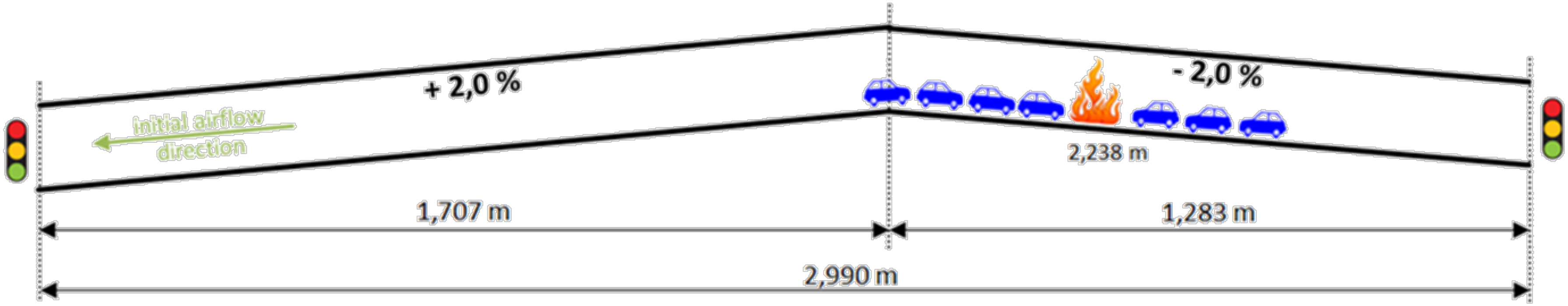


TuRisMo consequence analysis: evacuation model

- Output of smoke propagation simulation: temperature, flue gas concentrations, extinction co-efficient at a height of 1.6m
- Transferred directly into egress model, influencing the movements of people during evacuation
- Visibility influences walking speed, accumulated physiological effects may cause immobility (Purser model)

Results of assessment in a typical tunnel

Definition of a model tunnel



Tunnel system	Bidirectional tunnel with 1 tunnel tube and 1 lane per direction
Emergency exits	From 0 to 5
Tunnel cross section	Vaulted, 71m² (8.4 m diameter)
Traffic volume	1,438 vehicles/hour
Traffic mix	69.5 % passenger cars 30.5 % HGV (incl. busses)
Traffic speed	80 km/h

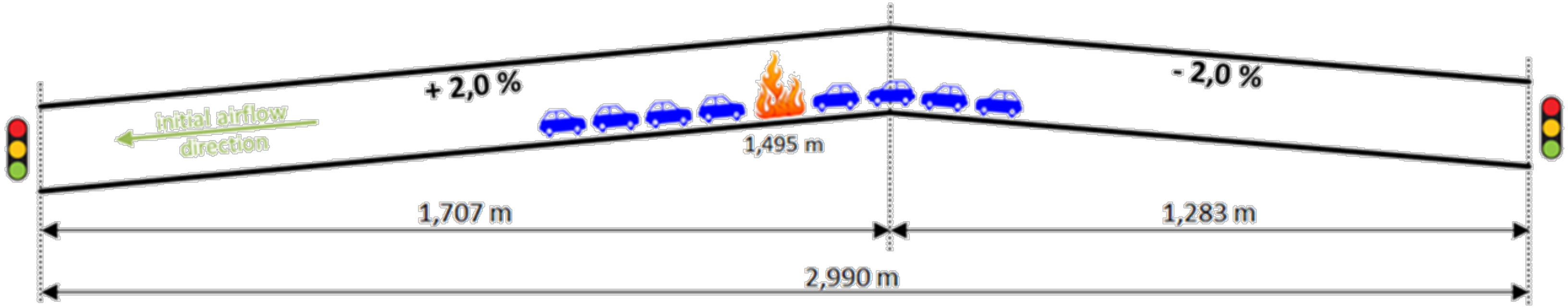
Results of assessment in a typical tunnel

Austrian Tunnel Risk Model: broad range of many different scenarios with varying parameters, taken into account in a statistical manner

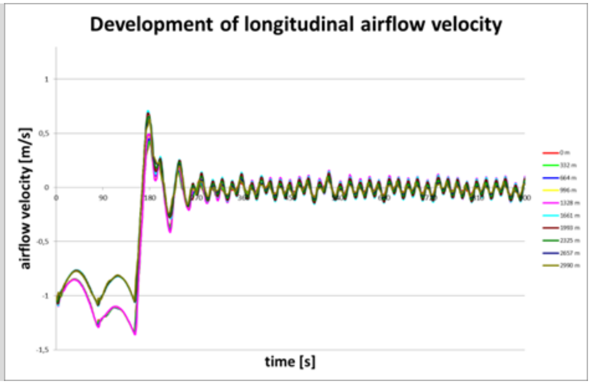
- **3 fire sizes** (5MW, 30MW, 100MW)
- **5 fire locations**– 3 in uphill, 2 in downhill section
- **9 traffic scenarios** (3 different traffic loads combined with 3 different symmetry scenarios)
- All together 135 fire / traffic combinations simulated for the model tunnel

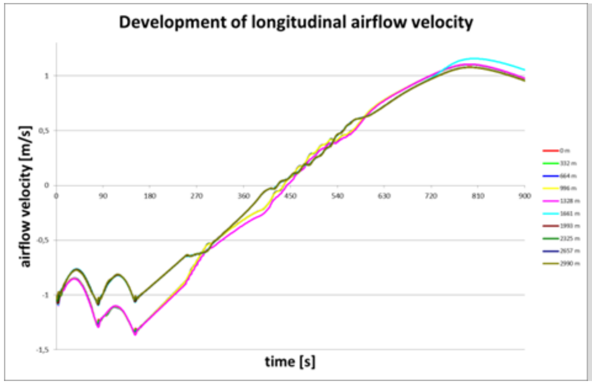
Results of assessment in a typical tunnel

Demonstration of effects of the two ventilation strategies on the basis of one selected scenario (30MW fire in central tunnel section)



Zero-flow strategy

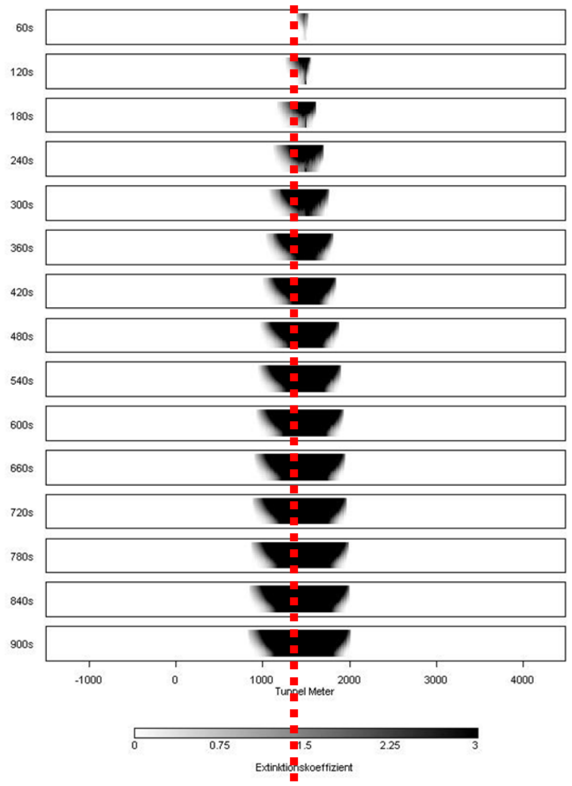


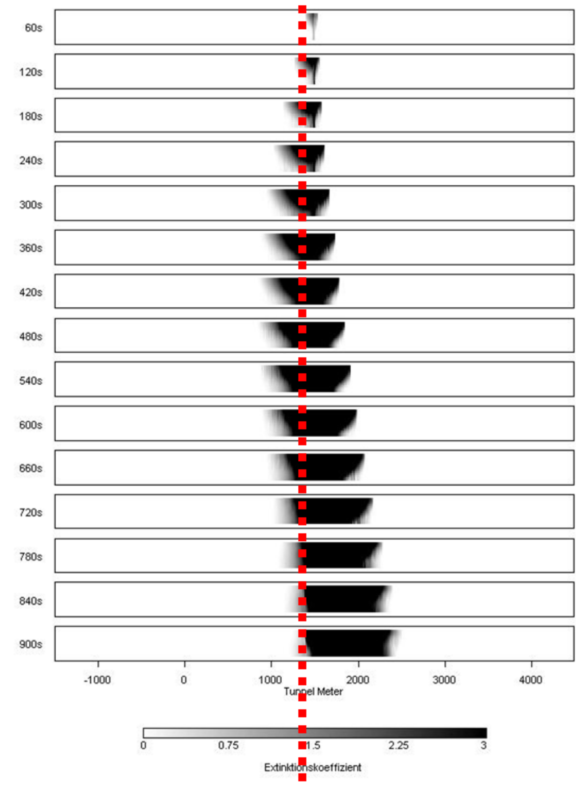


Shutdown strategy

Smoke propagation of a 30MW fire in time steps

Zero-flow strategy





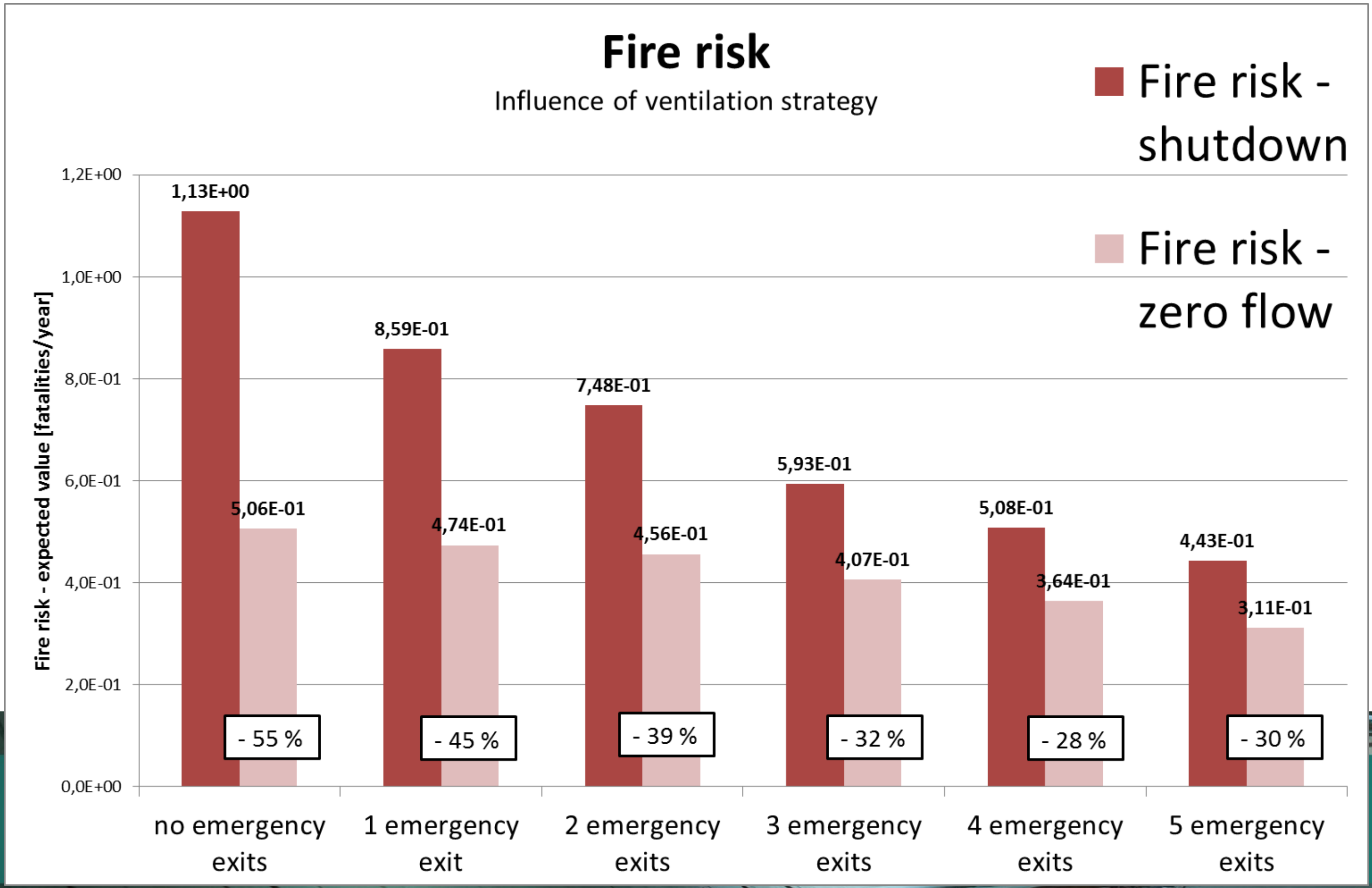
Shutdown strategy

Smoke propagation of a 30MW fire in time steps

- Initial airflow towards left side (operational ventilation), smoke propagates towards left side within the first 2-3 minutes, no difference between ventilation strategies
- Later the **zero-flow strategy** leads to smoke propagation to both sides at low speed
- The **shutdown strategy** leads to a change in direction of smoke propagation after 8-10 minutes (due to longitudinal ventilation and buoyancy effects)
- The **shutdown strategy** leads to considerably higher smoke propagation velocities and hence to a reduction of self rescue chances

Results of assessment in a typical tunnel

Fire risk in dependence of ventilation strategy and emergency exit distance – outcome of statistical approach



Pros & Cons
of different methodical approaches

	Pros	Cons
Scenario Analysis (deterministic)	• Easy to understand results • Enable to customize scenario to each tunnel • Statistical frequency data not required	• Will not represent whole scenarios
TuRisMo 2 (probabilistic)	• Outcomes of all scenarios included in composite overall result • Systematic quantitative assessment of safety measures • Allows look in detail at intermediate results	• No feedback between fire growth and other parameters (e.g. longitudinal airflow velocities)

Conclusions

- **Two risk assessment approaches** have been presented to assess zero-flow control as risk mitigation strategy for tunnel fires in bidirectional, longitudinally ventilated tunnels: a **scenario based deterministic approach** and a **system based probabilistic approach**
- Both approaches demonstrate that the **zero-flow strategy ensures more opportunities to evacuate safely** than the shutdown strategy
- The system-based approach shows that the **zero-flow strategy reduces the expected total fire risk by 50%** (without emergency exits)
- The relative advantage reduces with increasing number of emergency exits (e.g. to 30% with an emergency exit distance of 500m)

Thank you!

CONTACT:

Toshiaki Sakaguchi, Sohatsu Systems Laboratory Inc. *- toshiaki.sakaguchi@verizon.net*
Bernhard Kohl, ILF Consulting Engineers *- bernhard.kohl@ilf.com*
Alan Vardy, University of Dundee *- a.e.vardy@dundee.ac.uk*