Risk evaluation for road tunnels - Current developments

6th International Conference “Tunnel safety and ventilation”
Graz, 23rd April 2012

\[ R_m = \sum_{i,k} H_{ik} \cdot A_{ik} \cdot \varphi_k \left( A_{ik} \right) \cdot G_k \]
How safe is safe enough?
Perception and evaluation of risk (i)

«Zug-Surfer» tödlich verunfallt
Kopf schlug gegen Signal

Ein 20jähriger Mann ist in der Nacht auf den Samstag kurz vor dem Bahn-

S-Bahn rammte Schnellzug: 1 Todesopfer

Zürich. – Ein 22jähriger Mann ist am frühen Samstagabend bei einem schwe-
Perception and evaluation of risk (ii)

“Neue Zürcher Zeitung”, 6th June 2005

Tunnel fire Fréjus: 2 fatalities

Accident on French highway: 5 fatalities

Accident on Swiss rural road: 3 fatalities
Risk assessment: Process

- What might happen?
- How often?
- What are the consequences?
- Is the risk acceptable?
- Necessary (and cost-effective) measures in order to get a safe system?
Risk assessment: Types of risk

Different types of risk can be addressed in a risk analysis

- **Risk to man**
  - **Societal risk**: Harm to a specific group of people
  - **Individual risk**: Harm to an individual person

- **Economical loss**

- **Availability of infrastructure**

- **Damage to environment**

- **Damage to immaterial values**
Risk assessment: Methods / models

Intuitive Approach
- Expert judgment
- Brainstorming
- Delphi-method
- What-if-method
...

Standardised approach
- Checklist
- PHA
- HAZOP
- MORT
- Safety review audit
...

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Statistical approach
- Data appraisal
- Data analysis
...

Simulation

Qualitative

Spread/Effect models

Analytical approach
- Logical trees

Quantitative

Factor analysis
- \( R = x_1 \cdot x_2 \cdot x_3 \)
Risk assessment: Analysis and evaluation

Risks analysis

- Technical/scientific process: Identification, structuring and assessment of risk

Risk evaluation

- "Is the risk acceptable?"
- Socio-political process including ethical, political and societal aspects
- Strongly influenced by risk perception → common sense, culture, experiences, ...

→ No “right” or “wrong” risk evaluation criteria
Factors influencing risk perception (i)

<table>
<thead>
<tr>
<th>Understanding</th>
<th>Voluntariness</th>
<th>Controllability</th>
<th>Perceived benefit</th>
</tr>
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<tbody>
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</table>

### Risk case

<table>
<thead>
<tr>
<th>Risk case</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1.png" alt="Image A" /></td>
<td><img src="image2.png" alt="Image B" /></td>
<td><img src="image3.png" alt="Image C" /></td>
<td><img src="image4.png" alt="Image D" /></td>
</tr>
</tbody>
</table>

### Willingness for prevention

<table>
<thead>
<tr>
<th>Willingness for prevention</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image5.png" alt="Image A" /></td>
<td><img src="image6.png" alt="Image B" /></td>
<td><img src="image7.png" alt="Image C" /></td>
<td><img src="image8.png" alt="Image D" /></td>
</tr>
</tbody>
</table>
Factors influencing risk perception (ii)

- Familiarity
- Catastrophic potential
- Dreadfulness
- Awareness
- Natural / man-made
- Reversibility
- Scientific uncertainty
# Safety strategies for road tunnels

## Prescriptive approaches
- A tunnel is safe if it is designed in line with valid regulations
  - Guidelines / regulations
  - Safety Audits
  - Checklists
  - Expert judgments
  - …

## Risk based approaches
- A tunnel is safe if it meets predefined risk criteria
  - Societal risk, e.g.:
    - Expected value
    - FN diagram
    - Cost-effectiveness
  - Individual risk / mortality
  - …

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
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</table>

\[
R = \sum_{i=1}^{n} A_i \cdot q_i \cdot (A_i - G_i)
\]
### Evaluation of societal risk: Principles / criteria

<table>
<thead>
<tr>
<th>Relative criteria</th>
<th>Absolute criteria</th>
<th>Cost-effectiveness</th>
</tr>
</thead>
</table>

#### Risk at least as low as risk of “reference state / tunnel”
- → risk is acceptable

#### Risk lower than defined (absolute) threshold
- → risk is acceptable

#### Comparison of efficiency of safety measure and its risk reduction potential
- A tunnel is safe, if all cost-effective measures are implemented
Practical applications: EV (i)

**Expected value as relative criteria**

<table>
<thead>
<tr>
<th></th>
<th>DG risk</th>
<th>Fire risk</th>
<th>Mechanical risk</th>
<th>Overall risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference tunnel EC-Directive</td>
<td>0.0023</td>
<td>0.0034</td>
<td>0.0021</td>
<td>0.1079</td>
</tr>
<tr>
<td>Reference tunnel RVS trans. v.</td>
<td>0.0025</td>
<td>0.0024</td>
<td>0.0022</td>
<td>0.1075</td>
</tr>
<tr>
<td>Tunnel Učka incl. measures</td>
<td>0.1031</td>
<td>0.1017</td>
<td>0.1009</td>
<td>0.1052</td>
</tr>
</tbody>
</table>

**Austrian approach**

- **Comparison with reference tunnel/state**
- **Definition of reference tunnel**
Practical applications: EV (ii)

Expected value as absolute criteria

<table>
<thead>
<tr>
<th>Country</th>
<th>Target value EV (DG transports) [fatalities per year]</th>
<th>Application</th>
</tr>
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<tr>
<td>Austria, France, Greece</td>
<td>• Total EV: 1.0 x 10^-3</td>
<td>Per tunnel</td>
</tr>
<tr>
<td>Germany</td>
<td>• Fire: 5.0 x 10^-3</td>
<td>Per tunnel-km</td>
</tr>
<tr>
<td></td>
<td>• Fire/Explosion: 2.2 x 10^-3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Explosion: 1.0 x 10^-6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Toxic effects: 4.0 x 10^-4</td>
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- Definition of target values
- Target values linked to specific method and scope
- Uncertainties
Practical application: FN diagram

- Italy upper limit
- Italy (lower limit)
- Switzerland (DG; per 100 m; upper limit)
- Switzerland (DG; per 100 m; lower limit)
- Germany (DG; per 1 km)
Practical application: Cost-effectiveness (i)

- Definition of marginal cost → risk acceptance criteria
- Marginal cost / Value of statistical life:
  - Direct consequences
  - Indirect consequences
  - Willingness to pay to prevent consequences

\[ R_m = \sum_{i} F_i \cdot C_i \cdot \phi_k(C_k) \cdot MC \]

- \( R_m \): Perceived monetised risk
- \( F_j \): Frequency event j
- \( C_j \): Consequences for event j
- \( \phi_i \): Aversion factor
- \( MC \): Marginal cost / VSOL

Cost

Total Cost

Optimum = Minimum

Cost for Safety Measures

Loss Expenses

Safety Measures

Graph showing the relationship between cost, safety measures, and total cost.
Practical application: Cost-effectiveness (ii)

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| Willingness to pay | ![Image 2](image2.png) |
| Direct / indirect consequences | |

- **German risk analysis method according to 2004/54/EG:**
  - 5 Mio. per prevented fatality (mechanical)
  - 10 Mio. per prevented fatality (fires)
Recommendations / Conclusions

- **Strategy for risk evaluation strongly depends on**
  - Specific scope and circumstances of the risk assessment
  - Applied method of risk analysis

- **Uncertainty and fuzziness in results**
  - Awareness
  - Sensitivity analysis

- **Risk evaluation by relative comparison may improve the robustness of conclusions drawn**

- **Risk assessment is only one of several elements for decision-making**

- **No “right” or “wrong” risk evaluation criteria**
PIARC report «Risk evaluation»

- PIARC Technical Committee C.4 / Working Group No. 2 “Road Tunnel Safety”

- Contents of the report
  - Risk assessment for road tunnels
  - Background to risk evaluation
  - Principles for risk evaluation
  - Legal implications of risk analysis
  - Current practice of risk analysis for road tunnels

- PIARC website: [http://www.piarc.org](http://www.piarc.org)