Evaluation and interpretation of f/n-curves: Development of a new tool for transparent and traceable decision making

6th international conference on Tunnel Safety and Ventilation – Graz /Austria

14th March 2012

Dr.-Ing. Goetz Vollmann
Prof. Dr.-Ing. Markus Thewes
Dipl.-Ing. Sissis Kamarianakis

Ruhr University Bochum,
Institute for Tunnelling and Construction Management
Content

- The SOLIT² project
- Quantitative risk assessments and their evaluation
- Alternative approach for traceable decision making
- Exemplarily application
- Conclusions and outlook
Content

- The SOLIT² project
- Quantitative risk assessments and their evaluation
- Alternative approach for traceable decision making
- Exemplarily application
- Conclusions and outlook
Partners within SOLIT²

Gefördert durch das
Bundesministerium für Wirtschaft und Technologie

FOGTEC
FIRE PROTECTION

BUNG
Beratende Ingenieure

STUVA

TÜV SÜD
Rail

RUB

TLB
The scope of SOLIT²

Is it possible to compensate “traditional” safety equipment by using water mist systems as a substitution?

**Target**: lower level of risks while requiring an equal level of costs compared with “traditionally “ equipped tunnels:

**Or**: equal level of risks while requiring a lower level of costs
Procedure (TLB-related):

- Conducting full-scale fire test together with the other partners for the evaluation of the specific and corresponding parameters

- Development of an appropriate LCC-Model for the cost evaluation

- Development of a methodology for traceable decision making, involving all parameters and indicators
Parameters of the evaluation

- **User related risk**: possible reduction of temperature, gas and smoke propagation von Temperatur,

- **Facility related risk**: possible reduction of temperature etc. - thereby reduction of possible damages and cost for refurbishment

- **Costs**: Reduction of whole-life-costs
Corresponding indicators

- **User related risks**: probabilities and fatalities, accumulated risks

- **Facility related risks**: availability, duration of refurbishment and repair

- **Costs**: Initial invest, re-invest, costs for inspection, maintenance and repair

- **Quintessence**: A methodology for assessing the applicability of any measure has take all these parameters and their corresponding indicators into account.
Content

- The SOLIT² project
- Quantitative risk assessments and their evaluation
- Alternative approach for traceable decision making
- Exemplarily application
- Conclusions and outlook
State of the art

QRAs and their evaluation

Source: PIARC 2008
Risk distribution and risk reduction

<table>
<thead>
<tr>
<th>Risk reduction</th>
<th>Effectiveness</th>
<th>Effectiveness</th>
<th>Risk value (comparison, limits)</th>
<th>Cost-effectiveness diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>Consequence</td>
<td>Frequency and consequences</td>
<td>Cost-effectiveness ratio</td>
</tr>
<tr>
<td></td>
<td>ΔF</td>
<td>ΔN</td>
<td>FN Matrix</td>
<td>Δcost/ΔRisk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FN Curve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Individual risk Δr</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Societal risk ΔRo</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Perceived risk ΔRp</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3. Overview of methods for risk assessments [12] [13]**

Source: PIARC 2008
QRAs and their evaluation

Display of results

![Graph showing probability distribution over damage]

- Probability [1/a]
- Damage n

- Display of results
- QRAs and their evaluation
Display of results

QRAs and their evaluation

Acceptability line/curve
Display of results

Relative Risk Comparison
\[ R_{\text{plan}} \leq R_{\text{RABT}} \]

Source: Heimbecher, Helsinki 2011
Display of results

- Alternative no. 1 (blue line): Lower risk for more probable events with around 10 fatalities
- Alternative no. 2 (red line): Lower risk at big events with >100 fatalities and a very low probability
- Risk evaluation => Result?

Source: Heimbecher, Helsinki 2011
QRAs and their evaluation

Display of results

- Configuration I
- Configuration II
- Configuration III

Probability [1/a] vs. Damage [Persons]

Logarithmic scale for probability and damage.
Content

⇒ The SOLIT² project
⇒ Quantitative risk assessments and their evaluation
⇒ Alternative approach for traceable decision making
⇒ Exemplarily application
⇒ Conclusions and outlook
Solving an hierarchical decision problem using AHP (Analytical Hierarchy Process)

Alternative approach
### Pairwise comparison

#### Residual Materials vs. Water

<table>
<thead>
<tr>
<th>Okologische Kriterien</th>
<th>Evaluationsmatrix</th>
<th>Normalisierung</th>
<th>Gewicht</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Em.</td>
<td>Ener.</td>
<td>Was.</td>
</tr>
<tr>
<td>Emissionen</td>
<td>1.00</td>
<td>3.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Energieverbrauch</td>
<td>0.33</td>
<td>1.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Wasser</td>
<td>0.13</td>
<td>0.20</td>
<td>1.00</td>
</tr>
<tr>
<td>Boden</td>
<td>2.00</td>
<td>6.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Reststoffmengen</td>
<td>0.17</td>
<td>0.25</td>
<td>2.00</td>
</tr>
<tr>
<td>FFH</td>
<td>0.33</td>
<td>2.00</td>
<td>7.00</td>
</tr>
</tbody>
</table>

\[ n = 6 \]
\[ Cl = (\lambda - n) / (n-1) \]
\[ \lambda = 6.27514 \]
\[ CR = 0.044 < 0.1 \]
The AHP-approach for QRAs in a nutshell

- Application of specific areas to the corresponding curve (Risk areas)
- Calculation of the influence (read: weight) of the specific area regarding the accumulated risk
- Analysis of the specific areas regarding possible change in ranking regarding the preferred configuration
- Sensitivity analysis
Hierarchical decision problem of an f/n-curve

Alternative approach
Alternative approach

“Hierarchisation” of the specific decision problem

\[
N_{RA_j} = \frac{N_{k,\text{max}}}{4}
\]

\[
1,00E-12 \\
1,00E-11 \\
1,00E-10 \\
1,00E-09 \\
1,00E-08 \\
1,00E-07 \\
1,00E-06 \\
1,00E-05 \\
1,00E-04 \\
1,00E-03 \\
1,00E-02 \\
1,00E-01 \\
1,00E+00
\]

\[
1 \\
10 \\
100 \\
1000
\]

\[
N_{RA_1} \\
N_{RA_2} \\
N_{RA_3} \\
N_{RA_4} \\
N_{k,\text{max}}
\]
Content

- The SOLIT² project
- Quantitative risk assessments and their evaluation
- Alternative approach for traceable decision making
- Exemplarily application
- Conclusions and outlook
Exemplarily application

Decision problem

- Data from a real project
- Building a hierarchical structure using AHP
Exemplarily application

Weight within Area 1
(nearly identical with overall accumulated risk)
Exemplarily application

Weight within Area 3
(2 possible changes in ranking)
Weight within Area 4

(2 possible changes in ranking)
Exemplarily application

Rank distribution and analysis

The dashed lines show the overall weight, which is achieved when a criterion is evaluated with 100% within its category whereas the weight of all other categories is not changed.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Config. 1</td>
<td>17.9%</td>
</tr>
<tr>
<td>Config. 2</td>
<td>61.8%</td>
</tr>
<tr>
<td>Config. 3</td>
<td>20.1%</td>
</tr>
</tbody>
</table>
Content

- The SOLIT² project
- Quantitative risk assessments and their evaluation
- Alternative approach for traceable decision making
- Exemplarily application
- Conclusions and outlook
Conclusion and outlook

The AHP-approach provides a possibility for a transparent evaluation of QRA-results without modifying the specific data (e.g. by applying aversion factors) or underestimating incidents with low probability and high damage.

Assessments become traceable, even years after the original evaluation.

The AHP-approach can also be applied for the evaluation of dangerous goods transportation where acceptability lines are used.
**Current developments**

- Development of a tool for automatized import of QRA-data within the AHP-surrounding

- Implementation of such assessments as well as structural assessments and the evaluation of LCC within a broader approach

- Development of a corresponding QRA-approach for structural assessments
Assessment methodology

Selection of an technically and financially optimized tunnel safety system

User safety
- Fatalities
- Probabilities
- ...

Struc. safety
- Spalling
- Loss of integrity
- ...

LCC
- Repair
- Maintenance
- ...

Target

Criteria
- Main
- Sub

Alternatives
- Alternative A
- Alternative B
- Alternative C

Conclusion and outlook
"Glück auf" and thank you for your kind attention!

Dr.-Ing. Goetz Vollmann  
Prof. Dr.-Ing. Markus Thewes  
Dipl.-Ing. Sissis Kamarianakis

Institute for Tunnelling and Construction Management /RUB