COST Action
TU 1402

Quantifying the Value of Structural Health Monitoring

European Cooperation in Science and Technology

# Quantifying the Value of Structural Health Information for Decision Support

## Guide for Scientists

Sebastian Thöns
Technical University of Denmark, Denmark
BAM Federal Institute for Materials Research and Testing, Germany

# TU1402 WG5: Standardisation

Value of Structural Health Information for Decision Support

1. Guide for Operators: What should the infrastructure operators and owners ask for?

- Optimisation of the structural information and integrity management before implementation
- Why: You can save money, reduce risks and facilitate industry 4.0!

2. Guide for Practicing Engineers: How can an engineer perform and support the quantification of the Value of SHI?

- Engineering and application information
- Real case study for implementation

3. Guide for Scientists: How to enter research on value of SHI? How to apply decision analyses to my research field?

- Description and ready to use formulation of a framework and approaches for various structural health information
- Starting set of literature

# Contents

1 Introduction

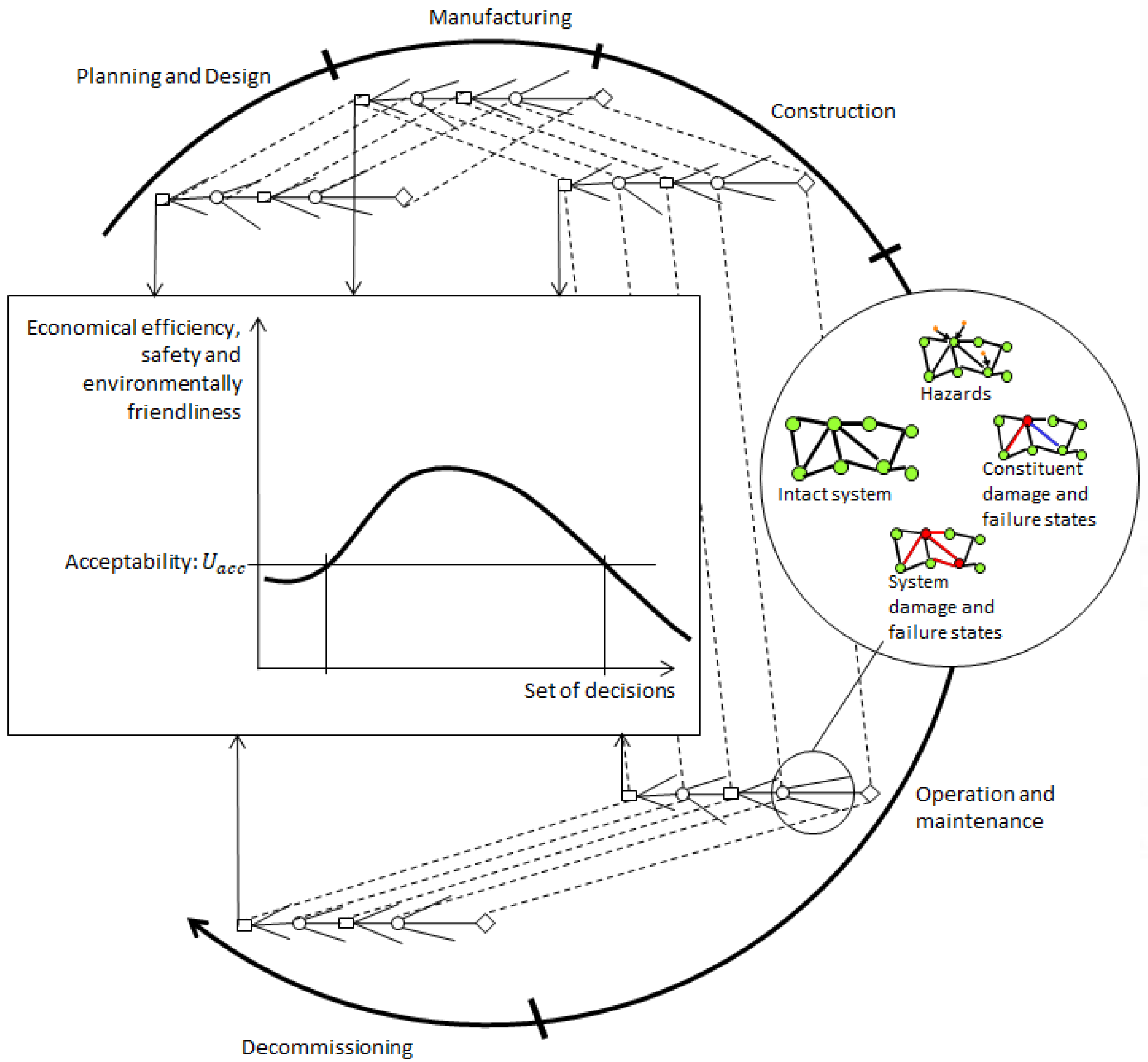
2 Value of structural health information

3 Structural health information

4 Structural performance adaptation and structural health information modelling

5 Principal example

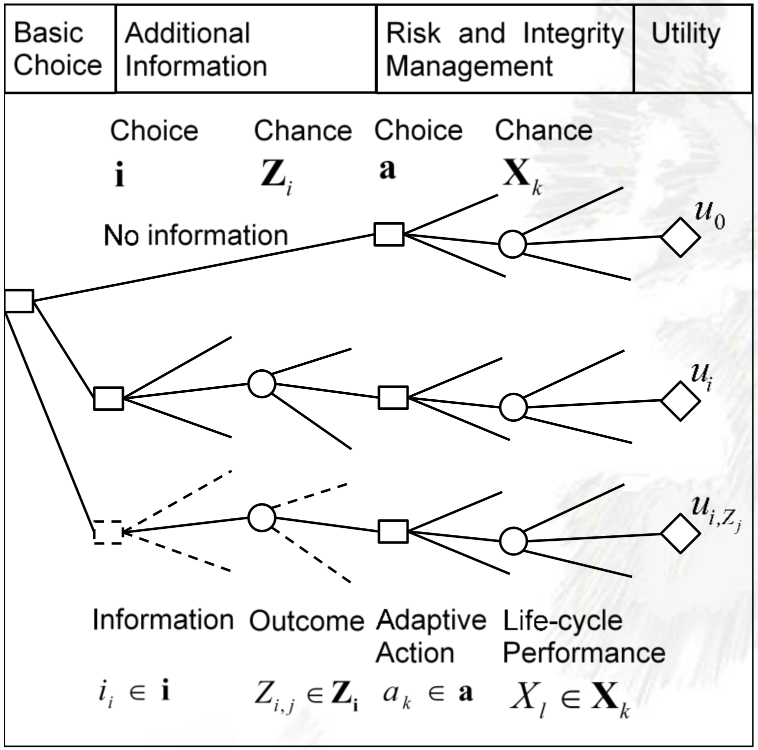
# Value of structural health information: decision scenario modelling and analysis



# Value of structural health information: examples for typical decision scenarios

- 1. Utility, functionality, integrity and risk management in the operation phase of an infrastructure system
  - Integrity management planning
  - Service life extension
  - Utilisation modification
  - Functionality enhancement
  - Damage progression monitoring
  - Early damage warning
- 2. Code and standard calibration - decision support in the design phase
- 3. Structure prototype development and design by testing – design phase
- 4. SHI system development

# Value of structural health information: objective functions




Value of SHI

$$V\left(i_i^*, \mathbf{a}^{*,i}, a_k^{*,0}\right) = U_1\left(i_i^*, \mathbf{a}^{*,i}\right) - U_0\left(a_k^{*,0}\right)$$

$$\left\{i_i^*, \mathbf{a}^{*,i}, a_k^{*,0}\right\} = \underset{i_i \in \mathbf{i}, \mathbf{a}^i \in \mathbf{a}}{arg\,max}\, U_1\left(i_i, \mathbf{a}^i\right) - \underset{a_k \in \mathbf{a}}{arg\,max}\, U_0\left(a_k\right)$$

s.t. $U_{acc} \le U_1\left(i_i^*, \mathbf{a}^{*,i}\right)$ and $U_{acc} \le U_0\left(a_k^{*,0}\right)$

Posterior value of SHI

$$V \mid Z_j = U_2\left(a_k^{*,i}\right) - U_0\left(a_k^{*,0}\right)$$

$$a_k^{*,i} = \underset{a_k^i \in \mathbf{a}}{arg\,max}\, U_2\left(a_k^i\right) - \underset{a_k^0 \in \mathbf{a}}{arg\,max}\, U_0\left(a_k^{*,0}\right)$$

s.t. $U_{acc} \le U_2\left(a_k^{*,i}\right)$ and $U_{acc} \le U_0\left(a_k^{*,0}\right)$

# Contents


1 Introduction

2 Value of structural health information

3 Structural health information

4 Structural performance adaptation and structural health information modelling

5 Principal example

# Structural health information

Decisions contributing to an efficient management of infrastructures rely on information conditions:

1) The information is relevant and precise.
2) The information is relevant but imprecise.
3) The information is irrelevant.
4) The information is relevant but incorrect.
5) The flow of information is disrupted or delayed.

Structural health information is information with relevance for the decisions influencing the infrastructure performance and utility.

A SHI model encompasses the information type and content, the probabilistic properties and the costs and consequences.

# Structural health information: types

The SHI type is classified in the context of the structural system performance models. The temporal (discrete, continuous) and spatial (constituent, system) boundaries and the direct and the indirect measurements of structural performance parameters determine the SHI type.

| SHI type | Temporal characteristic | Spatial characteristic | Direct / indirect |
|---|---|---|---|
| Damage detection with a distributed measurement systems and the analysis of static and dynamic behaviour | Continuous or periods of measurements | System or subsystem level | Indirect (indication of damage) |
| Inspection | Discrete | Constituent | Indirect (indication of damage) |
| Load testing | Discrete | Constituent, subsystem or system level | Indirect (indication of survival or damage or failure) |
| Monitoring | Continuous or periods of measurements | Constituent | Direct |
| Non-destructive testing | Discrete | Constituent | Direct |

# Structural health information: probabilistic characteristics

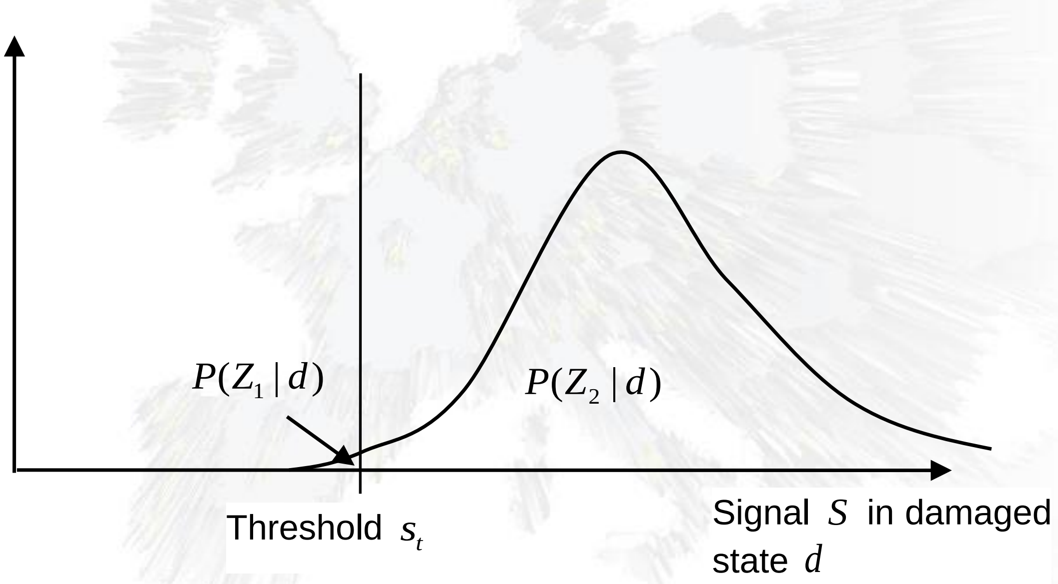
(1) Measurement process
  - Caused by e.g. the conversion of electrical or optical signals to structural properties and the process inherent uncertainties relating to the sensor precision, conversion and amplification unit.

(2) SHI installation and operation and
  - SHI system installation
  - Operational conditions (when not covered by data normalisation)
  - Human errors

(3) SHI data analysis
  - Statistical uncertainties due to a limited amount of data in relation to the temporal boundaries of the decision scenario
  - Limited precision of data analysis and data normalisation algorithms
  - Human errors
  - Dependencies between consecutive or multiple SHI

# Structural health information: probabilistic characteristics

Probabilistic characteristics may be described with: signal processing and detection theory and a dependency model




$$P(Z_1 | d) = \int_{-\infty}^{s_t} f_S\left(s | d\right) ds \qquad (1)$$

$$P(Z_2 | d) = \int_{s_t}^{\infty} f_S\left(s | d\right) ds \qquad (2)$$

# Contents

1 Introduction

2 Value of structural health information

3 Structural health information

4 Structural performance adaptation and structural health information modelling

5 Principal example

# Structural performance adaptation and structural health information modelling

- Damage detection for constituents
- Damage detection for systems
- Load testing
- Monitoring information modelling
- Equality information model

# Structural performance adaptation and structural health information modelling: Damage detection for constituents

$$P\left(X_{1,c} \mid \mathbf{Z}\right)P\left(\mathbf{Z}\right) = P\left(\mathbf{Z} \mid X_{1,c}\right)P\left(X_{1,c}\right)$$

- Pre-posterior probability of the constituent state for a value of SHI analysis

$$P\left(X_{1,c} \mid \mathbf{Z}\right) = \frac{P\left(\mathbf{Z} \mid X_{1,c}\right)P\left(X_{1,c}\right)}{P\left(\mathbf{Z}\right)}$$

- Posterior probability of the constituent state for a posterior value of SHI analysis

$$X_{1,c}: \quad g_{X_{1,c}}\left(\mathbf{X}_{X_{1,c}}\right) = M_{R_c} R_c\left(D_c\right) - M_{S_c} S_c \leq 0$$

$$Z_j: \quad g_{Z_j}\left(\mathbf{X}_{Z_j}\right) = P\left(Z_j\left(D_c\right)\right) - U \leq 0$$

- Limit state functions for constituents system states and indications
- Resistance $R_c$, damage $D_c$ and corresponding model uncertainties $M_{Rc}$ and $M_{Sc}$, constituent damage size dependent probability of indication curve $Z_j(D_c)$, uniformly distributed random variable $U$

# Contents


1 Introduction

2 Value of structural health information

3 Structural health information

4 Structural performance adaptation and structural health information modelling

5 Principal example

# Principal example

The principal example demonstrates the application of the documented approaches to a decision scenario with various structural health information.

- Pre-assessment of SHI with simplified approaches
- Assessment and optimisation before SHI system implementation
- Assessment and optimisation after SHI system implementation
- Literature for adding complexity to the principal example

The guideline will contain an exemplary implementation.

COST Action
TU 1402

Quantifying the Value of Structural Health Monitoring

European Cooperation in Science and Technology

# Thank you for your attention.