Resilient Road Infrastructure
Needs of Owners and Operators

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Road Infrastructure – Life Cycle

Plan/Design → Road Infrastructure (Eurocodes) → Actions → Operation: Maintenance Management

Condition based Maintenance Management

Condition

PMS/BMS

Resistance
Normal Operation

System Performance (condition)

Robustness

Time

System performance

design performance

measures

intervention level

„normal“ Operation

Condition based Maintenance Management
(Bridge Management, Pavement Management)

minimum performance
Challenges for Owners and Operators

- Economic growth, mobility, supply
- Traffic demand, traffic prognosis
- Level of service, availability, safety and security
  - Ageing infrastructure
  - Climate Change – extreme weather
  - Other threads – natural/man-made hazards
  - Cyber threads

N1: Resilience Engineering/Resilience Management (all-hazard)!
Resilience - Characteristics

A resilient system shows:

- reduced failure probabilities,
- reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences,
- reduced time to recovery (restoration of a specific system or set of systems to their “normal” level of functional performance)

* Bruneau, M.; Reinhorn, A.- Exploring the Concept of Seismic Resilience for Acute Care Facilities
Uncertain and ever-changing future

Black Swan (LFHC)*
know we don’t know

Turkey-Illusion**
multiple alternatives

* Nassim Nicholas Taleb: The Black Swan - The Impact of the Highly Improbable
** Gerd Gigerenzer: Risiko – wie man die richtigen Entscheidungen trifft
**Uncertain and ever-changing future**

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context</strong></td>
<td>A clear enough future (with sensitivity)</td>
<td>Alternate futures (with probabilities)</td>
<td>Alternate futures (with ranking)</td>
<td>A multiplicity of plausible futures (unranked)</td>
</tr>
<tr>
<td><strong>System model</strong></td>
<td>A single system model</td>
<td>A single system model with a probabilistic parameterization</td>
<td>Several system models, one of which is most likely</td>
<td>Several system models, with different structures</td>
</tr>
</tbody>
</table>

**N2: Systematic approach to decision taking under uncertainties!**

*Warren E. Walker et al: Deep Uncertainty*
Resilience of Road Infrastructure

N3: Organizational, operational and technical approaches!
Risk Management

N4: Holistic (all-hazard) approaches for Risk Management (safety and security)!
There is only one Budget!

Budget

Why?

How much?

When?

Where?

Infrastructure

N5: Answers to these questions!
Resilience Roadmap (1)

Methodologies

(1) All-hazard approach to resilience on object- and network level

- Risk-based processes to assess and manage road networks and their elements with regard to future challenges (uncertainties).
- GIS-based information systems for owners and operators identifying potentially vulnerable/critical elements and/or sections of road networks (in real time).
- Risk-based procedures to consider the cost of non-availability of road networks/network elements.
- Methodologies and approaches for benefit/cost analysis of adaptation

(2) Potential of vehicle/infrastructure interaction (C2I, C2X)

(3) Potential of Smart Data and Artificial Intelligence
Resilience Roadmap (2)

Materials/Construction and Monitoring Technologies

(1) Drainage systems, soil strengthening and rock stabilization, sensor based technologies and real time early warning systems.

(2) Resilient, long life and measures for the adaptation of existing road infrastructure.

(3) Protection systems for tunnel structures against flooding.

(4) Rapid and automated inspection methods.

(5) Automated and remote sensor systems for real time applications.
Resilience Roadmap (3)

Life Cycle Management

(1) Development and implementation of adaptation strategies.

(2) Quantification of performance on object and system level; consideration of reduced availability

(3) Quantification of Resilience (Resilience-Indicators)

(4) Real time management systems to provide early warning of extreme events for intelligent re-routing

(5) Guidelines for the design and the implementation of adaptation measures for new and existing road infrastructure

(6) Integration of the above into a risk- and resilience-based asset management
Thank you very much for your kind attention!