Towards effective standards for monitoring, data-informed safety assessment and maintenance of the transport infrastructure

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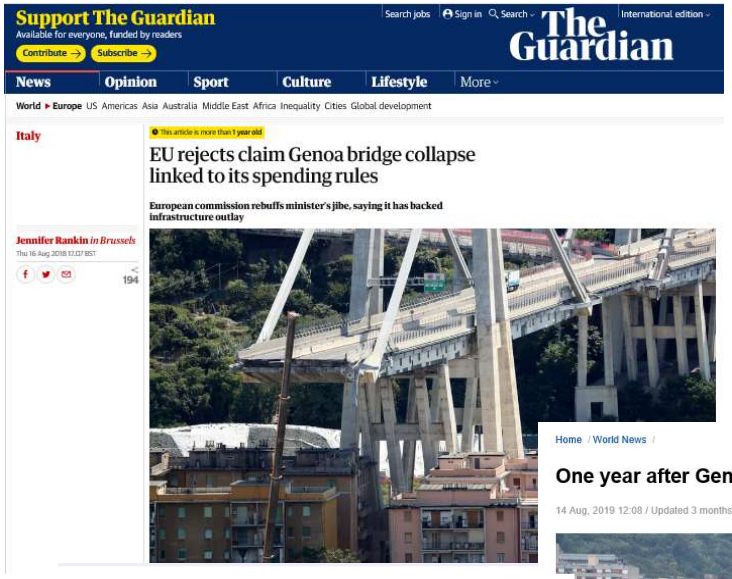
Context

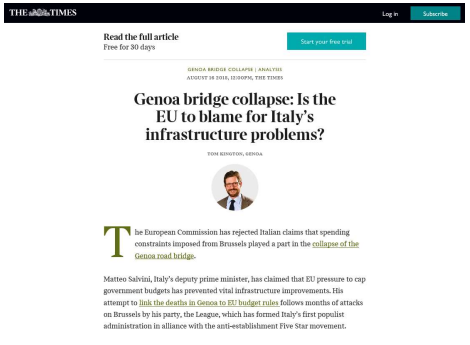
Transport infrastructure is facing **major challenges** due to ageing, rapid growth of traffic loads and natural and man-made resilience threats.

Safety risks have become critical in the recent years and manifested in major disasters caused i.e. by structural failures due to maintenance deficiencies.

Optimal maintenance is only possible with the right policies and decisions enabled by **timely and accurate information.**

Monitoring is recognized as **key enabler** of optimal maintenance strategies to be applied for ensuring the **safety of the infrastructure.**





Europe's aging transport infrastructure needs effective and proactive maintenance in order to continue its safe operation during the entire life cycle. This report focuses on research and innovation (R&I) in bridge maintenance, inspection and monitoring in Europe in the last quarter of a century. The assessment follows the methodology developed by the European Commission's Transport Research and Information Monitoring and Information System (TRIMIS). The report critically addresses issues and techniques, and also highlights new technological developments and future oriented approaches.

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- **Digitalization as enabling technology**

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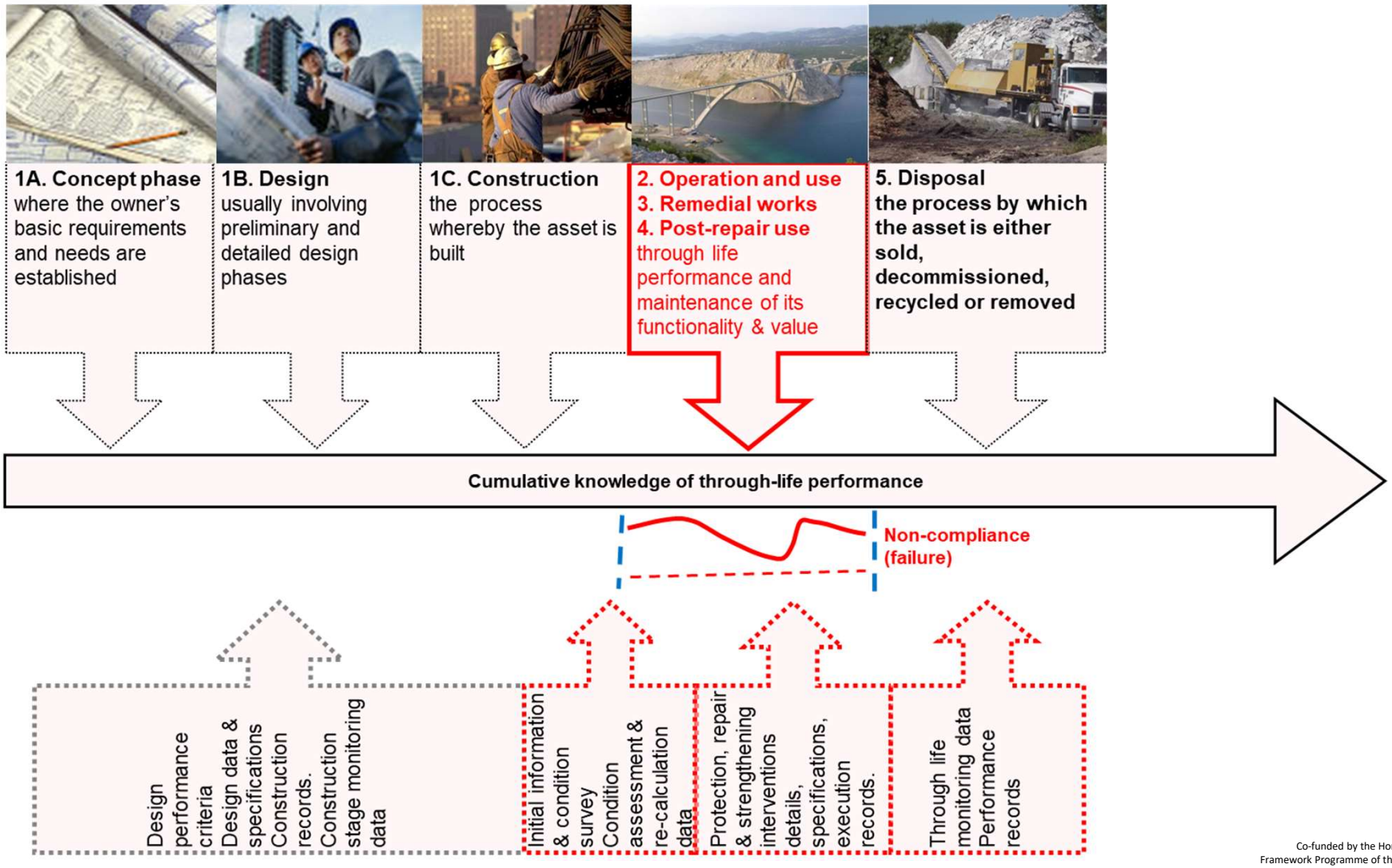
Risk-based & data-informed life cycle management



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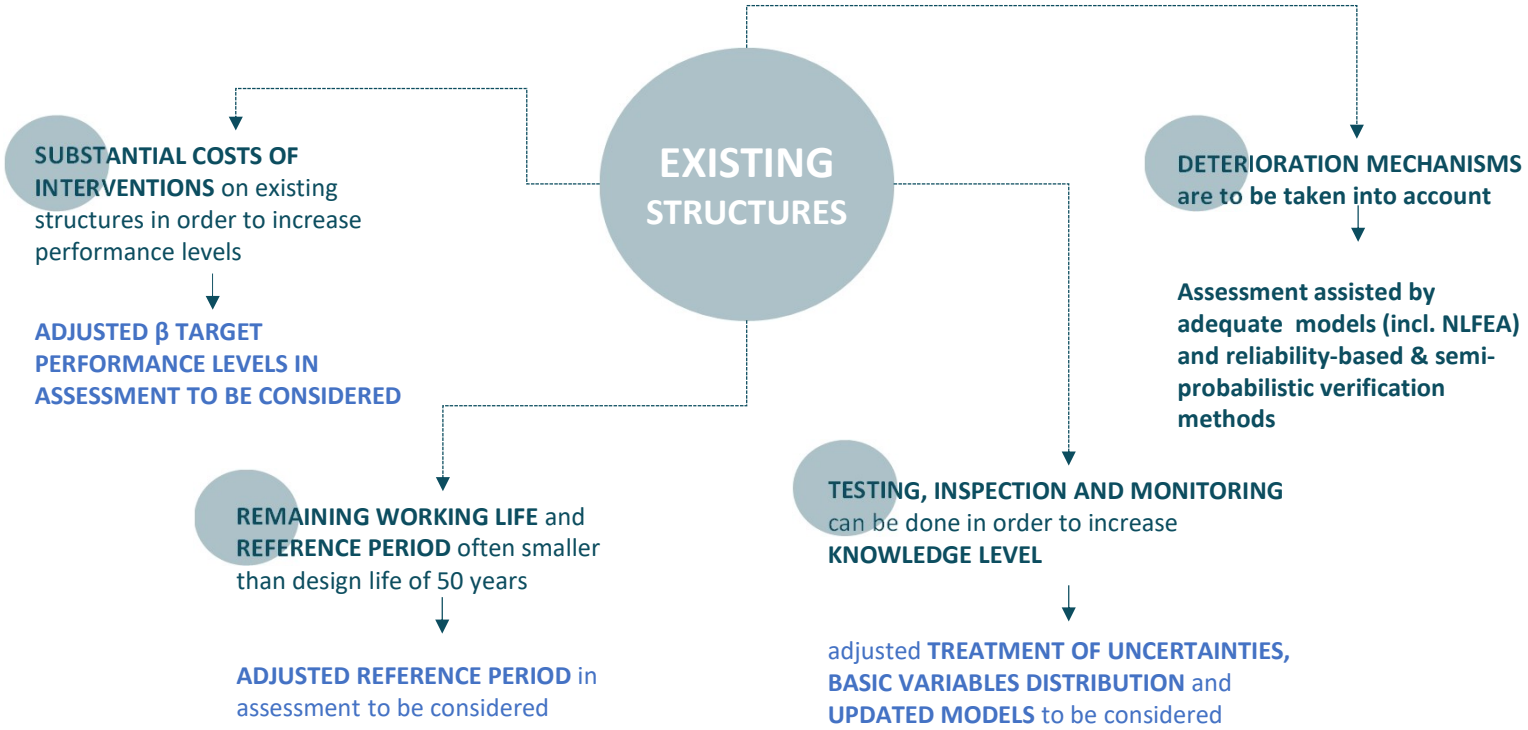
Risk-based & data-informed life cycle management



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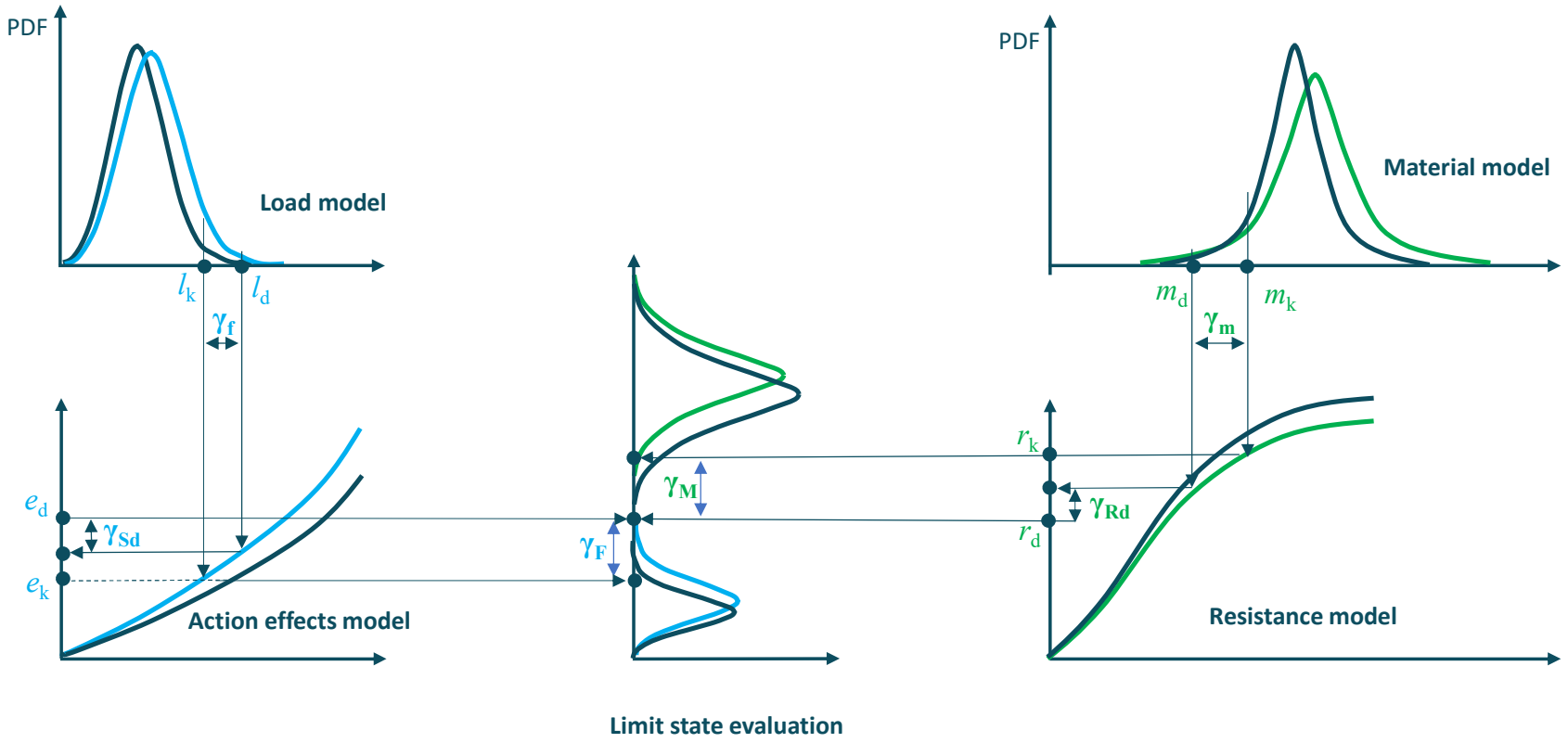
Data-informed assessment

Uncertainty treatment in structural assessment (partial safety factor format)



adopted form [M. Teichgäber, J. Köhler, D. Straub, Hidden safety in structural design codes, Engineering Structures, 2022]

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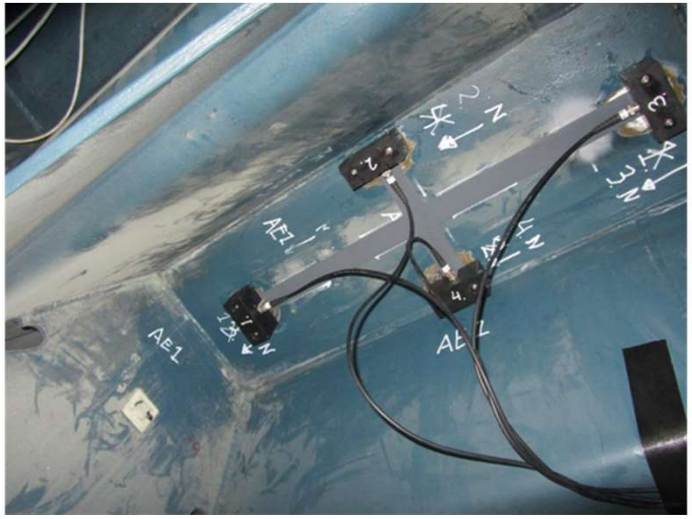
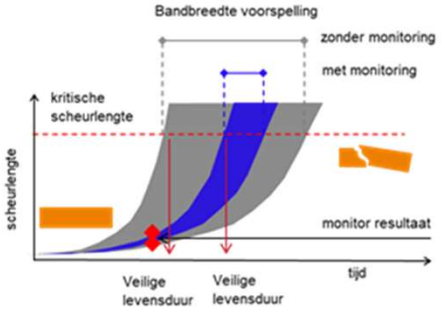
Best practices (example)

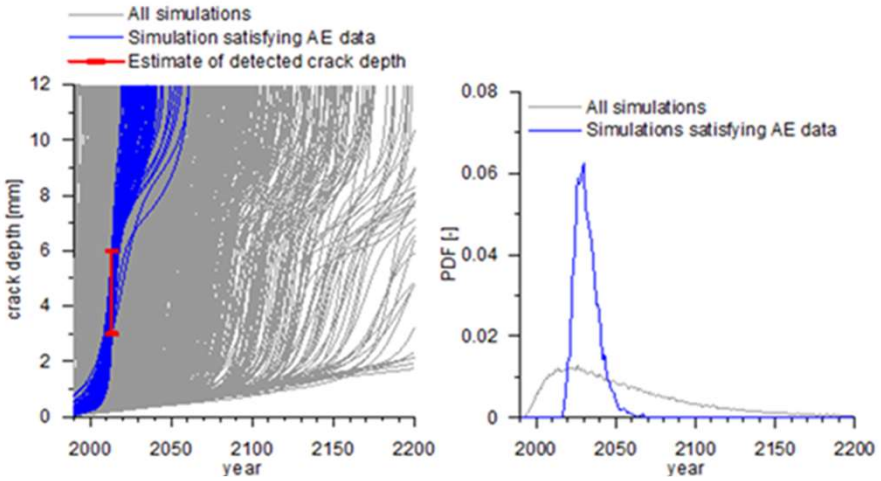
The data-informed service life prediction for fatigue in orthotropic bridge decks

Potential use of data: improving understanding of steel bridges behaviour and improving performance prediction

- detection of fatigue cracks orthotropic bridge decks
- early warning system
- real-time prediction of fatigue service life







Field-lab fatigue service life prediction based on crack growth monitoring and modelling (NL)

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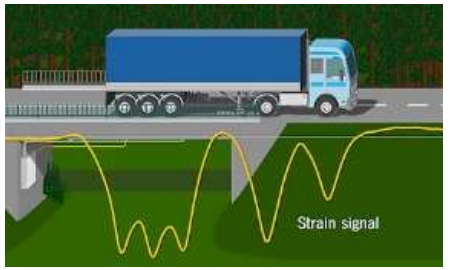
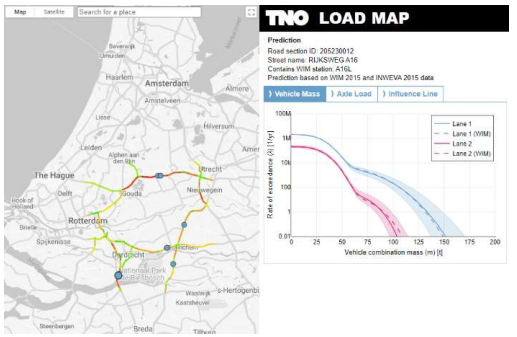
Best practices (example)

The traffic load information for optimized use and maintenance of pavements and structures

Potential use of data: improving understanding of live loads on infrastructure

- Short-term: underpinning development of 'lighter' traffic load model for specific objects
- Medium-term: improved predictive traffic load models for transport networks
- Long-term: real time integration with digital twin models





Application of Loadmap and Bridge-WiM in field-lab Moerdijk (NL)

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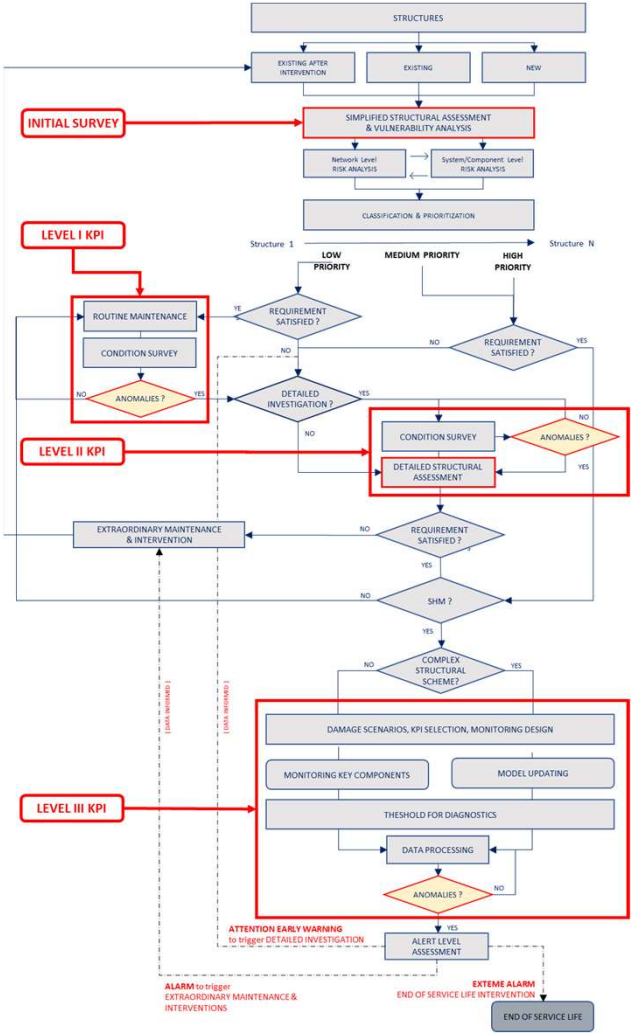
Data-informed life cycle management of structures

ASSESSMENT LEVEL

Top Down approach

- NETWORK
- SYSTEM
- COMPONENT

DATA COLLECTION & STORAGE



ASSESSMENT FLOW INCLUDING INFORMATION FROM INSPECTION MONITORING AND TESTING

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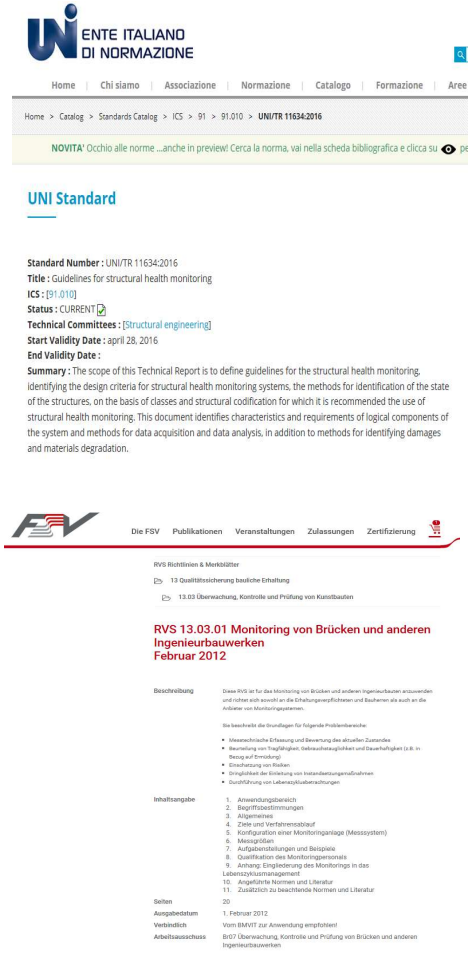
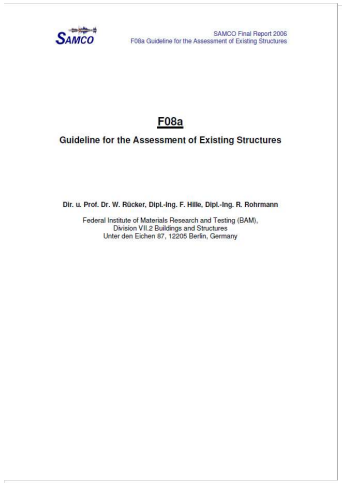
Current state of standardization

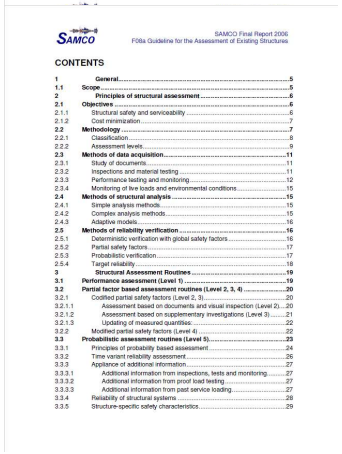
Decision-making regarding maintenance of infrastructure is regulated on national and even on infrastructure operators level.

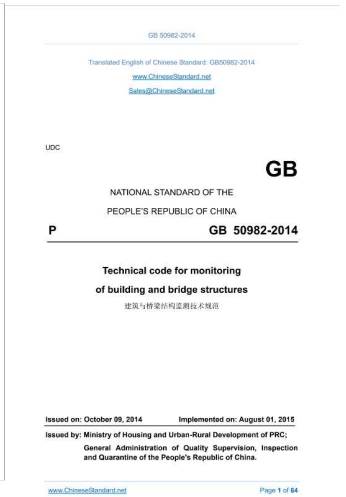
The current guidelines largely differ in how they **include condition information from inspections and monitoring** in the **evaluation of the likelihood of risk events** and in **prioritization of structures for maintenance**.

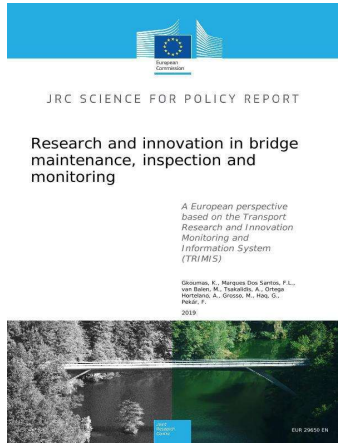
The experience form **R&D and best-practice** are **not consistently interpreted and implemented** in different European countries due to a lack of coherent policies and gaps in knowhow.











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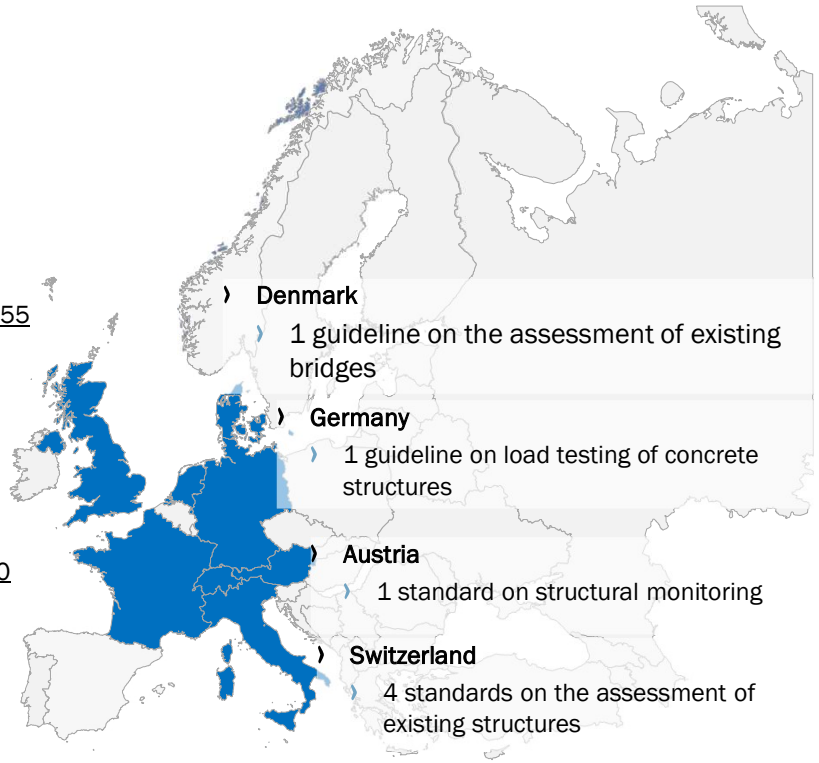
Current state of standardization

- **UK**
  - 1 guideline on inspections of road tunnels
  - 2 guideline on inspections of highway bridges
  - 1 guideline on load testing of bridges
  - 1 guideline on the management of road tunnels
  - 6 guideline on the management of highway bridges incl. CS 455
  - 8 guidelines on the assessment of bridges

- **The Netherlands**
  - 1 guideline on inspections
  - 2 standards on the assessment of existing structures
  - 1 guideline on the assessment of existing bridges NEN87000

- **France**
  - 1 guideline on load testing of bridges
  - 1 guideline on inspections of road tunnels
  - 1 information note on the safety assessment of existing bridges



- **Denmark**
  - 1 guideline on the assessment of existing bridges
- **Germany**
  - 1 guideline on load testing of concrete structures
- **Austria**
  - 1 standard on structural monitoring
- **Switzerland**
  - 4 standards on the assessment of existing structures

- **Italy**
  - 1 guideline on structural monitoring UNI/TR 11634:2016
  - 1 guideline on risk management, safety assessment and monitoring of existing bridges

- **China**
  - 1 standard on structural monitoring

- **CEN**
  - draft versions of 2 standards on the assessment of structures
  - 2 standards on inspection and maintenance

- **ISO**
  - 2 standards on structural monitoring
  - 1 standard on the assessment of existing structures
  - 1 standard on asset management

- **SAMCO**
  - 1 guideline on structural health monitoring
  - 1 guideline on the assessment of existing structures

- **DNVGL**
  - 1 guideline on inspection planning
  - 1 guideline on sensor systems
  - 1 guideline on data-driven algorithms and models
  - 1 guideline on data quality assessment
  - 2 guidelines on risk-based verifications

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Standardization outlook

- **New standard on structural monitoring**
  - decision-making regarding the design of the monitoring strategy
  - effective use of monitoring data to produce useful and meaningful information relevant for diagnostics of structures, safety assessment and maintenance approaches

- **Further amendment to the existing Eurocodes** on safety assessment taking into account inspections, monitoring and testing
  - full utilisation of structure-specific data in the safety assessment of existing structures
  - assessment of actual safety through consideration of deterioration and damage by models
  - better prediction of end-of-service life by appropriate choice of the safety framework

- **New standard for** risk-based maintenance management and preventive condition-based **maintenance of transport infrastructures**
  - improvement of the decision-making process regarding maintenance at network and object level
  - enabling transition from corrective maintenance towards risk-based maintenance management & preventive maintenance strategies

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Standardization outlook

New standard on structural monitoring

Objectives:

- to formulate the **principles of setting the objectives of structural monitoring**
- to formulate essential principles of setting the design of the monitoring system incl. requirements related to the reliability of sensor systems
- to provide essential requirements related to the **methodologies used for translating data into useful and meaningful information** relevant for diagnostics of structures, safety assessment and maintenance approaches
- to maintain the **openness to innovations** (i.e. in sensing technology and data analysis methods)

Preliminary definition of the scope :

- framework for **decision making** regarding the monitoring strategy:
  - definition of the objectives of the monitoring activities
  - choice of the monitoring type (e.g. periodic / continuous)
  - choice of the measured quantities
  - definition of the required measurement accuracy
  - selection of the monitoring technologies
  - design of the monitoring system, including amount and placement of the monitoring devices
  - evaluation of alternative monitoring strategies
- requirements for **data acquisition** (calibration, post-installation verification, management and maintenance of the acquisition system)
- requirements for **data pre-processing** (identification of outliers, removal of the environmental effects from the raw data, data validation, etc.)
- requirements for **data analysis** (updating of structural models, identification of damage and deterioration processes)
- requirements for **data storage and management** (in relation to through-life information management systems)
- requirements for **data security and ownership**

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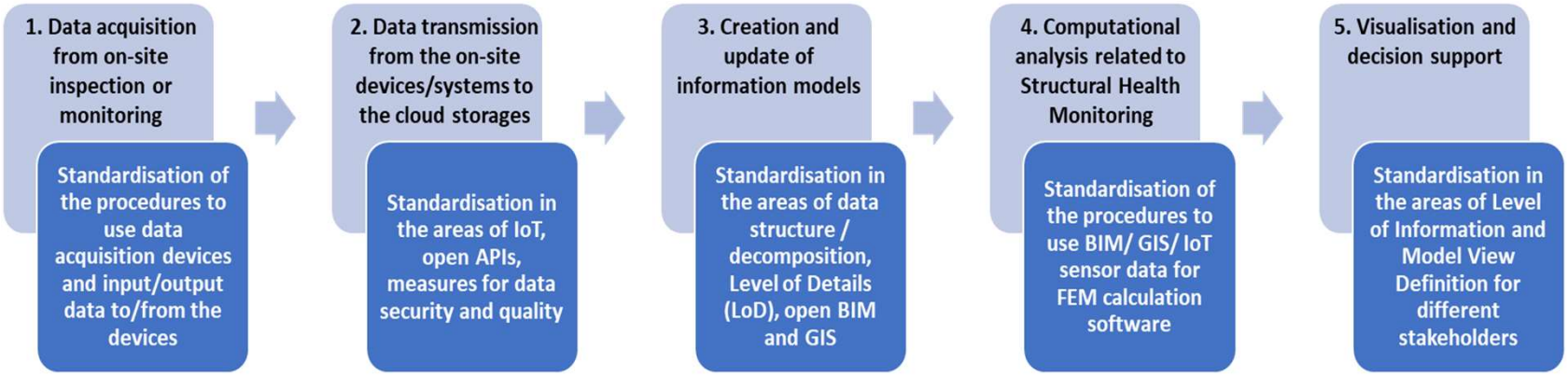
Digitalization as enabling technology

Data should be FAIR :

- Findable - think Internet/WWW
- Accessible - think identification/authentication/authorisation
- Interoperable - think standard data syntax (formats, direct access methods)
- Reusable - think standard data semantics (schemas, ontologies, OTLs)

FAIR approach delivers FutureProof / Scaleable / Sustainable solutions



Standardization domains & workflow from data acquisition till decision support in the context of inspection, monitoring, maintenance and safety of transport infrastructures

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Conclusions

- There are recognized needs for **new European standards** in alignment with national standards in monitoring, safety assessment and maintenance, and international standards in BIM and digitalization
- There is a **sufficient know-how across Europe** and there is the **common will to reach consensus among the stakeholders**
- **Technology advances** can enable the change towards new data-informed and risk-based approaches to **safety control and maintenance decision-making** for transport infrastructure, **supported by monitoring systems**.
- CSA IM-SAFE contributes to the future standards, by supporting **EC and CEN** in preparing **new standards in monitoring for optimal maintenance and safety of transport infrastructure**

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