Cost Evaluation for traffic and transport infrastructure projects taking account of project risks

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Geohazards - Technical, Economical and Social Risk Evaluation
Cost evaluation for traffic and transport infrastructure projects

■ Present situation

• Budget .NE. Costs

realistisch. Und nachgerechnet muss auch: 3,9 Milliarden Mark waren angesetzt – im schlimmsten Fall werden es wohl um die 5,5 Milliarden werden, um von Nürnberg aus eine halbe Stunde schneller in München zu sein. Das Problem liegt im 90 Kilometer langen Neubauabschnitt zwischen Ingolstadt und Nürnberg im Irland.

COST HAZARD
# Present situation

<table>
<thead>
<tr>
<th>Project</th>
<th>Previous Budget</th>
<th>Realisation Time</th>
<th>Budget overrun [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arlberg railway tunnel (A)</td>
<td>12 million fl</td>
<td>1880</td>
<td>58</td>
</tr>
<tr>
<td>Bosruck tunnel (A)</td>
<td>7 million Kronen</td>
<td>1900</td>
<td>32</td>
</tr>
<tr>
<td>Semmering Railway Line (A)</td>
<td>10 million fl</td>
<td>1850</td>
<td>130</td>
</tr>
<tr>
<td>Gotthard Tunnel (CH)</td>
<td>42 million Francs</td>
<td>1875</td>
<td>60</td>
</tr>
<tr>
<td>Eurotunnel (GB-F)</td>
<td>7,000 million €</td>
<td>1985</td>
<td>114</td>
</tr>
<tr>
<td>Gotthard Base Tunnel (CH)</td>
<td>6,300 million CHF</td>
<td>2000 -</td>
<td>27</td>
</tr>
<tr>
<td>Tunnel Stans – Terfens (A)</td>
<td>1,250 million €</td>
<td>2000</td>
<td>40</td>
</tr>
<tr>
<td>Betuwelnie (NL)</td>
<td>2 million €</td>
<td>1995</td>
<td>104</td>
</tr>
<tr>
<td>NBS Cologne – Frankfurt (D)</td>
<td>2,500 million €</td>
<td>1993</td>
<td>104</td>
</tr>
</tbody>
</table>
ÖGG Guideline 2005

Aims of the guideline:

• Standardisation of cost estimation taking risk costs into account

• Presentation of objective procedures for decision making

• Creating sound data basis for future projects

Benefit for:

• Clients, investors, construction companies, engineers, insurance companies
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Cost evaluation for traffic and transport infrastructure projects

**Fundamentals**

Budget = Total costs (TC)

- Basic costs (B)
- Cost estimation of risks (R)
- Cost estimation of financial risk (F)

\[ TC = B + R + F \]
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**Fundamentals**

- The **basic costs** (B) are based on the design of the relevant project phase (degree of knowledge of the project), project sequence and market conditions, and can be calculated from the corresponding design status.
Risk costs

- Principal technical risks (R):
  - Geological risks
  - Design risks
  - Construction risks

- Principal other risks (F):
  - Financial risks
  - Operation risks
  - Political risks
  - Economic risks
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Risks in tunnelling

- **GEOLOGICAL RISK**
  - Level of extension and adequacy of investigations

- **DESIGN RISK**
  - Knowledge of rock and soil behaviour
  - Availability of resources

- **CONSTRUCTION RISK**
  - Tunnel depth and alignment
  - Surface constraints

- **FINANCIAL RISK**

- **OPERATION RISK**
Risks in tunnelling

- **GEOLOGICAL RISK**
  - Design flexibility vs. actual ground conditions

- **DESIGN RISK**
  - Experience of the designer
  - Constructability of proposed solutions

- **CONSTRUCTION RISK**
  - Management of environmental impact

- **FINANCIAL RISK**
  - Identification of potentially affected building, utilities and/or infrastructures

- **OPERATION RISK**
  - Contractual constraints
Risks in tunnelling

- GEOLOGICAL RISK
  - Appropriateness of construction method vs. actual ground conditions

- DESIGN RISK
  - Lack in industrializing the production cycle
  - Lack of experience on the contractor side
  - Contractual constraints

- CONSTRUCTION RISK
  - Stability of the excavation

- FINANCIAL RISK
  - Impact of the works on the surrounding environment

- OPERATION RISK

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Development of costs
Evaluation of costs

- Basic costs (B) and risk costs (R) can be determined by deterministic methods or probabilistic methods:

<table>
<thead>
<tr>
<th></th>
<th>BASIC COSTS</th>
<th>RISK COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMALL PROJECTS</td>
<td>Deterministic Method</td>
<td>Deterministic Method</td>
</tr>
<tr>
<td>BIG or COMPLEX</td>
<td>Deterministic or Probabilistic</td>
<td>Probabilistic Method</td>
</tr>
<tr>
<td>PROJECTS</td>
<td>Method</td>
<td></td>
</tr>
</tbody>
</table>
Deterministic risk cost evaluation - general

- Risk costs: $R_{\text{General}} = u \times B$

<table>
<thead>
<tr>
<th>Factor $u_{\text{General}}$</th>
<th>Complexity of the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design status</td>
<td>simple</td>
</tr>
<tr>
<td>Conceptual Design</td>
<td>11.5%</td>
</tr>
<tr>
<td>FEED</td>
<td>8.0%</td>
</tr>
<tr>
<td>Detailed Design</td>
<td>4.5%</td>
</tr>
</tbody>
</table>
Deterministic risk cost evaluation - geotechnical

- Risk costs: \( R_{\text{Geotechnical}} = u_{\text{Geotechnical}} \times B_{\text{Geotechnical}} \)

<table>
<thead>
<tr>
<th>Design status</th>
<th>Complexity of the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual Design</td>
<td>10.0%  15.0%  20.0%</td>
</tr>
<tr>
<td>FEED</td>
<td>7.5%   11.25%  15.0%</td>
</tr>
<tr>
<td>Detailed Design</td>
<td>5.0%   7.5%   10.0%</td>
</tr>
</tbody>
</table>
Deterministic risk cost evaluation - total

- Total risk costs (R):

\[ R = R_{\text{General}} + R_{\text{Geotechnical}} \]

\[ = u_{\text{General}} \times B + u_{\text{Geotechnical}} \times B_{\text{Geotechnical}} \]
## Probabilistic cost evaluation – Risk identification

<table>
<thead>
<tr>
<th>Risk potential</th>
<th>Risk scenarios</th>
</tr>
</thead>
</table>
| Locally confined failure – such as outbreaks from the crown area or small-scale failure of the excavation face | Outbreak up to 5 m³  
Outbreak up to 20 m³  
Local face failure up to 20 m³  
Local marked deformation (>50 mm heading, L = 20 m) |
| Extensive failure – from collapses (scope 500m³) to cave to the surface or extensive failure | Collapse 500 m³  
Extensive face failure >20 m³  
Cave to the surface |
Quantification of risk

- In the next step during risk assessment the risks determined in the risk identification process have to be quantified.

\[ R_i = W_i \times A_i \]

\( W \) .. Frequency of occurrence
\( A \) ... Costs of incident
**Frequency of occurrence in the construction period**

<table>
<thead>
<tr>
<th>Descriptive frequency class</th>
<th>Frequency class</th>
<th>Central value</th>
<th>Frequency interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very likely</td>
<td>5</td>
<td>1</td>
<td>&gt; 0.3</td>
</tr>
<tr>
<td>Likely</td>
<td>4</td>
<td>0.1</td>
<td>0.03 - 0.3</td>
</tr>
<tr>
<td>Occasional</td>
<td>3</td>
<td>0.01</td>
<td>0.003 - 0.03</td>
</tr>
<tr>
<td>Unlikely</td>
<td>2</td>
<td>0.001</td>
<td>0.0003 - 0.003</td>
</tr>
<tr>
<td>Very unlikely</td>
<td>1</td>
<td>0.0001</td>
<td>&lt; 0.0003</td>
</tr>
</tbody>
</table>

Eskesen et al. 2004
### Consequence classes

<table>
<thead>
<tr>
<th></th>
<th>Disastrous</th>
<th>Severe</th>
<th>Serious</th>
<th>Considerable</th>
<th>Insignificant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury to workers and emergency crew</td>
<td>&gt; 30 F</td>
<td>3 &lt; F &lt; 30</td>
<td>1 - 3 F</td>
<td>1 - 3 SI</td>
<td>&lt; 3 MI</td>
</tr>
<tr>
<td>(No. of fatalities / injuries*)</td>
<td></td>
<td>3 - 30 I</td>
<td>3 - 30 I</td>
<td>3 - 30 MI</td>
<td></td>
</tr>
<tr>
<td>Injury to third party persons</td>
<td>&gt; 3 F</td>
<td>1 - 3 F</td>
<td>1 - 3 SI</td>
<td>&lt; 3 MI</td>
<td>-</td>
</tr>
<tr>
<td>(No. of fatalities / injuries*)</td>
<td></td>
<td>3 - 30 I</td>
<td>3 - 30 MI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic loss to third party</td>
<td>&gt; 3</td>
<td>0.3 to 3</td>
<td>0.03 to 0.3</td>
<td>0.003 to 0.03</td>
<td>&lt; 0.003</td>
</tr>
<tr>
<td>(mio. Euro)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic loss to owner</td>
<td>&gt; 30</td>
<td>3 to 30</td>
<td>0.3 to 3</td>
<td>0.03 to 0.3</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td>(mio. Euro)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay in construction (per hazard)</td>
<td>&gt; 2 years</td>
<td>½ - 2 years</td>
<td>2 - 6 months</td>
<td>½ - 2 months</td>
<td>&lt; 2 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harm to the environment</td>
<td>permanent severe damage</td>
<td>permanent minor damage</td>
<td>longterm effects</td>
<td>impermanent severe damage</td>
<td>impermanent minor damage</td>
</tr>
</tbody>
</table>

* F = fatality, SI = serious injury, MI = minor injury

Eskesen et al. 2004
## Risk classification

<table>
<thead>
<tr>
<th>Risk Classification</th>
<th>Example of actions to be applied against each class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unacceptable</td>
<td>The risk shall be reduced at least to Unwanted regardless of the costs of risk mitigation</td>
</tr>
<tr>
<td>Unwanted</td>
<td>Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportional with the risk reduction obtained (ALARP principle, as low as reasonably practicable)</td>
</tr>
<tr>
<td>Acceptable</td>
<td>The hazard shall be managed throughout the project. Consideration of risk mitigation is not required</td>
</tr>
<tr>
<td>Negligible</td>
<td>No further consideration of the hazard is needed</td>
</tr>
</tbody>
</table>
## Hazard Ranking

<table>
<thead>
<tr>
<th>Risk Matrix</th>
<th>Frequency</th>
<th>Disastrous</th>
<th>Severe</th>
<th>Serious</th>
<th>Considerable</th>
<th>Insignificant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very likely</td>
<td>5</td>
<td>Unacceptable</td>
<td>Unacceptable</td>
<td>Unacceptable</td>
<td>Unwanted</td>
<td>Unwanted</td>
</tr>
<tr>
<td>Likely</td>
<td>4</td>
<td>Unacceptable</td>
<td>Unacceptable</td>
<td>Unwanted</td>
<td>Unwanted</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Occasional</td>
<td>3</td>
<td>Unacceptable</td>
<td>Unwanted</td>
<td>Unwanted</td>
<td>Acceptable</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Unlikely</td>
<td>2</td>
<td>Unwanted</td>
<td>Unwanted</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Negligible</td>
</tr>
<tr>
<td>Very unlikely</td>
<td>1</td>
<td>Unwanted</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
## Probabilistic cost evaluation – Risk identification

<table>
<thead>
<tr>
<th>Identified risk (groups)</th>
<th>Risk scenarios</th>
</tr>
</thead>
</table>
| $Z_1$: Stability of construction site | Outbreak up to 5 m³ ($X_1$)  
Outbreak up to 20 m³ ($X_2$)  
Local face failure up to 20 m³ ($X_3$)  
Local marked deformation (>50 mm heading, $L = 20$ m) ($X_4$) |
| $Z_2$: Excavation and support | Extensive face failure >20 m³ ($X_5$) |
| $Z_3$: Difficulties | Water ingress  
Gas - impairment |
| $Z_4$: Special construction measures | Lowering groundwater level |
| $Z_5$: Environmental impact | Noise  
Settlements |
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Cost evaluation for traffic and transport infrastructure projects

- **Risk cost determination**

\[ Z_i = f\sum(\lambda_i, (X_i), X_i) \]

- \( Z_1 \): probabilistic costs of incident \( Z_i \)
- \( \lambda_i \): Frequency of incident \( X_i \)
- \( X_i \): costs of risk \( X_i \)
Risk cost aggregation

Stability Z1
Excavation/Support Z2
Difficulties Z3
Special Construction Measures Z4
Environmental Impacts Z5

AGGREGATOR

Risk Costs (R)
Aim: Budget = Total cost at project end

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\[ B(PP) = B_0 + \Delta B(PP) \]
\[ R(PP) = R_0 + \Delta R(PP) \]

Financial cost (F) not shown
Thank you for your attention!
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Cost evaluation for traffic and transport infrastructure projects

Fundamentals

- The responsibility of the risk costs has to be determined:
  - Investor
  - Owner
  - Construction company
  - Consulting company
  - Others

- Judgement of risks has to be done by the relevant partner.
Risk assessment

- Hazard identification through brainstorming sessions with risk screening teams
- Classification of the frequency, consequence and risk levels of the identified hazards
- Identification of risk reduction measures
- Documentation of risk management work in risk register
Combining information

- Statistical
- Bayes' Theorem
Quantification of risk costs

Risk quantification is based on a combination of:

- objective (statistical) and
- judgmental approaches (experts’ opinion).

Judgmental quantification becomes necessary when:

- the nature and extent of the data is not suitable to statistical manipulation
- or, the statistical analysis of data cannot identify the specific problem.
Combining information

- Random Set Theory

Dempster Shafer Theory