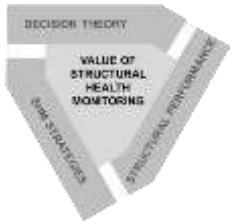
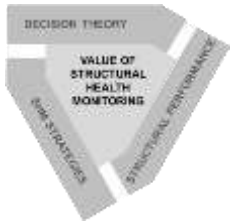


Test case for offshore wind park operation

Factsheet WG1-6

Sebastian Thöns
Michael H. Faber



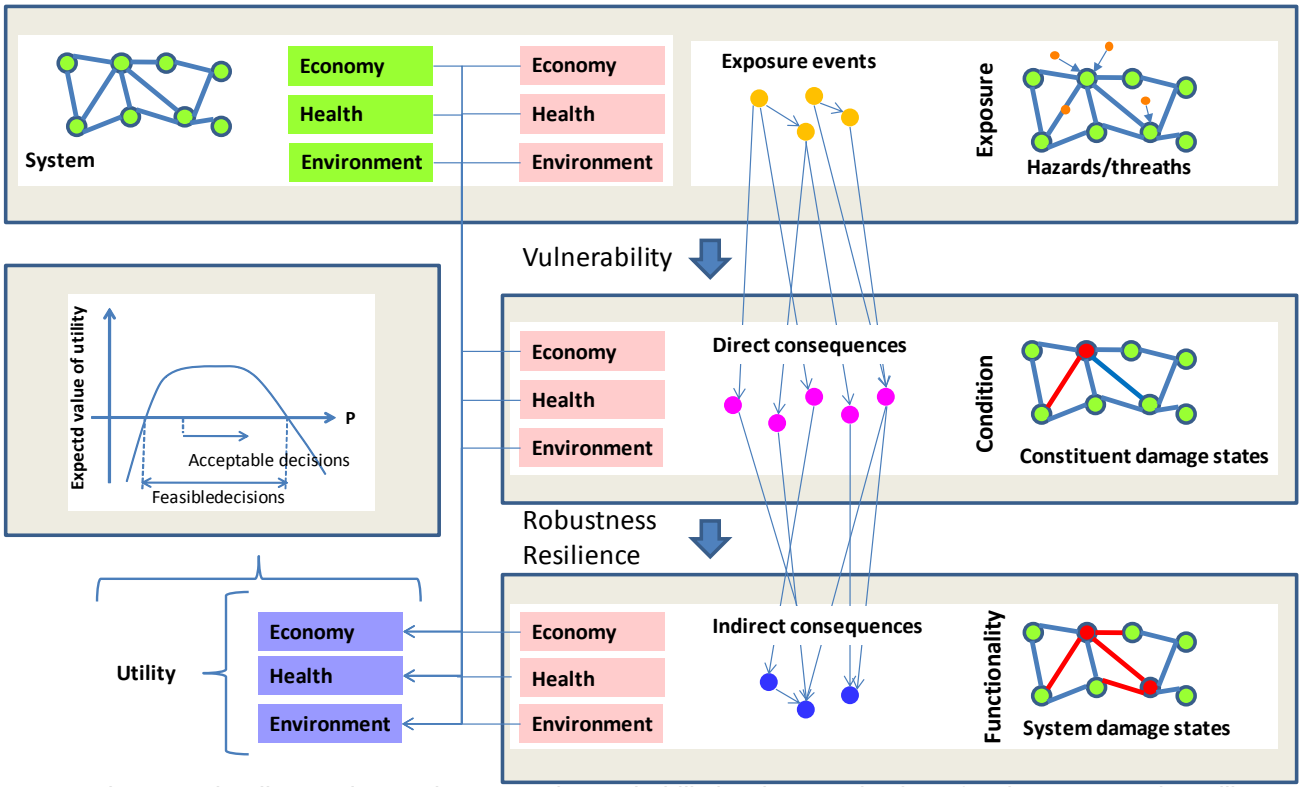
Introduction

Traditionally in SHM the emphasis is on the loading acting on structures and on internal structural properties.

The utility of infrastructures for society is highly related to the functionality provided and the benefits earned. The utility for society can only be realised when the costs and risks are sufficiently low.

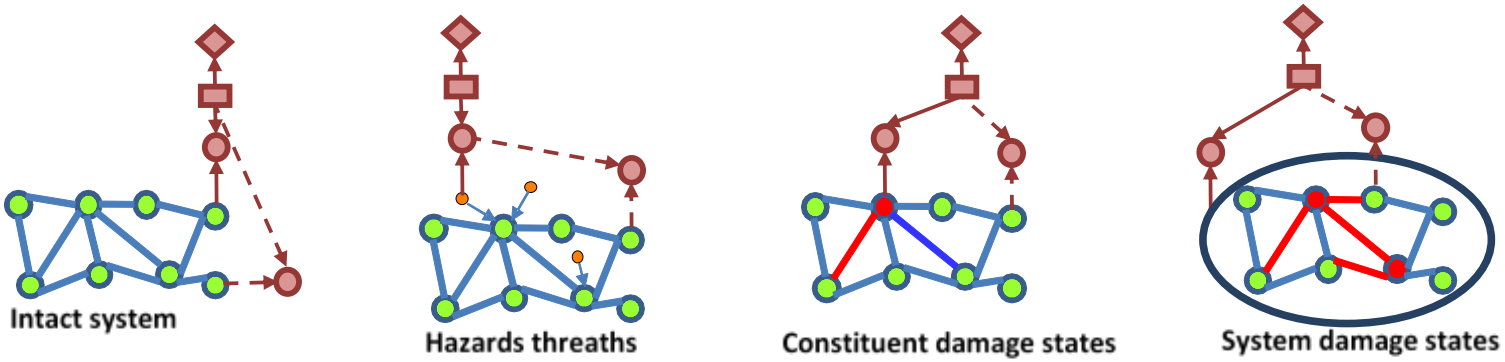
The Value of Information (VoI) should build upon a benefit, cost and risk informed assessment of the infrastructure performance.

Framework for infrastructure system utility and decision analysis

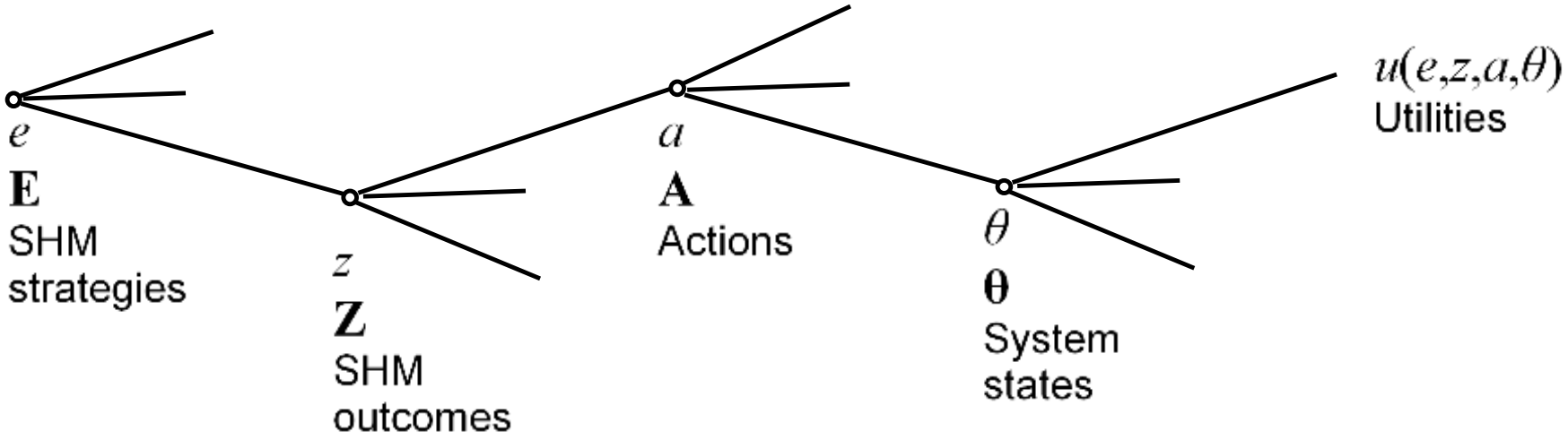


M.H. Faber, S. Miraglia, J. Qin, S. Thöns, On the Probabilistic Characterization of Robustness and Resilience, in: Urban Transitions Conference, Elsevier Ltd., Shanghai, China, Under review.

Illustration of SHM decision, information, precision and cost

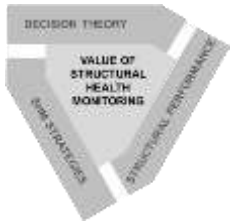


Decision tree for value of SHM information analysis



$$VoI = u_1^* - u_0^*$$

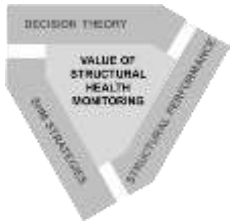
$$\overline{VoI} = \left(u_1^* - u_0^*\right) / u_0^*$$



Offshore wind park operation

Wind parks combine uniquely sustainable, renewable, greenhouse gas free and low risk energy production and are becoming important parts of the energy mix throughout Europe and worldwide.

- Substantial investments in wind parks in the last decade
- Operation of wind parks is crucial for energy efficiency
- There is a large number of identical structures

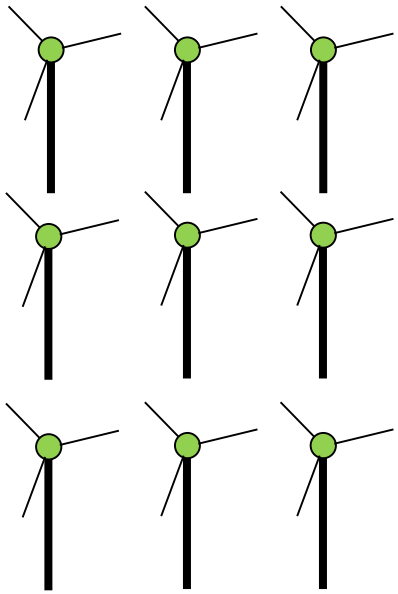


Offshore wind park operation

An actual challenge in the operation starting phase is what data needs to be collected to allow for a service life extension.

- An operator assesses in the commissioning phase of an offshore wind park the action of a service life extension from 20 to 25 years
- The operator aims at the highest utility throughout the service life (decision objective)
- Different SHM systems (decision variables)

Intact wind park



The power production and operation pf an offshore wind park with 50 turbines of 5MW is considered.

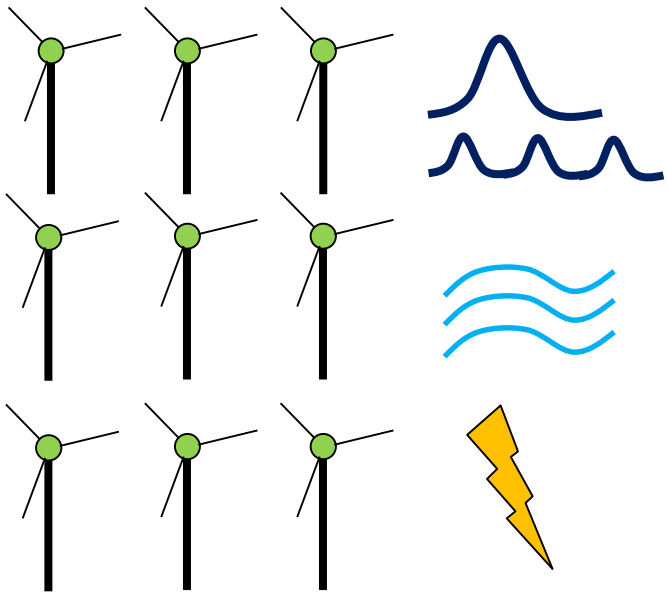
Turbine availability factor	0.95	
Nominal capacity availability factor	0.45	
Feed-in-tariff	0.12	Euro
Turbine investment	20.0	Million Euro
Wind park operation	0.02	1/a
Discount rate	0.05	

Return over investment

- 20 years operation: 15.1%
- 25 years operation: 30.1%

SHM is here only visible as additional costs.

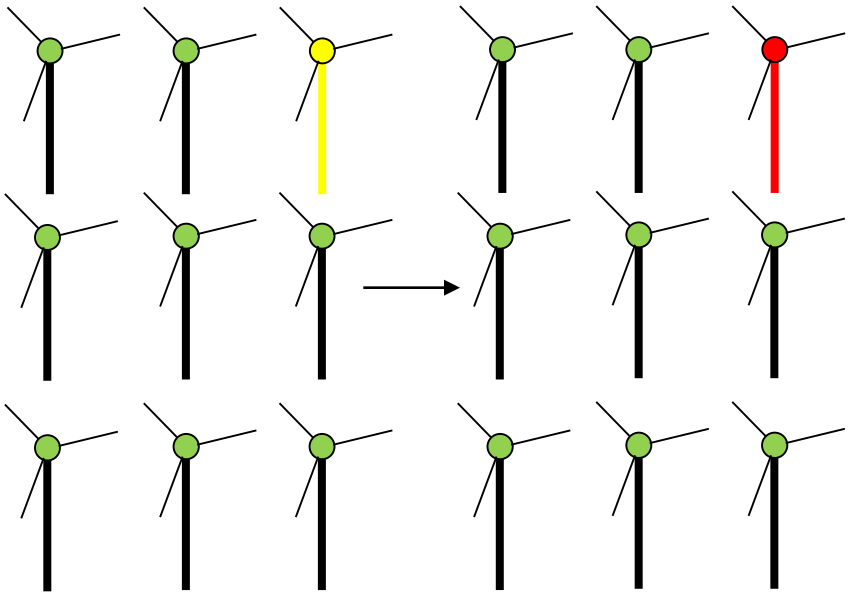
Exposures



Fatigue and extreme exposure events are considered.

- Fatigue exposure due wind, waves and operation
- Extreme event due wind, waves, normal and e.g. abnormal operation

Constituent damage and failure states



Wind turbine fatigue damage

- Characterised with FDF of 2.5

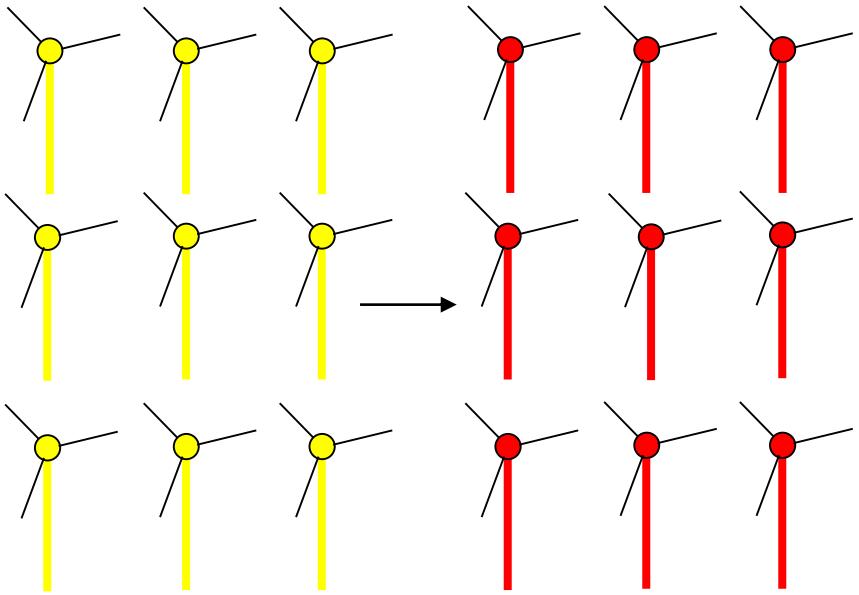
Wind turbine failure

- Probability of failure $5 \cdot 10^{-4}$ for minor consequences, normal cost of safety measures (JCSS Basis of Design)
- Coupled fatigue damage and resistance

Any of the wind turbine can be damaged or can fail.

- Series system models with a correlation 0.8

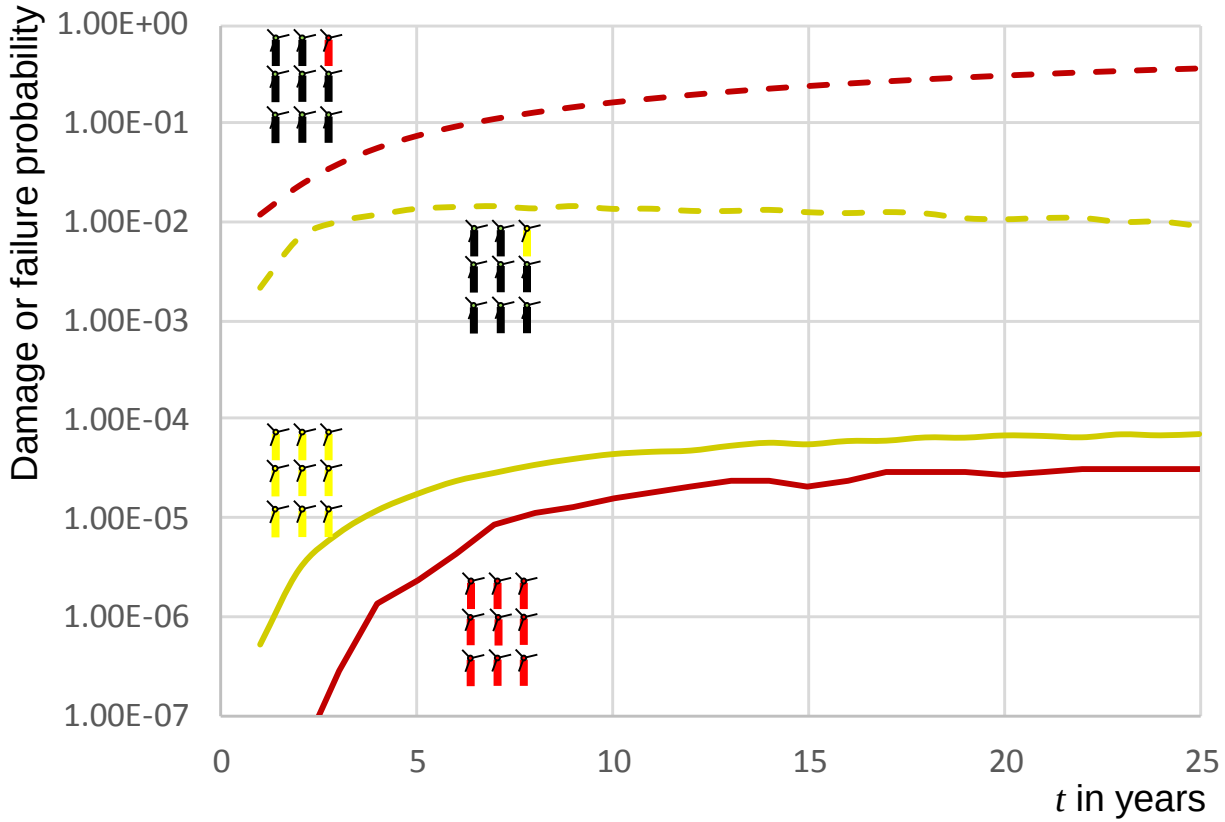
System damage and failure states



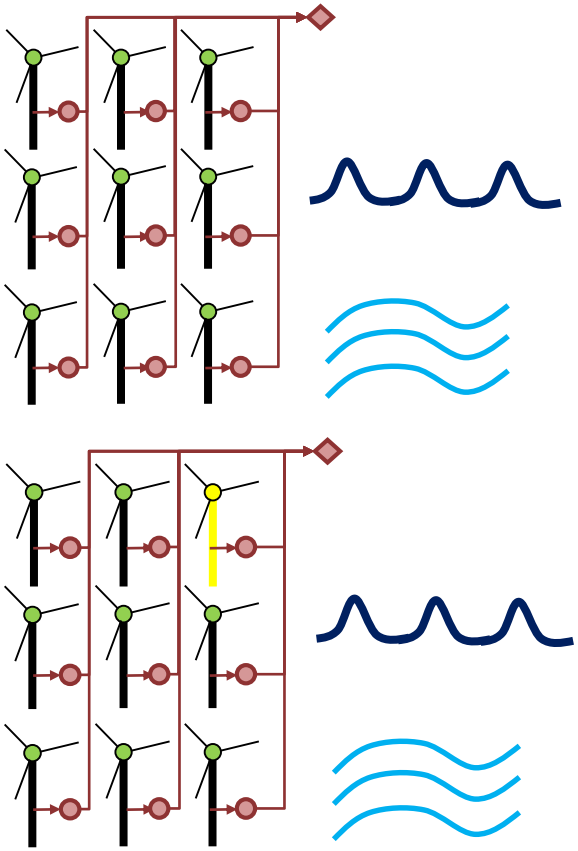
When a turbine is damaged or has failed, then there is a probability that the wind park is in a damaged or failed state.

- Brittle Daniels system model is utilised
  - Redundant system with a correlation 0.8
  - (Production) Capacity loss after failure
- Consequences
  - (Part of) Wind park investment
  - Production loss

Constituent and system damage and failure states



SHM strategies



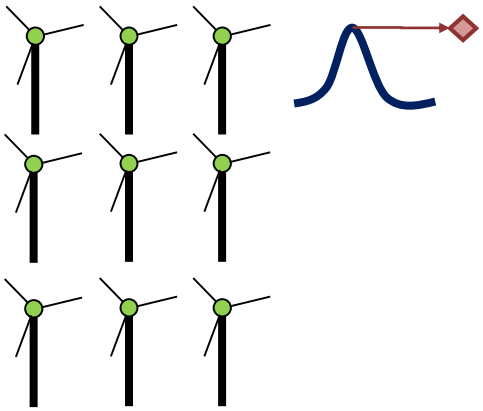
SHM Strategy 1: Fatigue loading (exposure)

- Pre-posterior model of fatigue loading measurement

SHM Strategy 2: Hot spot monitoring (exposure and constituent damage)

- Pre-posterior model of hot spot stress range measurement

SHM strategies



SHM Strategy 3: System load monitoring (exposure)

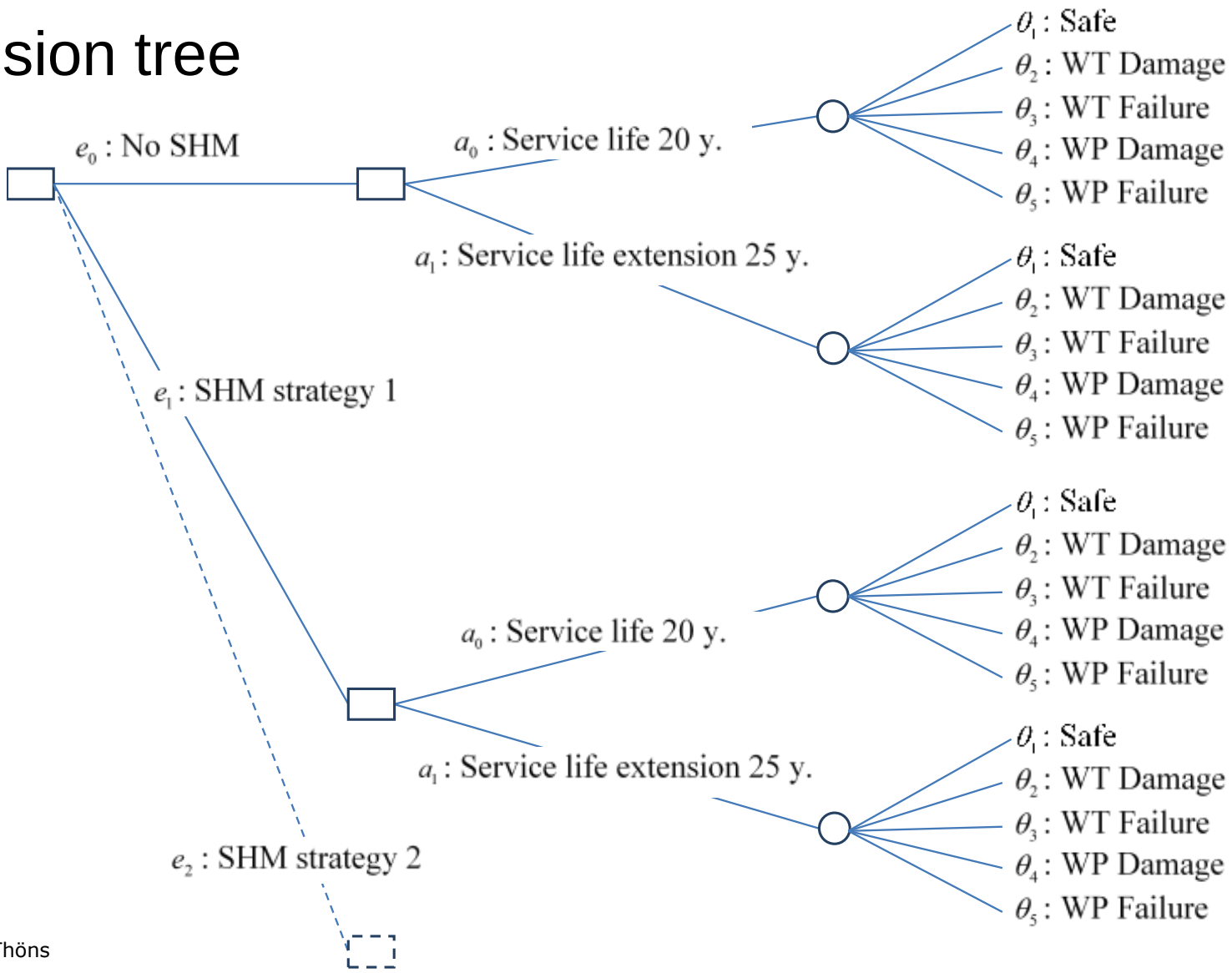
- Pre-posterior model of system loading measurement

The SHM precision is accounted for including statistical uncertainties.

The SHM costs is accounted for:

Investment	500,000.00 €
Installation	500,000.00 €
Operation	20,000.00 €/a
Replacement interval	10 a

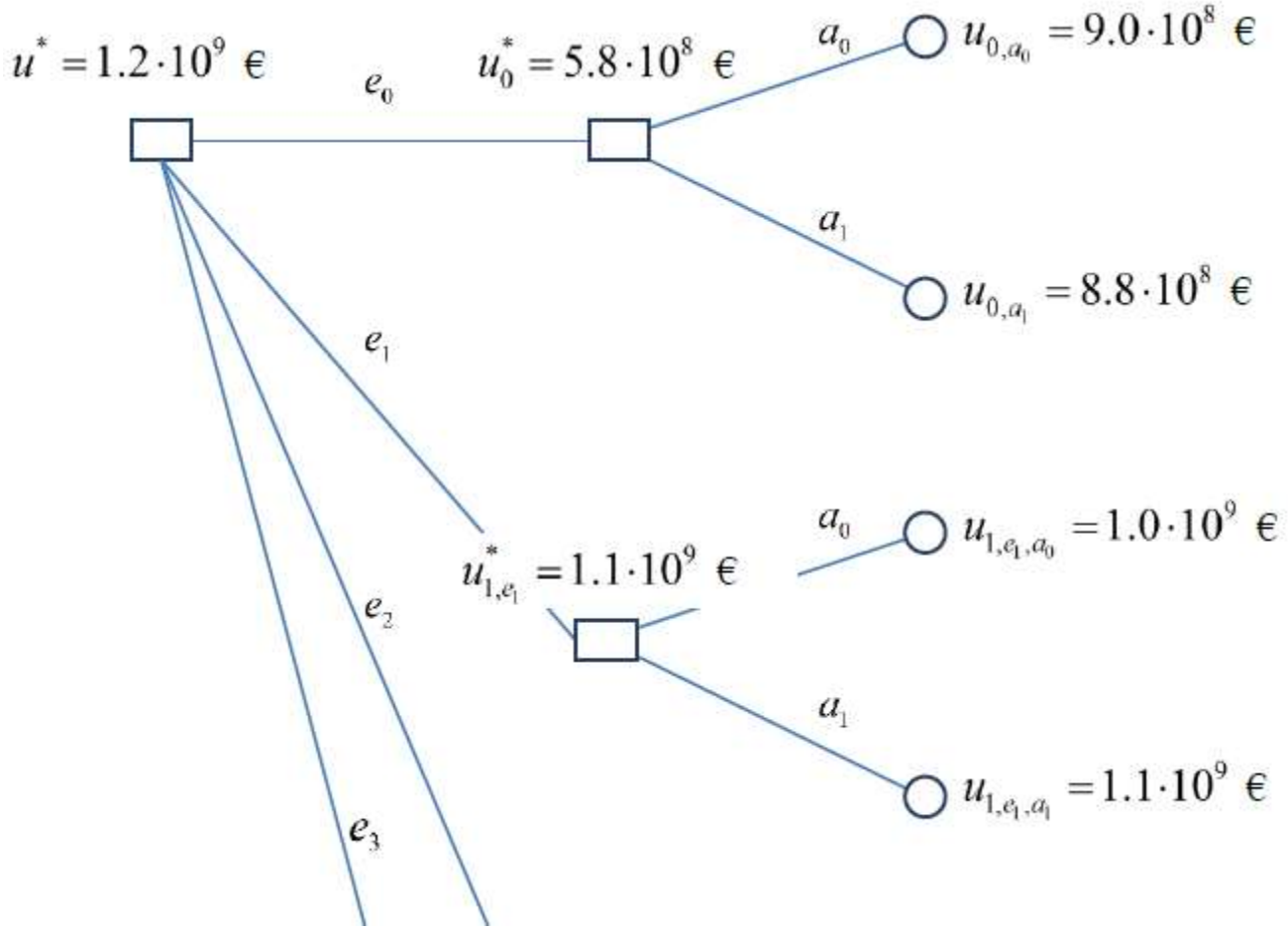
Decision tree



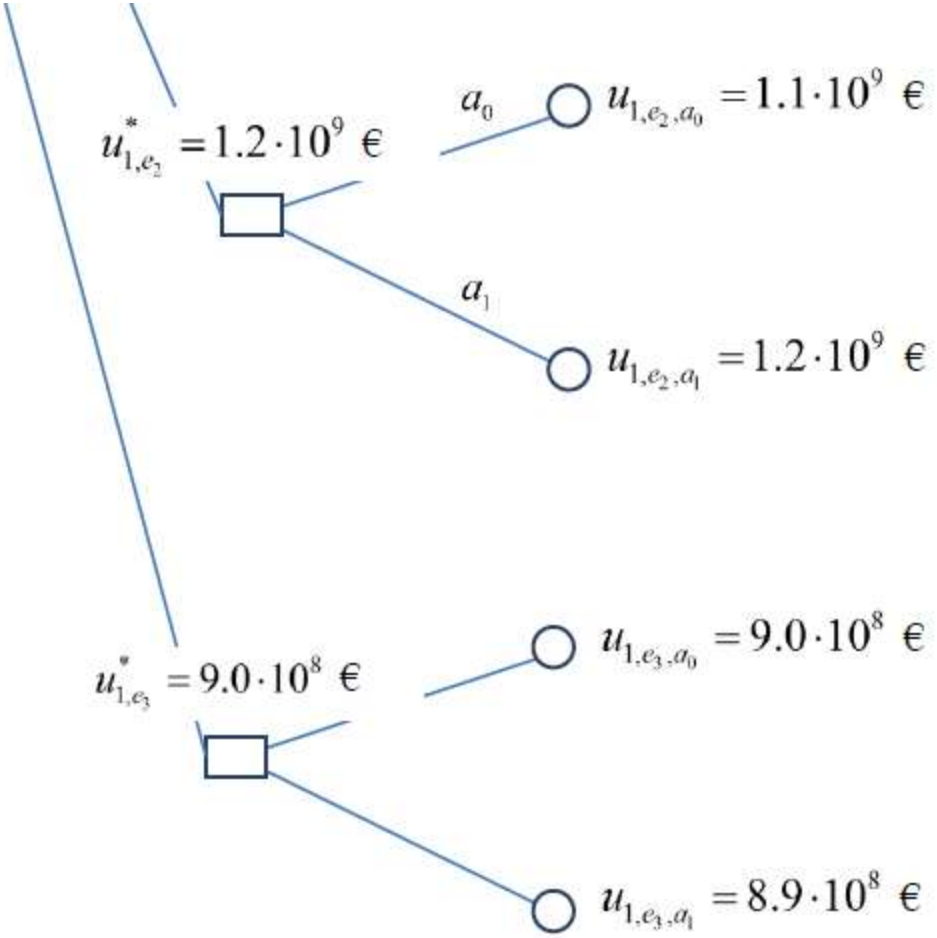
Value of Information

No.	Strategy	System state	Value of Information
1	Fatigue loading	Exposure	$\overline{VoI}_{e_1} = 18\%$
2	Hot spot monitoring	Exposure and constituent damage	$\overline{VoI}_{e_2} = 31\%$
3	System loading monitoring	Exposure	$\overline{VoI}_{e_3} = 0.7\%$

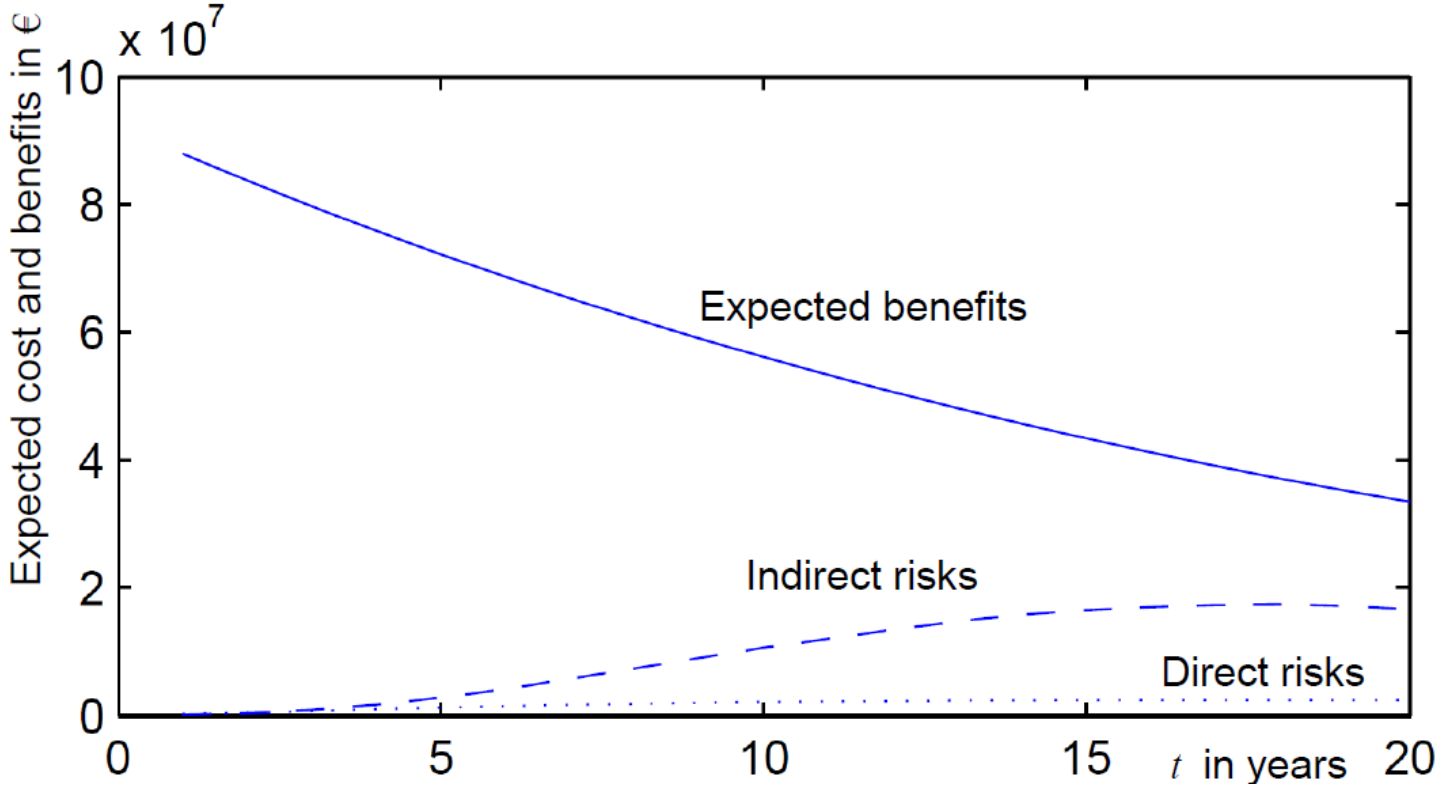
Utilities


$u^* = 1.2 \cdot 10^9$ €
e_0
$u_0^* = 5.8 \cdot 10^8$ €
a_0
$u_{0,a_0} = 9.0 \cdot 10^8$ €
a_1
$u_{0,a_1} = 8.8 \cdot 10^8$ €
e_1
$u_{1,e_1}^* = 1.1 \cdot 10^9$ €
a_0
$u_{1,e_1,a_0} = 1.0 \cdot 10^9$ €
e_2
a_1
$u_{1,e_1,a_1} = 1.1 \cdot 10^9$ €
e_3

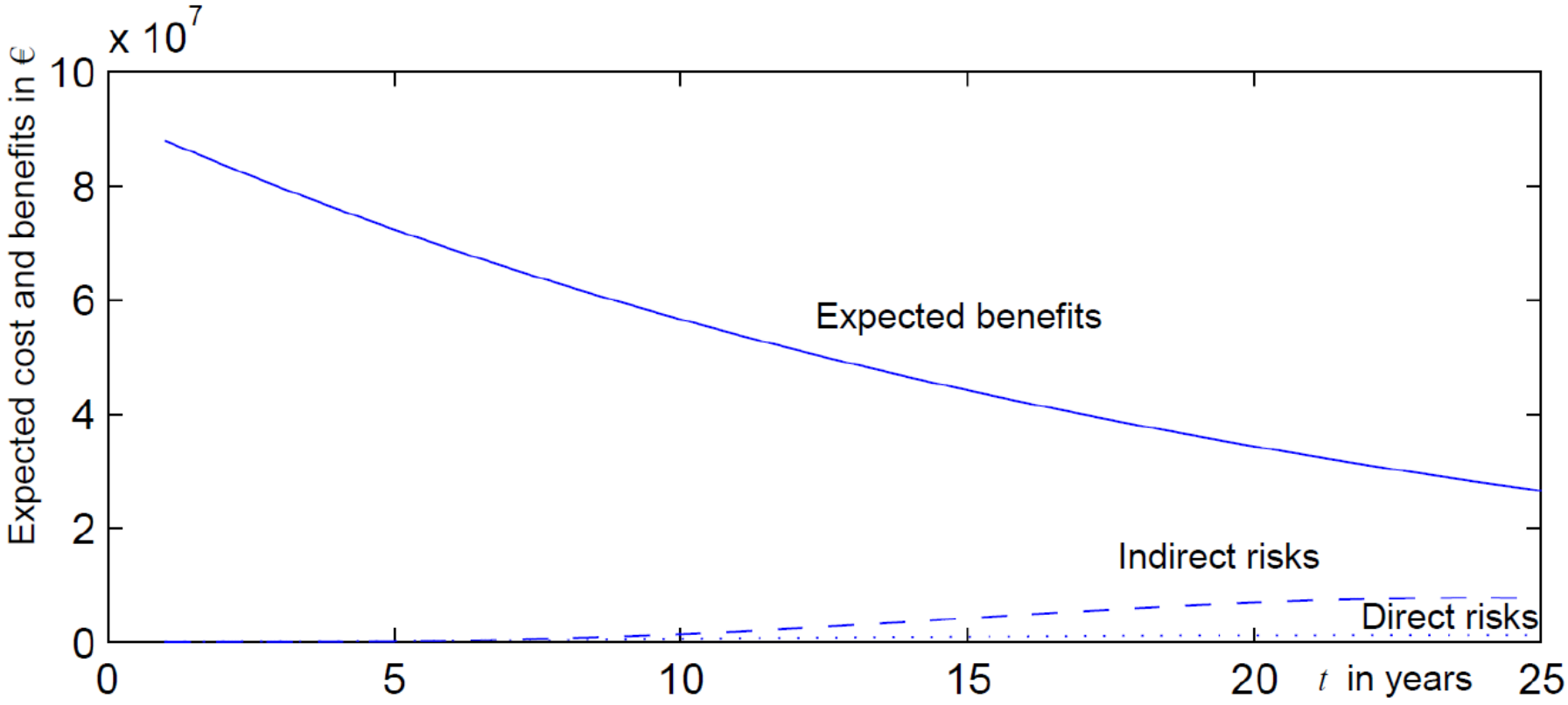
Utilities

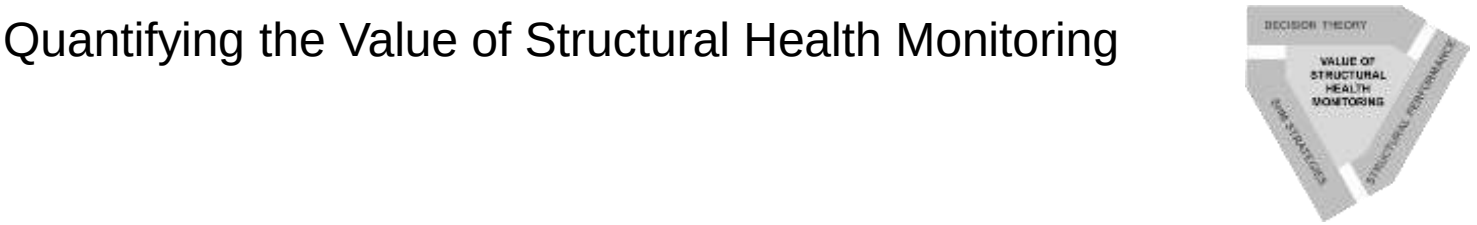

$u^*_{1,e_2} = 1.2 \cdot 10^9$ €
a_0
$u_{1,e_2,a_0} = 1.1 \cdot 10^9$ €
a_1
$u_{1,e_2,a_1} = 1.2 \cdot 10^9$ €
$u^*_{1,e_3} = 9.0 \cdot 10^8$ €
$u_{1,e_3,a_0} = 9.0 \cdot 10^8$ €
$u_{1,e_3,a_1} = 8.9 \cdot 10^8$ €

Utility for optimal prior decision

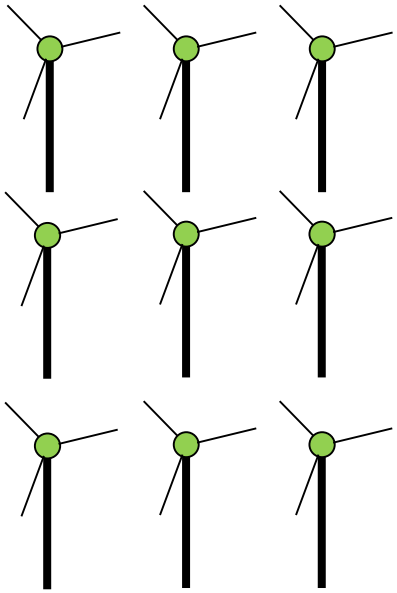


Utility for optimal pre-posterior decision





Further SHM strategies



Ideas for SHM strategies for the intact system state:

SHM strategy 4: More efficient wind park operation (10%) $\overline{VoI}_{e_4} = 2.6\%$

SHM strategy 5: Lower down times (10%) $\overline{VoI}_{e_5} = 15\%$

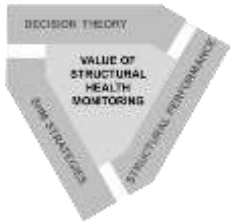
These STSM strategies also impact the cost-benefit analysis.

Conclusions

A test case is presented which should be further developed by adding complexity and/or to calibrate to assess and illustrate issues of interest in the future.

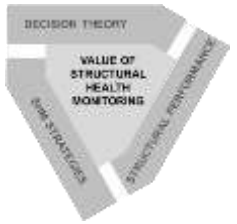
Wind park service life extension may only be optimal with relevant additional information of relative high precision.

There is a wide range of SHM strategies within the framework for infrastructure system utility and decision analysis.



WG Interaction

- WG2: Orientation and inspiration of how the SHM strategies and structural performance models for the system states may work together
- WG3: Starting point for adding complexity to the test case and provision of tools to handle the complexity
- WG4: Starting point for case studies

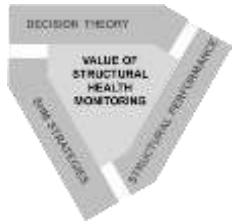


Further steps

1. Further feedback request
- Cost-benefit analysis, decision scenarios: wind park operators

2. Further development
- Further structural performance models, SHM strategies, refinement of models and algorithms
- Contributors are welcome. We will share the code.

3. Development of further test cases
- Deteriorating concrete structures
- …



Thank you for your attention.