Risk Analysis for the Adaptation of the German Road Network to Climate Change

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Outline

- Introduction
- Risk based Approach
- Case Studies
- Summary and Conclusions
Challenges for Owners and Operators

- Economic growth, mobility, quality of life
- Traffic demand – traffic prognosis
- Aging infrastructure beyond design limits
- Disasters will continue to occur, whether natural or human-induced

Owners and Operators have to understand, manage and reduce natural and/or man made disaster risks and thereby ensure that their assets are available, durable, safe and secure
Outline

- Introduction
- Risk based Approach
- Case Studies
- Summary and Conclusions
Risk Identification

- Regional Projections (Temperature, Wind, Precipitation, Irradiation)
  - Road
  - Bridges Tunnels
  - Drainage
  - Flooding (fluvial)
  - Landslides
  - Guidelines

- Hazard Potential/ Possible Consequences
  - Blue Spot
  - Hazard map

- Design/Upgrade Operation
  - Road
  - Bridges Tunnels
  - Drainage
  - Flooding (fluvial)
  - Landslides

- Levees, Polders
  - Reinforcement, Rerouting
  - Updating Guidelines

- Cost/Benefit-Assessment
Regional Climate Projections – Ensemble Approach

Climate Characteristics
- Thermal
- Solar Radiation
- Precipitation
- Strong Wind (Storms)


First International Conference on Surface Transportation System Resilience to Climate Change and Extreme Weather Events
Risk Elements

- Bridges
- Tunnels
- Pavements
- Slopes
- Retaining Structures
- Drainage
- Equipment
### Damage Pattern Categories

<table>
<thead>
<tr>
<th>Nr.:</th>
<th>Schadensbildkategorie</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bridges</td>
</tr>
<tr>
<td>1a</td>
<td>Heat induced damages and restrictions</td>
</tr>
<tr>
<td>1c</td>
<td>Schäden und Einschränkungen an Brücken infolge Frost-Tau-Veoneis</td>
</tr>
<tr>
<td>1d</td>
<td>Schäden und Einschränkungen an Brücken durch extreme Regenereignisse durch Hochwasser</td>
</tr>
<tr>
<td>1e</td>
<td>Schäden und Einschränkungen an Brücken durch extreme Windgeschwindigkeiten</td>
</tr>
<tr>
<td>2</td>
<td>Durchlässe</td>
</tr>
<tr>
<td>2a</td>
<td>Schäden und Einschränkungen an Durchlässen durch Hochwasser</td>
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<tr>
<td>3</td>
<td>Tunnels</td>
</tr>
<tr>
<td>3a</td>
<td>Niederschlagsbedingte Schäden und Einschränkungen an Tunnels</td>
</tr>
<tr>
<td>3b</td>
<td>Hitzebedingte Schäden und Einschränkungen an Tunnels (Portabereich)</td>
</tr>
<tr>
<td>3c</td>
<td>Frostbedingte Schäden und Einschränkungen an Tunnels (Portabereich)</td>
</tr>
<tr>
<td>3d</td>
<td>Niederschlagsbedingte Schäden und Einschränkungen an Trögen</td>
</tr>
<tr>
<td>3e</td>
<td>Hitzebedingte Schäden und Einschränkungen an Trögen</td>
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<tr>
<td>3f</td>
<td>Frostbedingte Schäden und Einschränkungen an Trögen</td>
</tr>
<tr>
<td>4</td>
<td>Stützauwerke, Hang-und Felssicherung</td>
</tr>
<tr>
<td>4a</td>
<td>Hitzebedingte Schäden und Einschränkungen an Stützauwerken &amp; Hang-und Felssicherungen</td>
</tr>
<tr>
<td>4b</td>
<td>Frostbedingte Schäden und Einschränkungen an Stützauwerken &amp; Hang-und Felssicherungen</td>
</tr>
<tr>
<td>4c</td>
<td>Niederschlagsbedingte Schäden und Einschränkungen an Stützauwerken &amp; Hang-und Felssicherungen</td>
</tr>
<tr>
<td>5</td>
<td>Böschungen</td>
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<table>
<thead>
<tr>
<th>Nr.:</th>
<th>Schadensbildkategorie</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Asphalt Pavements</td>
</tr>
<tr>
<td>6a</td>
<td>Heat induced damages and restrictions</td>
</tr>
<tr>
<td>6c</td>
<td>Einschränkungen auf Asphaltfahrbahnen durch Hochwasser</td>
</tr>
<tr>
<td>6d</td>
<td>Einschränkungen auf Asphaltfahrbahnen d. ungenügenden. Wasserabfluss (Aquaplaning in Zusammenhang mit Neigungsverhältnissen)</td>
</tr>
<tr>
<td>6e</td>
<td>Einschränkungen auf Asphaltfahrbahnen durch Glätteereignisse</td>
</tr>
<tr>
<td>7</td>
<td>Fahrbahn-Beton</td>
</tr>
<tr>
<td>7a</td>
<td>Hitzebedingte Schäden und Einschränkungen an Betonfahrbahnen</td>
</tr>
<tr>
<td>7b</td>
<td>Frostbedingte Schäden und Einschränkungen an Betonfahrbahnen</td>
</tr>
<tr>
<td>7c</td>
<td>Einschränkungen auf Betonfahrbahnen durch Hochwasser</td>
</tr>
<tr>
<td>7d</td>
<td>Einschränkungen auf Betonfahrbahnen durch ungenügende Wasserabfluss (Aquaplaning in Zusammenhang mit Neigungsverhältnissen)</td>
</tr>
<tr>
<td>7e</td>
<td>Einschränkungen Betonfahrbahnen durch Glätteereignisse</td>
</tr>
<tr>
<td>8</td>
<td>Ausstattung, Verkehrszeichenbrücken, Lärmschutz</td>
</tr>
<tr>
<td>8a</td>
<td>Schäden und Einschränkungen an Ausstattungselementen durch extreme Windgeschwindigkeiten</td>
</tr>
<tr>
<td>9</td>
<td>Entwässerung (Ableitungssysteme)</td>
</tr>
<tr>
<td>9a</td>
<td>Schäden / Einschränkungen durch Aquaplaning in Zusammenhang mit Funktionsversagen der Entwässerung bei extremen Regenereignissen</td>
</tr>
</tbody>
</table>
RIVA – Indicator based Approach

Input Variables

Results

Infrastructure Attributes

Indicator 1
Indicator 2
....

Indicator 1
Indicator 2
....

Consequences (direct)

Consequences (indirect)

Risk Potential

Potential Consequences

Hazard Potential

Vulnerability

Climate

Causes

Climate Attributes

Indicator 1
Indicator 2
....

Indicator 1
Indicator 2
....

Infrastructure Attributes

Indicators

Consequences

Infrastructure Attributes

Indicators

Climate Attributes

Indicators

In order to evaluate the resilience of surface transportation systems to climate change and extreme weather events, the RIVA (Indicator based Approach) is employed. This approach involves the identification of indicators related to climate attributes, which are then used to assess vulnerability, consequences, potential risks, and finally, the overall risk potential.
Combination of Indicators

Risk Element: Asphalt Pavement
Damage Category: Heat related damages and restrictions

<table>
<thead>
<tr>
<th>Climate Indicator</th>
<th>Value</th>
<th>Categories</th>
<th>Weight</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of hot days/year</td>
<td>15.58</td>
<td>low: $x &lt; 10$</td>
<td>25%</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium: $10 \leq x &lt; 20$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>high: $20 \leq x &lt; 30$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>very high: $30 \leq x$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of summer days/year</td>
<td>49.07</td>
<td>low: $x &lt; 35$</td>
<td>20%</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium: $35 \leq x &lt; 50$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>high: $50 \leq x &lt; 65$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>very high: $65 \leq x$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of heat waves/year</td>
<td>0.7</td>
<td>low: $x &lt; 1$</td>
<td>30%</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium: $1 \leq x &lt; 2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>high: $2 \leq x &lt; 3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>very high: $3 \leq x$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of tropical nights/year</td>
<td>5.02</td>
<td>low: $x &lt; 1$</td>
<td>5%</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium: $1 \leq x &lt; 3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>high: $3 \leq x &lt; 5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>very high: $5 \leq x$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest temperature of period</td>
<td>39.87</td>
<td>low: $x &lt; 33$</td>
<td>20%</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium: $33 \leq x &lt; 37$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>high: $37 \leq x &lt; 41$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>very high: $41 \leq x$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

100%  2.0
**RIVA – Indicator based Approach**

- **Input Variables**
  - Climate Attributes
    - Indicator 1
    - Indicator 2
    - ....
  - Infrastructure Attributes
    - Indicator 1
    - Indicator 2
    - ....

- **Results**
  - Hazard Potential
  - Risk Potential
  - Potential Consequences
  - Consequences (direct)
  - Consequences (indirect)

**Why RIVA?**
- Indicator based approach
- Robust method to assess risk
- Comprehensive framework for analysis

**Benefits**
- Quantifiable results
- Identifies vulnerabilities
- Adaptation measures development

**Key Components**
- Causes
- Consequences
# Combination of Indicators

**Risk Element: Asphalt Pavement**  
**Damage Category: Heat related damages and restrictions**

<table>
<thead>
<tr>
<th>Vulnerability Indicator</th>
<th>Weight</th>
<th>Categories</th>
<th>Percentages in section</th>
<th>Weight result</th>
<th>Combination Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Volume DTV-SV</td>
<td>25%</td>
<td>planned</td>
<td>low: x &lt; 4.000</td>
<td>100% 0% 0% 0%</td>
<td>28% 0.278</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium: 4.000 ≤ x &lt; 9.000</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>high: 9.000 ≤ x &lt; 12.000</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>very high: 12.000 ≤ x</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location, Orientation</td>
<td>10%</td>
<td>Mountains Slope (north)</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td>0% 0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mountains Slope (east)</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mountains Slope (west)</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lowland Mountain (south)</td>
<td>0% 0% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal Inclination</td>
<td>20%</td>
<td>x &lt; 2%</td>
<td>81% 10% 0% 0%</td>
<td></td>
<td>22% 0.267</td>
</tr>
<tr>
<td>Cracks</td>
<td>5%</td>
<td>x &lt; 2</td>
<td>57% 21% 14% 8%</td>
<td></td>
<td>6% 0.095</td>
</tr>
<tr>
<td>Top Layer Material</td>
<td>15%</td>
<td>PA (OPA), MA, (GA)</td>
<td>0% 100% 0% 0%</td>
<td></td>
<td>17% 0.333</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SMA, AC (AB)</td>
<td>0% 100% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth of ruds</td>
<td>10%</td>
<td>x &lt; 4</td>
<td>89% 11% 0% 0%</td>
<td></td>
<td>11% 0.123</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 ≤ x &lt; 7</td>
<td>89% 11% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 ≤ x &lt; 10</td>
<td>89% 11% 0% 0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness of Asphalt Layer</td>
<td>15%</td>
<td>x ≥ 30</td>
<td>0% 0% 0% 100%</td>
<td></td>
<td>17% 0.667</td>
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<tr>
<td></td>
<td></td>
<td>30 &gt; x ≥ 25</td>
<td>0% 0% 0% 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 &gt; x ≥ 22</td>
<td>0% 0% 0% 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>x &lt; 22</td>
<td>0% 0% 0% 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td></td>
<td>100% 100% 100%</td>
<td></td>
<td>1,760</td>
</tr>
</tbody>
</table>
RIVA – Indicator based Approach

- **Input Variables**
  - Climate Attributes
    - Indicator 1
    - Indicator 2
    - ...
  - Infrastructure Attributes
    - Indicator 1
    - Indicator 2
    - ...

- **Results**
  - Risk Potential
    - Hazard Potential
    - Vulnerability
    - Consequences
      - Consequences (direct)
      - Consequences (indirect)
    - Potential Consequences

- **Causes**
  - Climate Attributes
  - Infrastructure Attributes

- **Consequences**
  - Consequences
    - Direct
    - Indirect
RIVA – Indicator based Approach

Input Variables

Results

Infrastructure Attributes

- Indicator 1
- Indicator 2
- ...

Consequences

- Consequences (direct)
- Consequences (indirect)

Hazard Potential

Potential Consequences

Climate

Vulnerability

Causes

Climate Attributes

- Indicator 1
- Indicator 2
- ...

Consequences

- Direct
- Indirect

RIVA – Indicator based Approach
RIVA – Indicator based Approach

- **Indicators**:
  - Climate Attributes
    - Indicator 1
    - Indicator 2
    - ....
  - Infrastructure Attributes
    - Indicator 1
    - Indicator 2
    - ....

- **Processes**:
  - Climate
  - Vulnerability
  - Consequences (direct)
  - Consequences (indirect)

- **Outputs**:
  - Hazard Potential
  - Potential Consequences
  - Risk Potential

**Input Variables** → **Results**

**Infrastructure Attributes**
- Indicator 1
- Indicator 2
- ....

**Climate Attributes**
- Indicator 1
- Indicator 2
- ....
Outline

- Introduction
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- Case Studies
- Summary and Conclusions
Case Studies

- \(\approx 10\%\) of highway network
- 8 sections with lengths from 60 to 130 km
- Various regions, climatic and geographic conditions
- High and low traffic volume
- Sections close to borders
- Various construction types
- Range of construction year and condition
Risk Map

Hazard Potential for damage category 07b „frost related damages and restrictions for concrete pavements“
Risk Map

Total Hazard Potential for “frost related damages and restrictions”

1977 - 2000

2071 - 2100

Legend:

<table>
<thead>
<tr>
<th>Wert vorhanden</th>
<th>Farbe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2-1.2</td>
<td>gelb</td>
</tr>
<tr>
<td>1.2-4.4</td>
<td>grün</td>
</tr>
<tr>
<td>4.4-10.6</td>
<td>blau</td>
</tr>
<tr>
<td>10.6-20.0</td>
<td>lila</td>
</tr>
<tr>
<td>20.0-30.0</td>
<td>rötlich</td>
</tr>
<tr>
<td>30.0-45.0</td>
<td>rot</td>
</tr>
<tr>
<td>45.0-60.0</td>
<td>rot</td>
</tr>
</tbody>
</table>

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im Rahmen des Forschungsprojektes
RIVA Risikoanalyse wichtiger Güter- und
Transitverkehrsräumen
unter Einbeziehung von Seehäfen
PE 09.0147/2011/ARBB
Outline

- Introduction
- Risk based Approach
- Case Studies
- Summary and Conclusions
Summary

- Risk based approach for the analysis of road networks with regard to Climate Change.
- Indicators from regional climate projections.
- Indicators for damage pattern categories of infrastructure elements.
- Hazard Potential by combining climate indicators with vulnerability indicators.
- Potential consequences (direct and indirect).
- “Risk Potential” is derived using four dimensions (climate incidents, vulnerability of road infrastructure elements, direct and indirect consequences).
- Case studies for about 1.200 km of Federal Highways.
Conclusions

- Disasters will continue to occur, whether natural or human-induced.
- Extreme weather incidents are expected to increase.
- Aging infrastructure, poor condition and increasing traffic will lead to more vulnerabilities.
- Direct and indirect (economical) consequences for non-availability of road infrastructure will increase.
- Risk based approaches are important for the identification of vulnerable and/or critical elements and road infrastructure.
- Owners and operators need reliable tools for risk analysis, risk assessment and risk management.
- RIVA methodology can be used as a tool to add more resilience to the management of road infrastructure.
Thank You very much for your kind attention!

Additional information: www.bast.de

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