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

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Contents

• Background and objective of paper
• Zero-flow control strategy in tunnel fires
• Methodical approach
• Results of assessment in a typical tunnel
• Analysis of assessment
• Conclusions
Tunnels in Japan

Distribution map over tunnel length

[Graph showing the distribution of tunnels based on length, with categories for different lengths and the number of tunnels in each category.]
**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

Air Velocity Meter

FD Cable

Variable speed Jet Fan

Fire Detection Cable

Air Velocity Meter

Equipment for zero-flow response to fire
Realization of zero-flow control at the Yoka Tunnel

Inverter Panels for the Yoka Tunnel
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**)
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 propagation

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

- Time of closure
- Portal pressure
- Jet Fans
- Number of driving vehicles
- Number of stopped vehicles
- Buoyancy
- Smoke Extraction
- Gradient
- Portal loss

Implementation

1d

Global Factors

3d

Local Factors

1d

Global Factors
TuRisMo consequence analysis: evacuation model

- Output of smoke propagation simulation: temperature, flue gas concentrations, extinction coefficient 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

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

Fire risk
Influence of ventilation strategy

Fire risk - shutdown

Fire risk - zero flow

<table>
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<tr>
<th>Fire risk - expected value [fatalities/year]</th>
<th>1,13E+00</th>
<th>5,06E-01</th>
<th>8,59E-01</th>
<th>7,48E-01</th>
<th>5,93E-01</th>
<th>5,08E-01</th>
<th>4,43E-01</th>
<th>4,43E-01</th>
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</thead>
<tbody>
<tr>
<td>no emergency exits</td>
<td>- 55 %</td>
<td>- 45 %</td>
<td>- 39 %</td>
<td>- 32 %</td>
<td>- 28 %</td>
<td>- 30 %</td>
<td>- 30 %</td>
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<tr>
<td>1 emergency exit</td>
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<tr>
<td>5 emergency exits</td>
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## Pros & Cons
of different methodical approaches

<table>
<thead>
<tr>
<th></th>
<th>Pros</th>
<th>Cons</th>
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</table>
| **Scenario Analysis**  | • Easy to understand results  
  • Enable to customize scenario to each tunnel  
  • Statistical frequency data not required | • Will not represent whole scenarios                          |
| **(deterministic)** |                                                                      |                                                             |
| **TuRisMo 2**       | • 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)                  |
| **(probabilistic)** |                                                                      |                                                             |
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!

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