Support for Case Studies

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ERDA
Engineering Risk and Decision Analysis

Contents

Domains, frameworks, categorizations

Domains of SHM Value

1. Operation of structures and portfolios of structures
   a) Decisions about e.g. service life extension and structural utilisation modification

2. Code making and code calibration
   a) Decisions about e.g. target reliability level for design and assessment

3. Early damage warning
   a) Decisions about e.g. evacuation measures and risk mitigation

H. Brüske and S. Thöns (2016). Domains of the Value of Information in Structural Health Monitoring. Factsheet WG1-4 in Proceedings of the 3rd and 4th Workshop of the COST Action TU1402 on Quantifying the Value of Structural Health Monitoring. Technical University of Denmark, Denmark.

Domains, frameworks, categorizations

Domains of SHM Value cont.

4. Structure prototype development / Design by testing
   a) Decisions about e.g. design approach procedure development and identification of the best tools

5. SHM systems prototype development
   a) Decisions about e.g. the SHM system (duration, location, precision) in the context of the previous domains

H. Brüske and S. Thöns (2016). Domains of the Value of Information in Structural Health Monitoring. Factsheet WG1-4 in Proceedings of the 3rd and 4th Workshop of the COST Action TU1402 on Quantifying the Value of Structural Health Monitoring. Technical University of Denmark, Denmark.

Domains, frameworks, categorizations

LEVEL 0

Formulate an objective function

DECISION MAKER

Public/Private

LIFE CYCLE COST OPTIMIZATION

CONSTRAINTS

- Budget
- Life Safety
- Performance/Functionality
- Regulations
- Stakeholders

BENEFITS

LEVEL -1

CONTEXT

- Design new
- Existing
- End of Life

FUNCTIONALITY

LEVEL -2

- Element
- Network

LEVEL -3

Structural Types:

- Bridges,
- Offshore,
- Nuclear,
- Building
- …

Performance

Criteria:

- ULS
- SLS
- Fatigue

Basic Variables

- Loads
- Resistance
- …

SHM

Observations:

- …

ACTIONS

- Maintenance
- Inspection
- Repair
- Strengthening
- SHM
- …

LEVEL -4

Materials

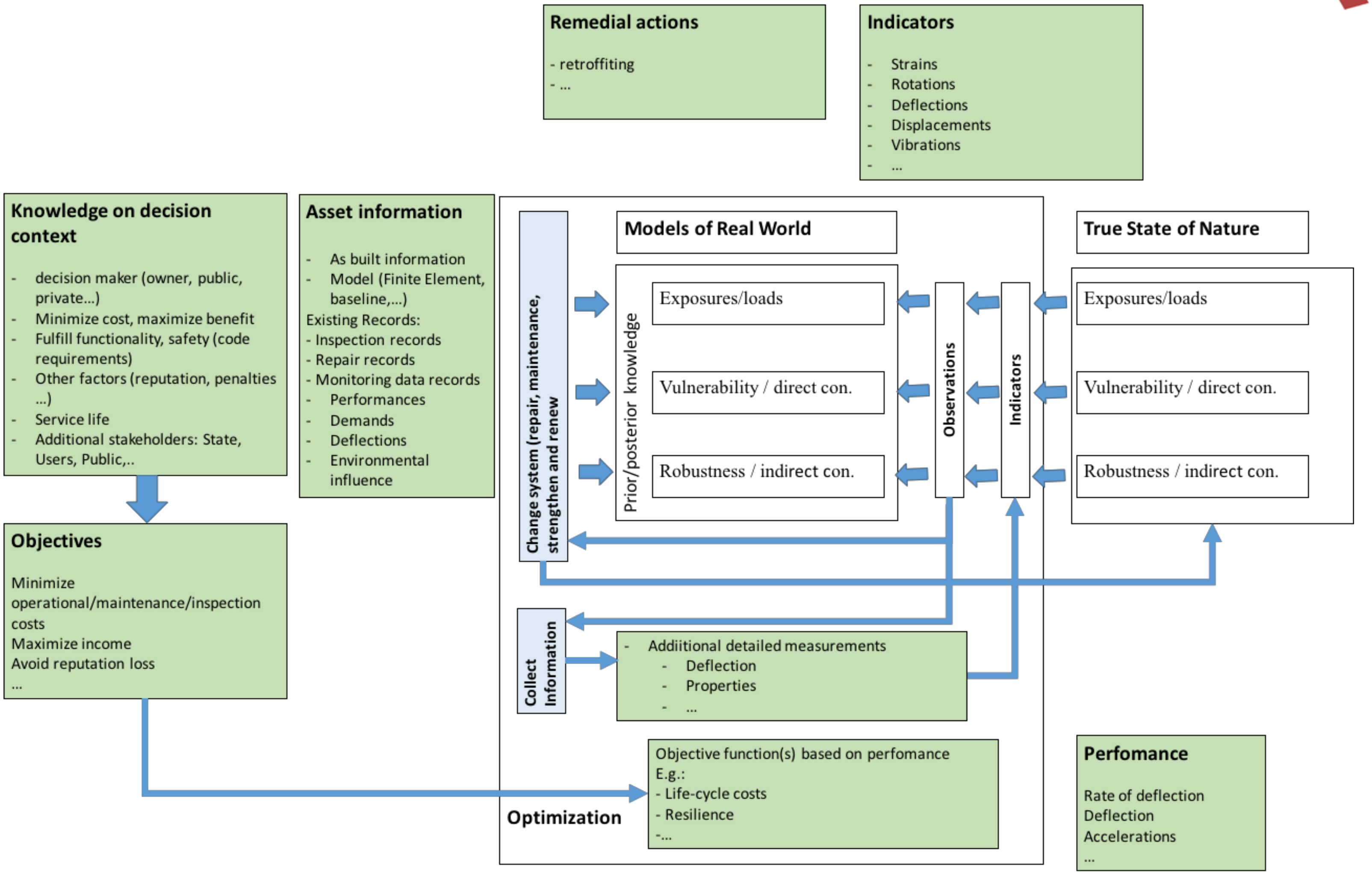
- Degradation mechanisms
- …

Technologies:

- Visual inspection
- …

Elizabeth Bismut, Ronald Schneider, Helder Sousa, Daniel Straub (2017). Draft WG3 Factsheet. Categorizations for Value of Information Analysis.

Domains, frameworks, categorizations



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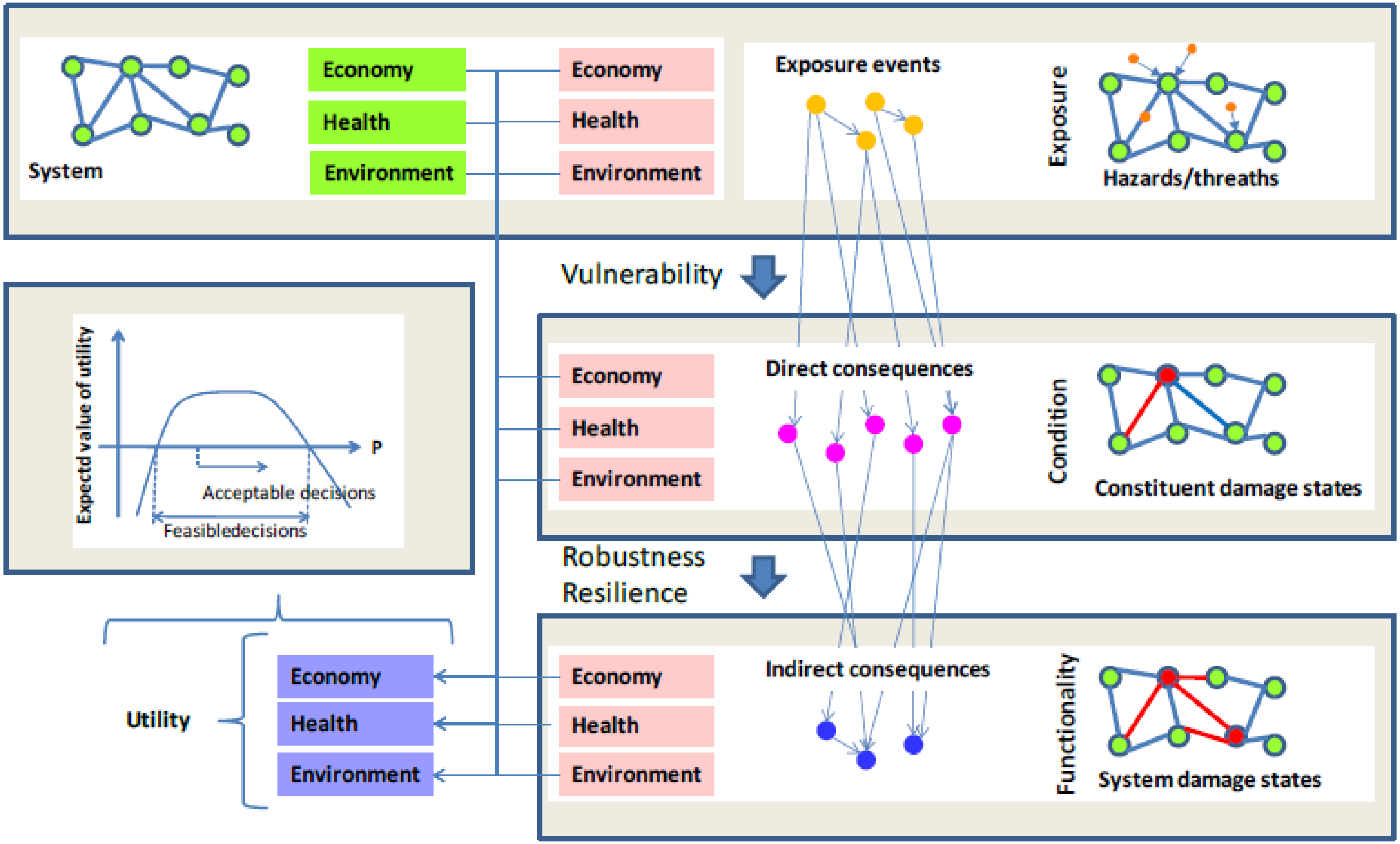
Domains, frameworks, categorizations

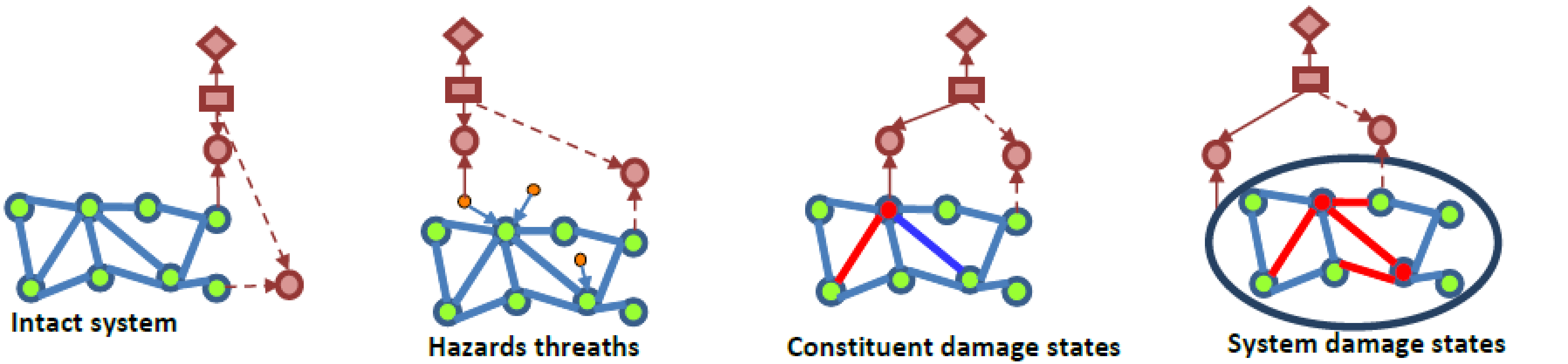


Faber, M. H., J. Qin, S. Miraglia and S. Thöns (In press). On the Probabilistic Characterization of Robustness and Resilience. Procedia Engineering.

Domains, frameworks, categorizations

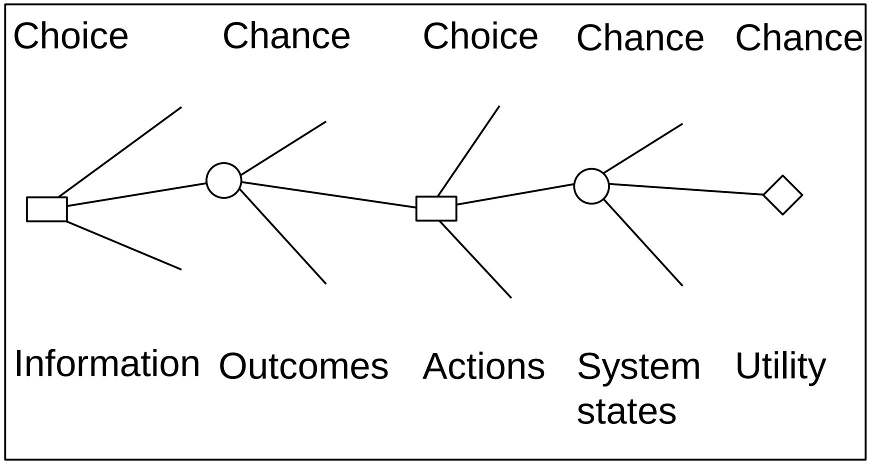
Illustration of SHM in different system states

- characterized by type, precision (circular node), cost (diamond shaped node)
- two measurement locations (dashed and continuous lines)



Thöns, S., M. H. Faber and D. Val (Accepted). On the Value of Structural Health Monitoring Information for the Operation of Wind Parks. ICOSSAR 2017, Vienna, Austria

Basics



A Value of Information analysis is defined as the quantification of the utility or benefit increase due to additional or unknown information.

A Value of Information analysis is characterised with a decision tree encompassing:

- Choice of information
- Chance of outcomes
- Choice of actions
- Chance of system states
- Utilities

Basics: Example

A bridge has been built. The operating and maintenance company becomes concerned about the functioning of the bridge as unusual vibrations are observed. It is estimated that with a probability of 20% there is a damage (system state X_2).

Basics: Example

You have two action options:

- Do nothing (action a_0)
- Lower the load bearing class (action a_1). This costs 20 and provides less benefit.

Benefits and costs:

System state		Action a_0	Action a_1
X_1	Intact	100	70
X_2	Damaged	-200	70

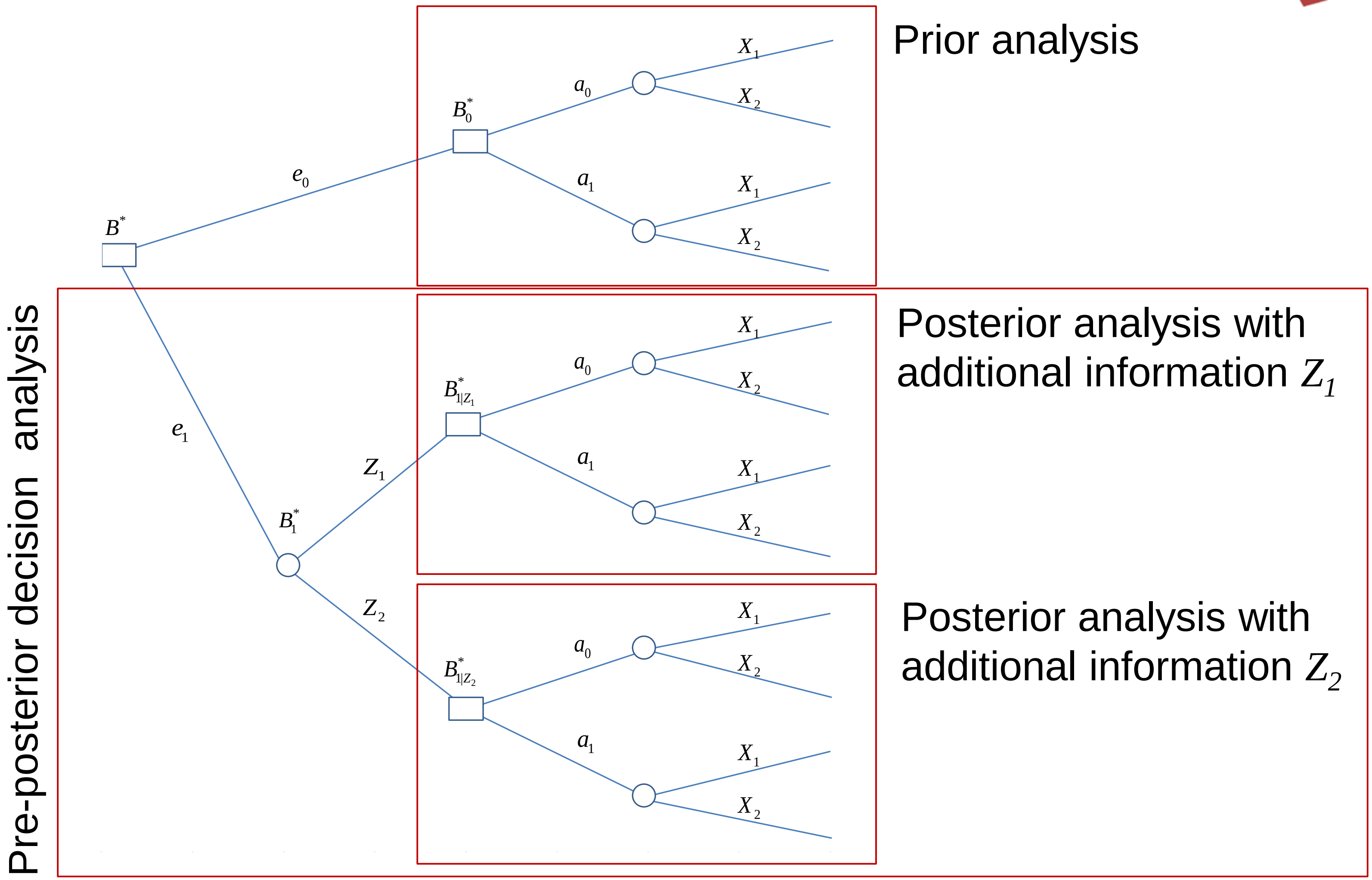
Basics: Example

Based on prior experience and studies you know the probabilities of indication (e.g. $P(Z_1 \mid X_1)$ = 90% indicating an intact state) according to the table below. The cost of the analysis is 10.

	X_1	X_2
Z_1	0.9	0.15
Z_2	0.1	0.85

Denotation: e_1 denotes performing the modal analysis, e_0 denotes not performing the modal analysis

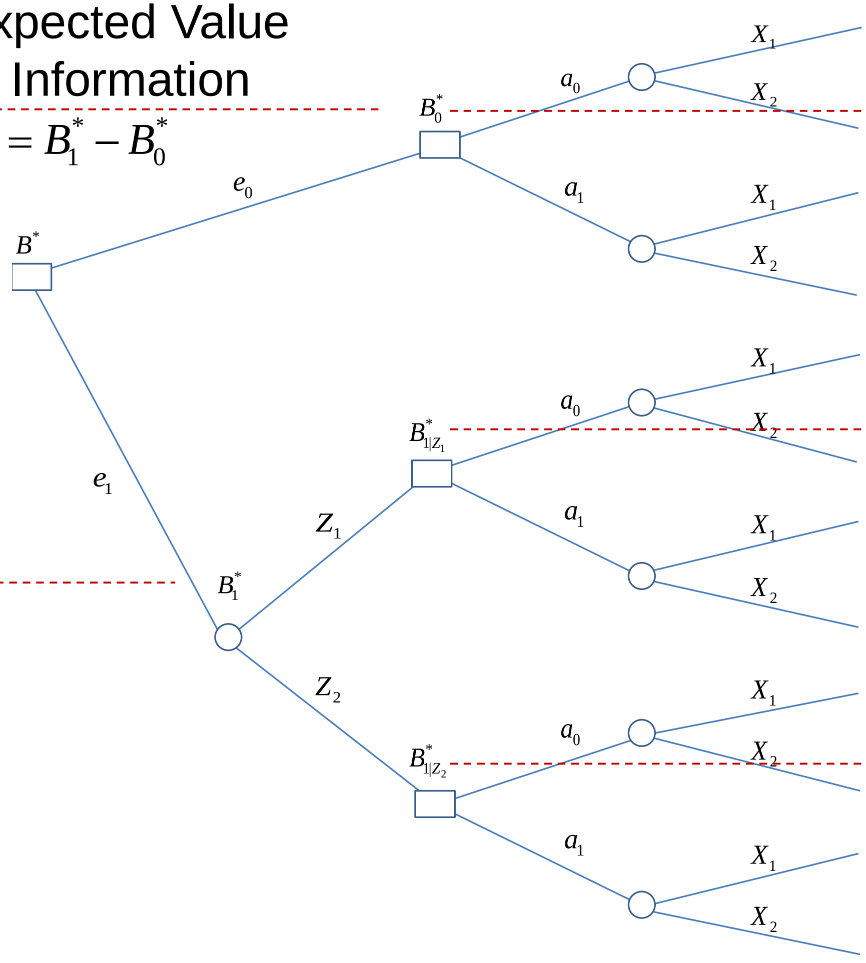
Decision analyses



Value of Information analyses

Expected Value of Information

$V = B_1^* - B_0^*$



Conditional Value of Information (Z_1)

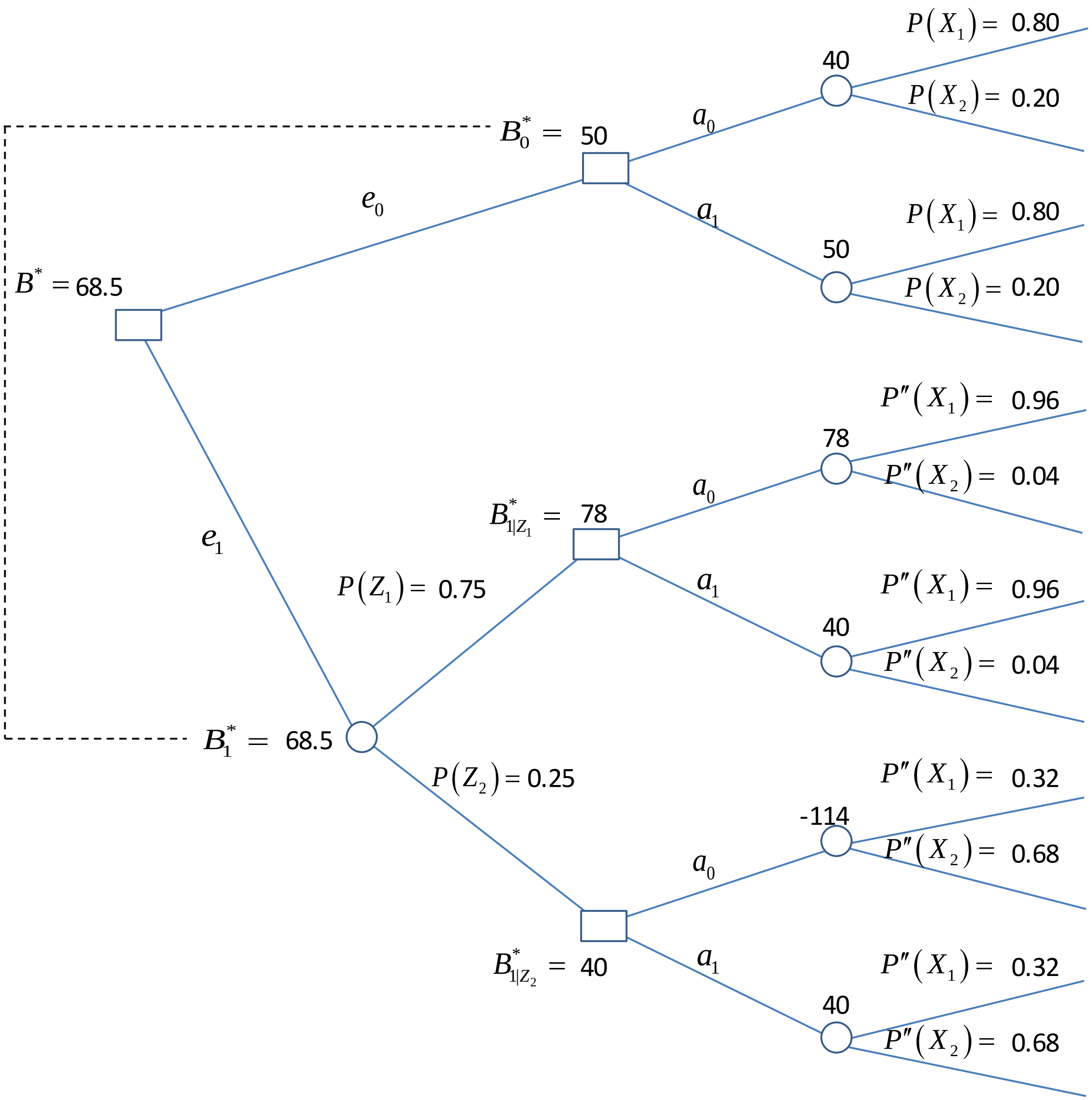
$V \mid Z_1 = B_{1|Z_1}^* - B_0^*$

Conditional Value of Information (Z_2)

$V \mid Z_2 = B_{1|Z_2}^* - B_0^*$

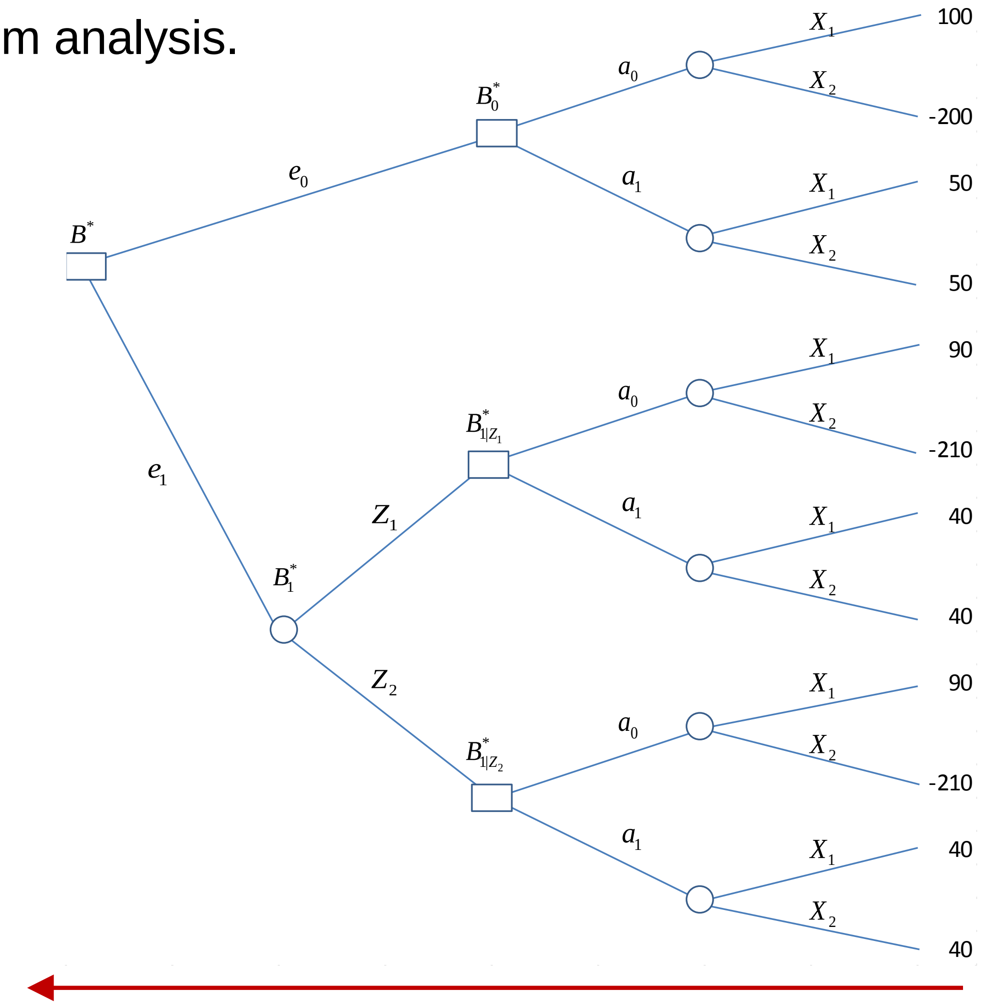
Analysis

$$V = B_1^* - B_0^* = 18.5$$

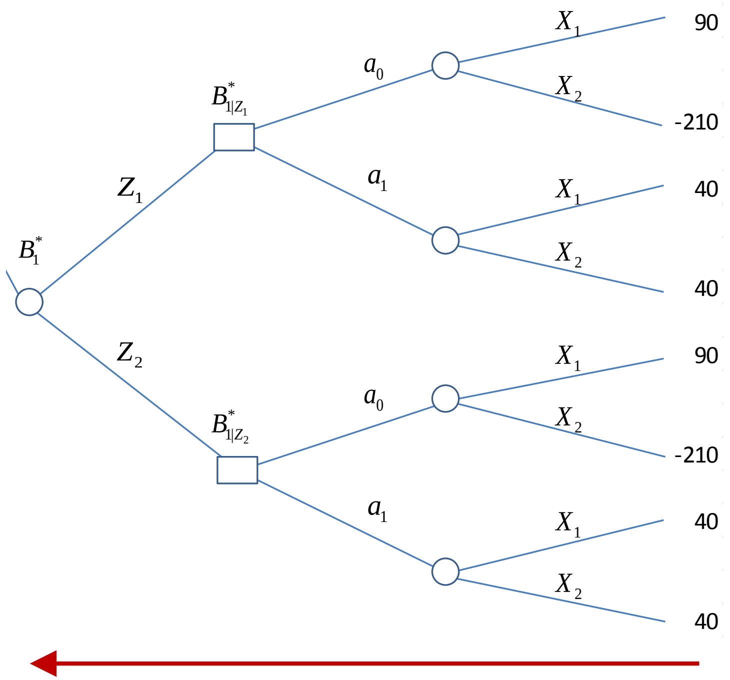


Normal and extensive form analysis

Extensive form analysis.



Normal and extensive form analysis



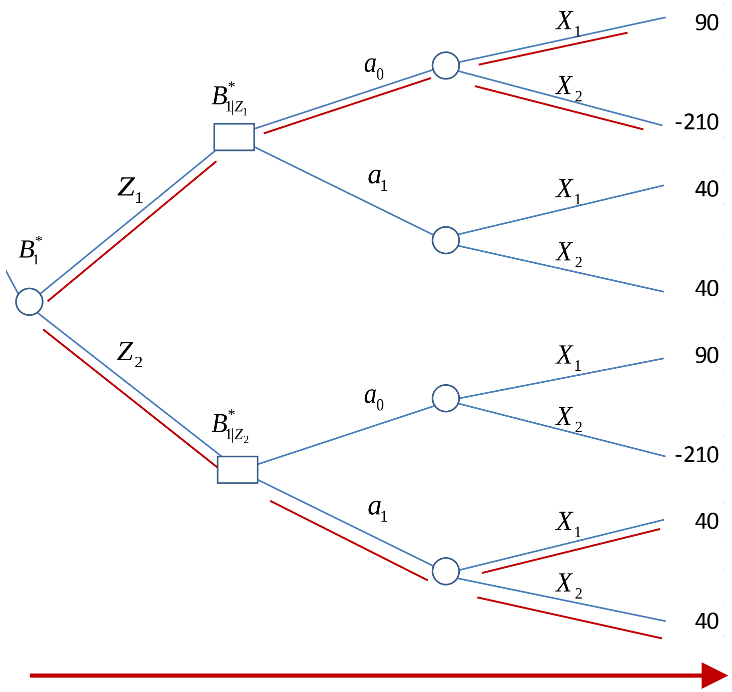
Extensive form analysis

$$B_1^* = P(Z_1)\cdot\max\begin{bmatrix}\begin{pmatrix}P''(X_1)\cdot b(e_1,Z_1,a_0,X_1)\\ +P''(X_2)\cdot b(e_1,Z_1,a_0,X_2)\end{pmatrix}\\ \begin{pmatrix}P''(X_1)\cdot b(e_1,Z_1,a_1,X_1)\\ +P''(X_2)\cdot b(e_1,Z_1,a_1,X_2)\end{pmatrix}\end{bmatrix}$$

$$+P(Z_2)\cdot\max\begin{bmatrix}\begin{pmatrix}P''(X_1)\cdot b(e_1,Z_2,a_0,X_1)\\ +P''(X_2)\cdot b(e_1,Z_2,a_0,X_2)\end{pmatrix}\\ \begin{pmatrix}P''(X_1)\cdot b(e_1,Z_2,a_1,X_1)\\ +P''(X_2)\cdot b(e_1,Z_2,a_1,X_2)\end{pmatrix}\end{bmatrix}$$

Can this expression be simplified?

Normal and extensive form analysis

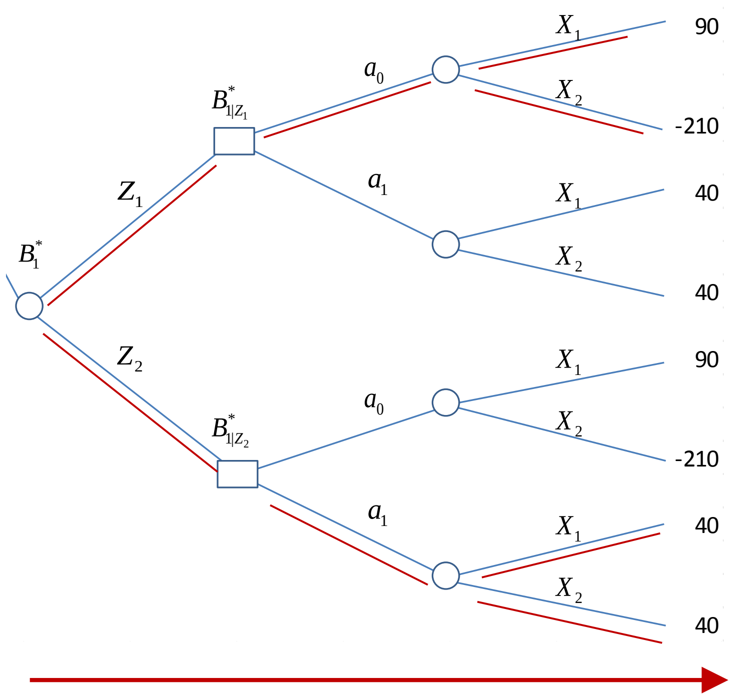


Normal form analysis

$$
\begin{aligned}
B_1^* &= P(Z_1 \mid X_1)\cdot P(X_1)\cdot b(e_1, Z_1, a_0, X_1) \\
&+ P(Z_1 \mid X_2)\cdot P(X_2)\cdot b(e_1, Z_1, a_0, X_2) \\
&+ P(Z_2 \mid X_1)\cdot P(X_1)\cdot b(e_1, Z_2, a_1, X_1) \\
&+ P(Z_2 \mid X_2)\cdot P(X_2)\cdot b(e_1, Z_2, a_1, X_2)
\end{aligned}
$$

But how do we allocate the actions to the outcomes?

Normal and extensive form analysis

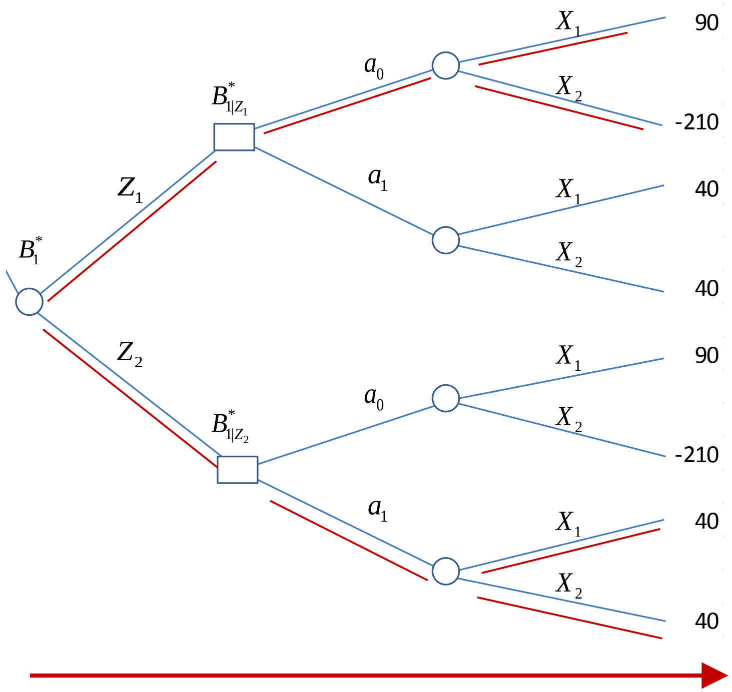


We need to define decision rules to connect the outcomes with the actions.

- Decision rule: do experiment and perform actions according to outcomes

$$\mathbf{d} = \begin{bmatrix} e_1 \\ Z_1 : a_0 \\ Z_2 : a_1 \end{bmatrix}$$

Normal and extensive form analysis



We can reproduce the expected benefits with a normal form analysis.

$$B_0^* = 40.0 + 10.0 = 50.0$$

$$\begin{aligned}
B_1^* &= P(Z_1 \mid X_1) \cdot P(X_1) \cdot b(e_1, Z_1, a_0, X_1) \\
&+ P(Z_1 \mid X_2) \cdot P(X_2) \cdot b(e_1, Z_1, a_0, X_2) \\
&+ P(Z_2 \mid X_1) \cdot P(X_1) \cdot b(e_1, Z_2, a_1, X_1) \\
&+ P(Z_2 \mid X_2) \cdot P(X_2) \cdot b(e_1, Z_2, a_1, X_2) \\
&= 64.8 - 6.3 + 3.2 + 6.8 = 68.5
\end{aligned}$$

$$V_{EVSI,\mathrm{e}_1} = B_1^* - B_0^* = 68.5 - 50.0 = 18.5$$

Prior decision analysis: required models

System state models ($\mathbf{X}$) are required.

- Models of the actual performance and prediction of performance, i.e. the probability that the system is or will be in a specific state (intact, damage, failure).

- The basis of the models are either observations and databases or empirical, physical or chemical models.
  - Observations: Maximum Likelihood for probabilistic modelling
  - Models and observations: Regression analysis

Prior decision analysis: required models

$$\mathbf{X} = \begin{bmatrix} \bar{F} & F & \bar{D} & D \end{bmatrix}^T$$

$$g_F = z_R M_R R\left(1 - M_D D\right) - M_S S$$

$$F : g_F \leq 0$$

$$S : g_F > 0$$

$$g_D = z_\Delta M_\Delta \Delta - M_D D$$

Example: System State Model

- Generic limit state function for failure and survival
- Failure
- Survival
- Generic limit state function for damage and no damage

Definitions: Model uncertainty M, Resistance R, Δ, Loading S, Design z, Damage D

Prior decision analysis: required models

Action models ($\mathbf{a}$) are required.

- Actions can be described with their influence on the system state models ($\mathbf{X}$).

The consequences for the system states and the actions are required.

- E.g. benefits for system functionality and costs for actions and damage and failure states.

Posterior decision analysis: required models

A model for the information Z is required.

Information in the context of the Bayesian decision theory are characterised by the type, the precision and the costs.

- The type may encompass and experiment, an additional analysis or model providing information in relation to the system states.

- The precision includes the relevant uncertainties of the information.

Pre-posterior decision analysis: required models

A pre-posterior model for information acquirement $\mathbf{i}$ is necessary.

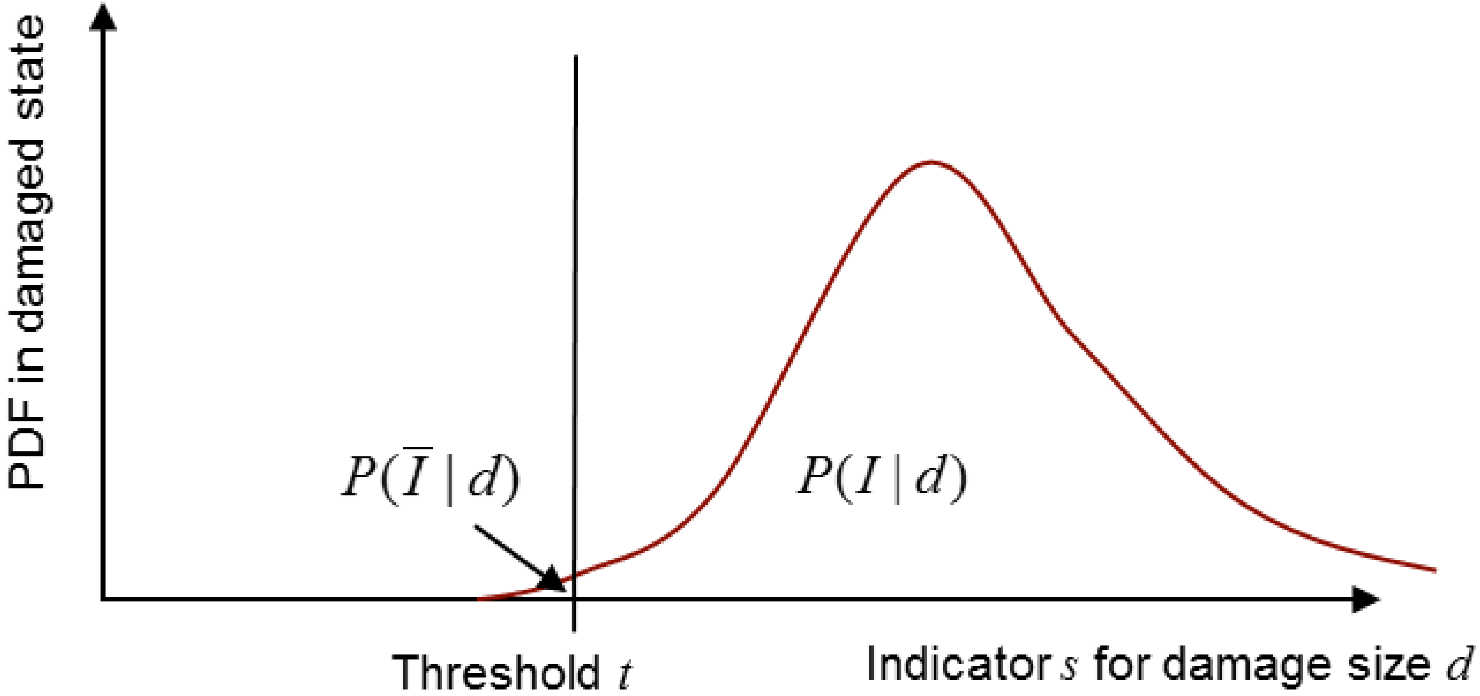
- All outcomes of the information acquirement strategy $\mathbf{Z}_i$ need to be modelled probabilistically in conjunction with the prior model of the system states $\mathbf{X}$.

- The information acquirement strategy type may encompass and experiment, an additional analysis or model providing information in relation to the system states.

- The precision of the information $P\left(\mathbf{Z}_i \mid \mathbf{X}\right)$ includes the relevant uncertainties of the information.

Pre-posterior decision analysis: required models

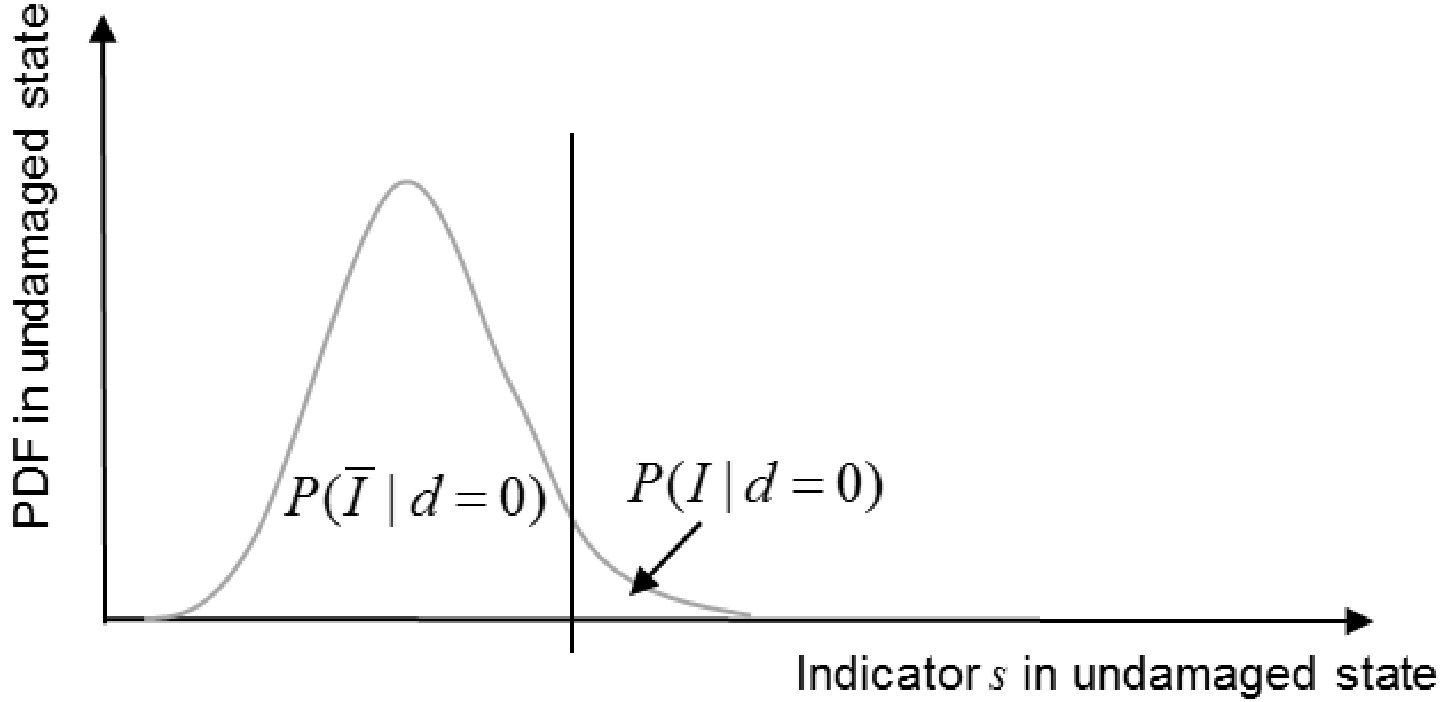
Basic NDT/NDE reliability modelling



$$P(\bar{I} \mid d) = \int_{-\infty}^{t} f\left(s \mid d\right) ds \qquad P(I \mid d) = \int_{t}^{\infty} f\left(s \mid d\right) ds$$

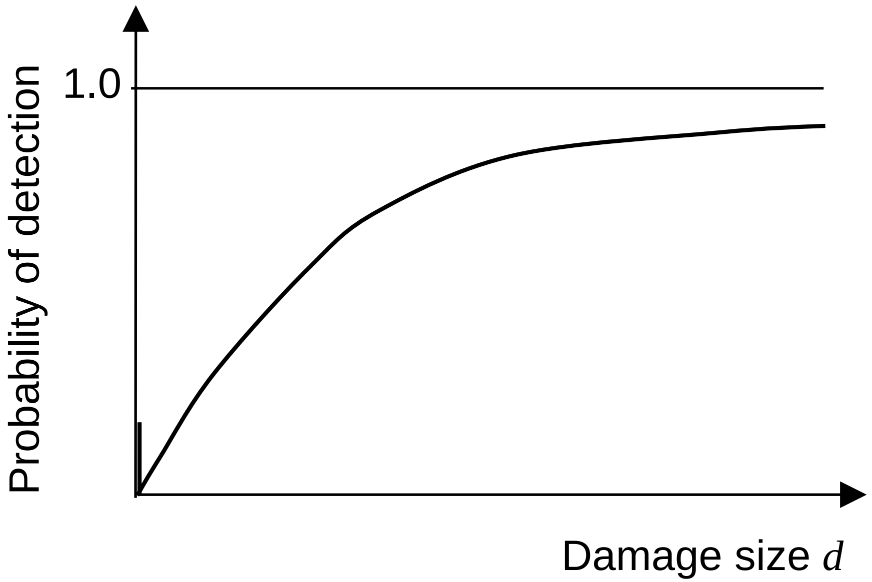
Pre-posterior decision analysis: required models

Basic NDT/NDE reliability modelling



$$P(\overline{I} \mid d=0) = \int_{-\infty}^{t} f\left(s \mid d=0\right) ds \qquad P(I \mid d=0) = \int_{t} f\left(s_R \mid d=0\right) ds$$

Pre-posterior decision analysis: required models



$$P(I)=\int_D F(I\,|\,d=0,d)\,f_D\left(d\right)dd$$

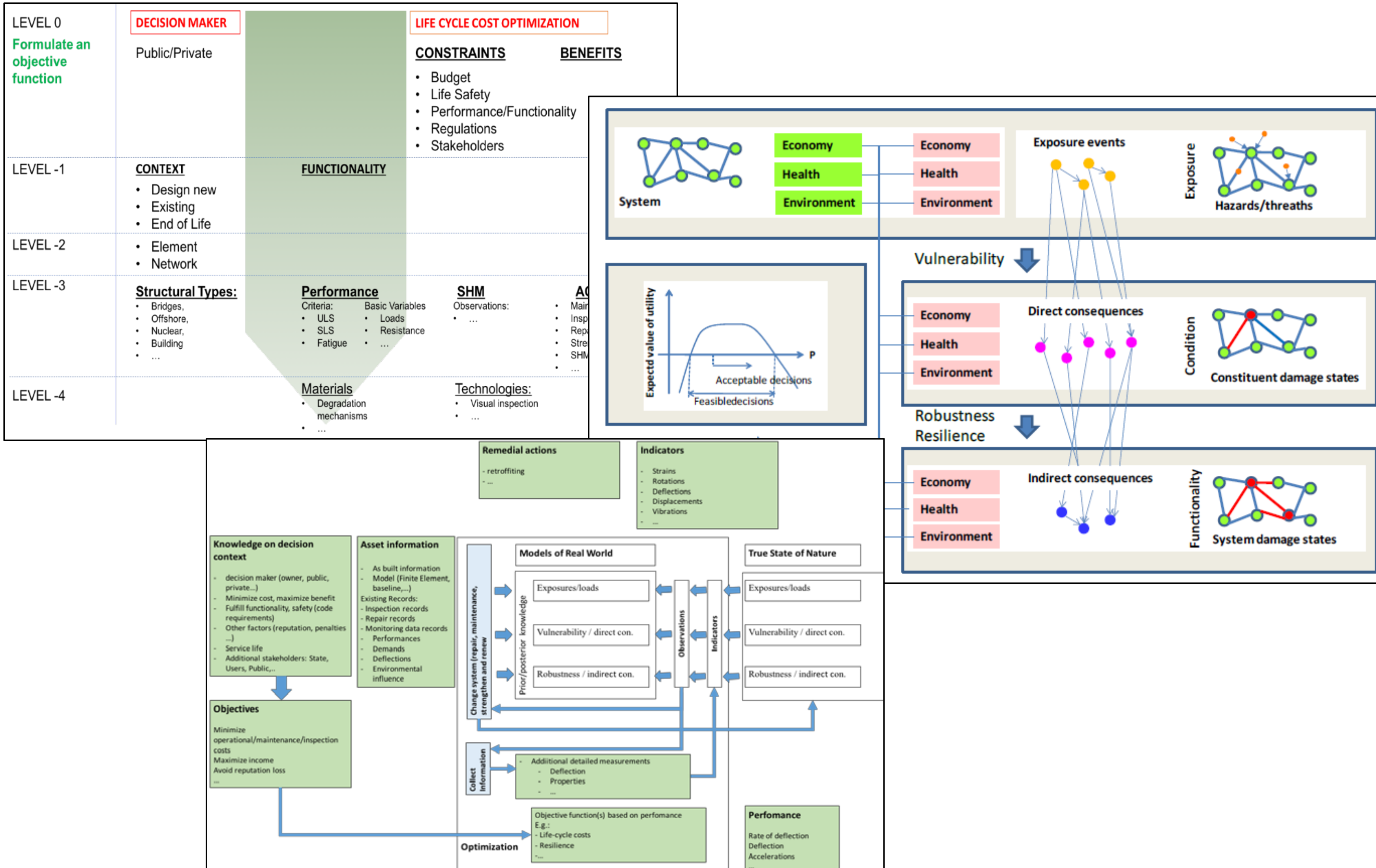
Basic NDT/NDE reliability modelling

- Probability of detection/indication is dependent on the damage size

- Marginal probability s to be determined in conjunction with the prior (damage) state.

$$\mathbf{Z}=\begin{bmatrix} Z_1=\overline{I} \\ Z_2=I \end{bmatrix}$$

Complexity: System models



Complexity: SHM system modelling

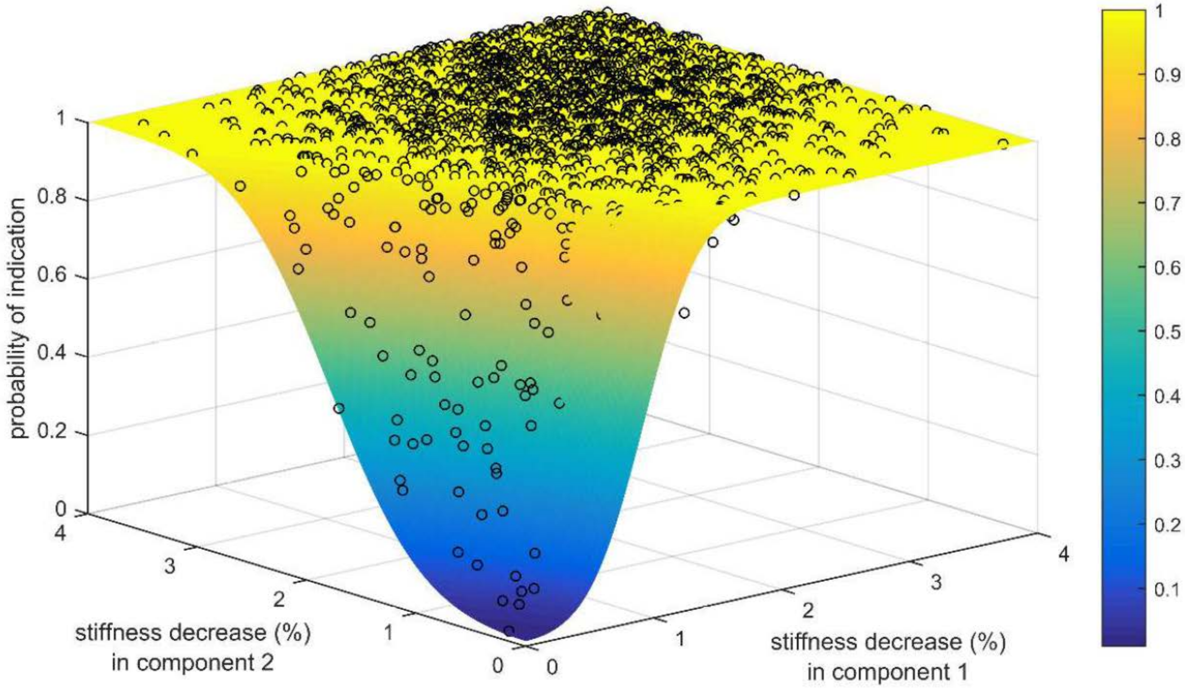
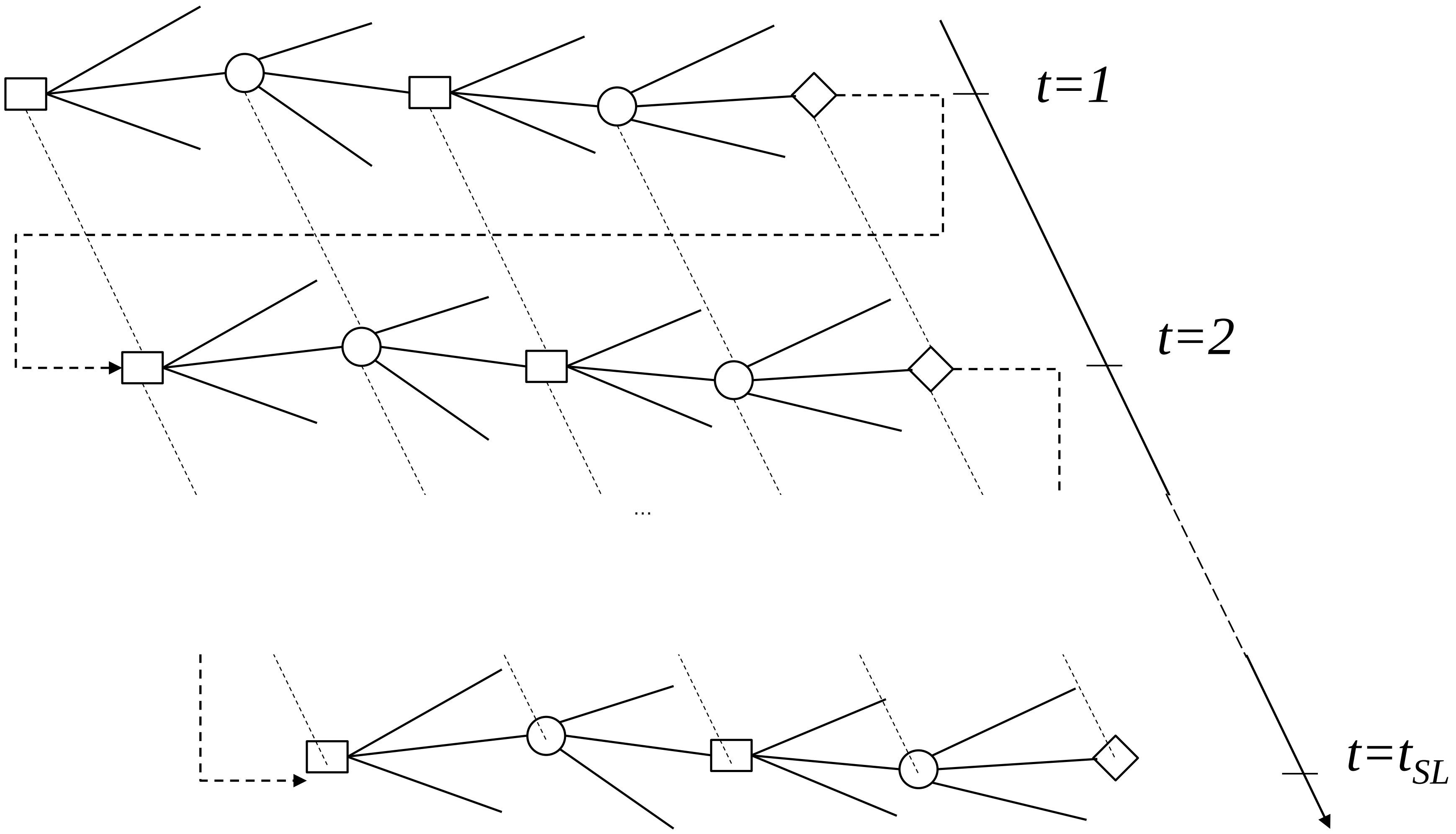


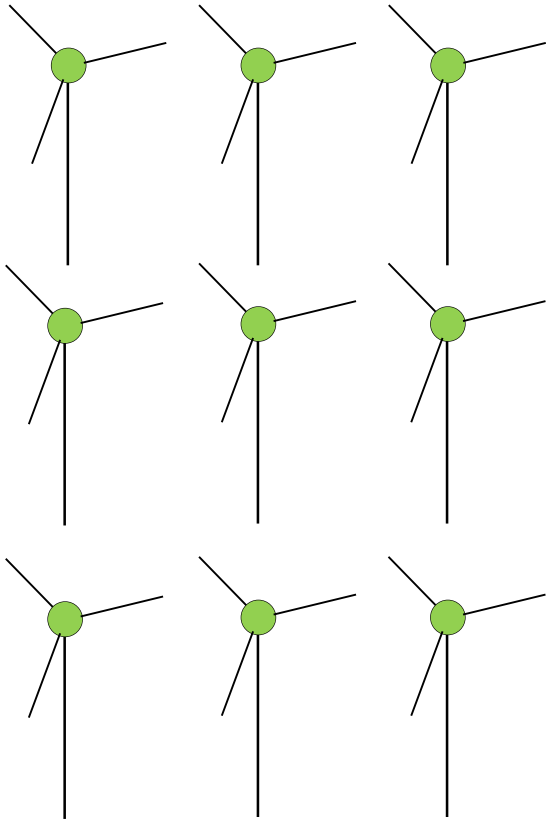
Figure 3: Probability of indication for damages in both structural components.

Döhler, M. and S. Thöns (2016). Efficient Structural System Reliability Updating with Subspace-Based Damage Detection Information. European Workshop on Structural Health Monitoring (EWSHM), Bilbao, Spain, 5-8 July 2016.

Complexity: Temporal modelling



Example: Service Life Extension of a Wind Park



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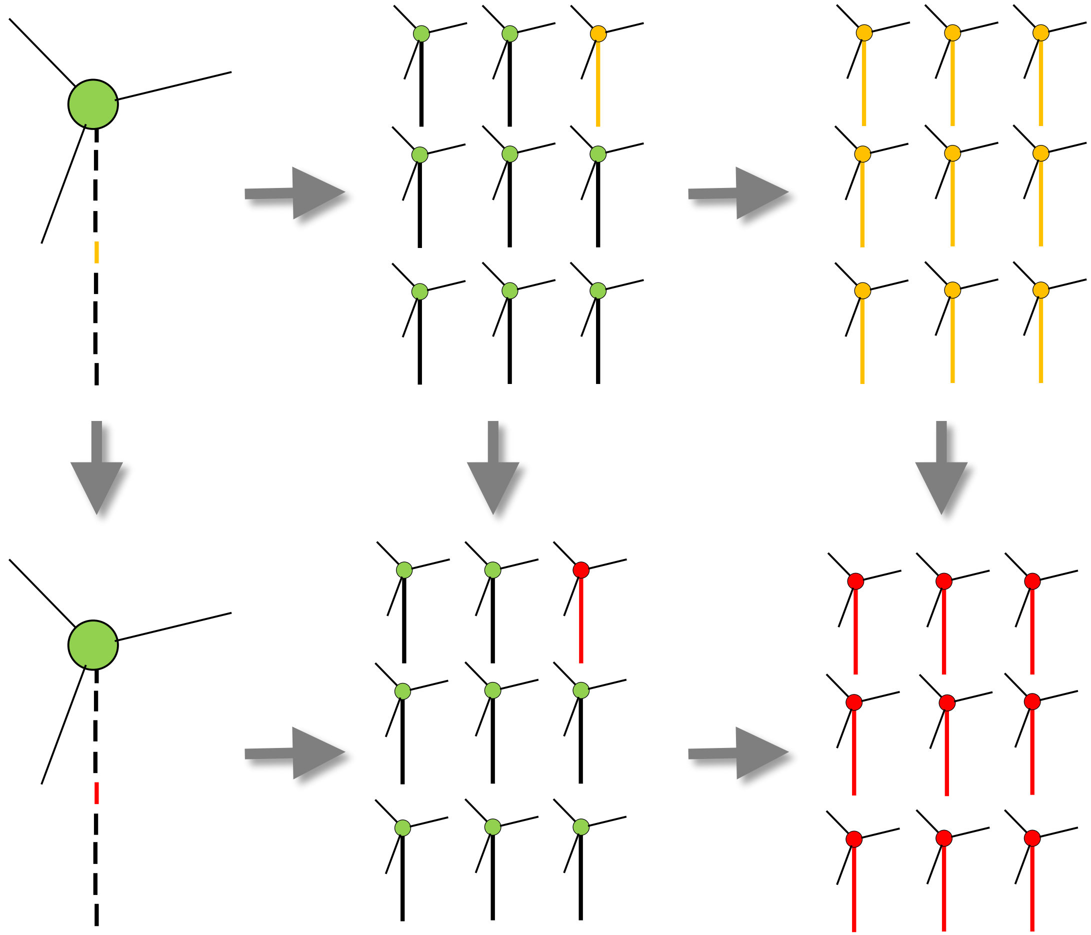
Example: Service Life Extension of a Wind Park



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Example: Service Life Extension of a Wind Park

No.	Strategy	Model	System state
1	Component loading monitoring	Pre-posterior model of component stress measurement	Exposure on component level
2	Hot spot monitoring	Pre-posterior model of hot spot damage accumulation measurement	Direct consequences on component level
3	Wind turbine loading monitoring	Pre-posterior model of wind turbine system extreme loading monitoring	Exposure on component, wind turbine and wind park level

No.	Strategy	Value of Information		Vulnerability	Robustness
		VoI_i	$\overline{VoI_i}$		
1	Component loading monitoring	$4.9 \cdot 10^{7}$	$2.7 \cdot 10^{-1}$	$8.9 \cdot 10^{-2}$	$6.5 \cdot 10^{-1}$
2	Hot spot monitoring	$6.1 \cdot 10^{7}$	$3.3 \cdot 10^{-1}$	$5.4 \cdot 10^{-2}$	$7.5 \cdot 10^{-1}$
3	Wind turbine loading monitoring	$-1.6 \cdot 10^{6}$	$-8.8 \cdot 10^{-3}$	$1.9 \cdot 10^{-1}$	$5.6 \cdot 10^{-1}$

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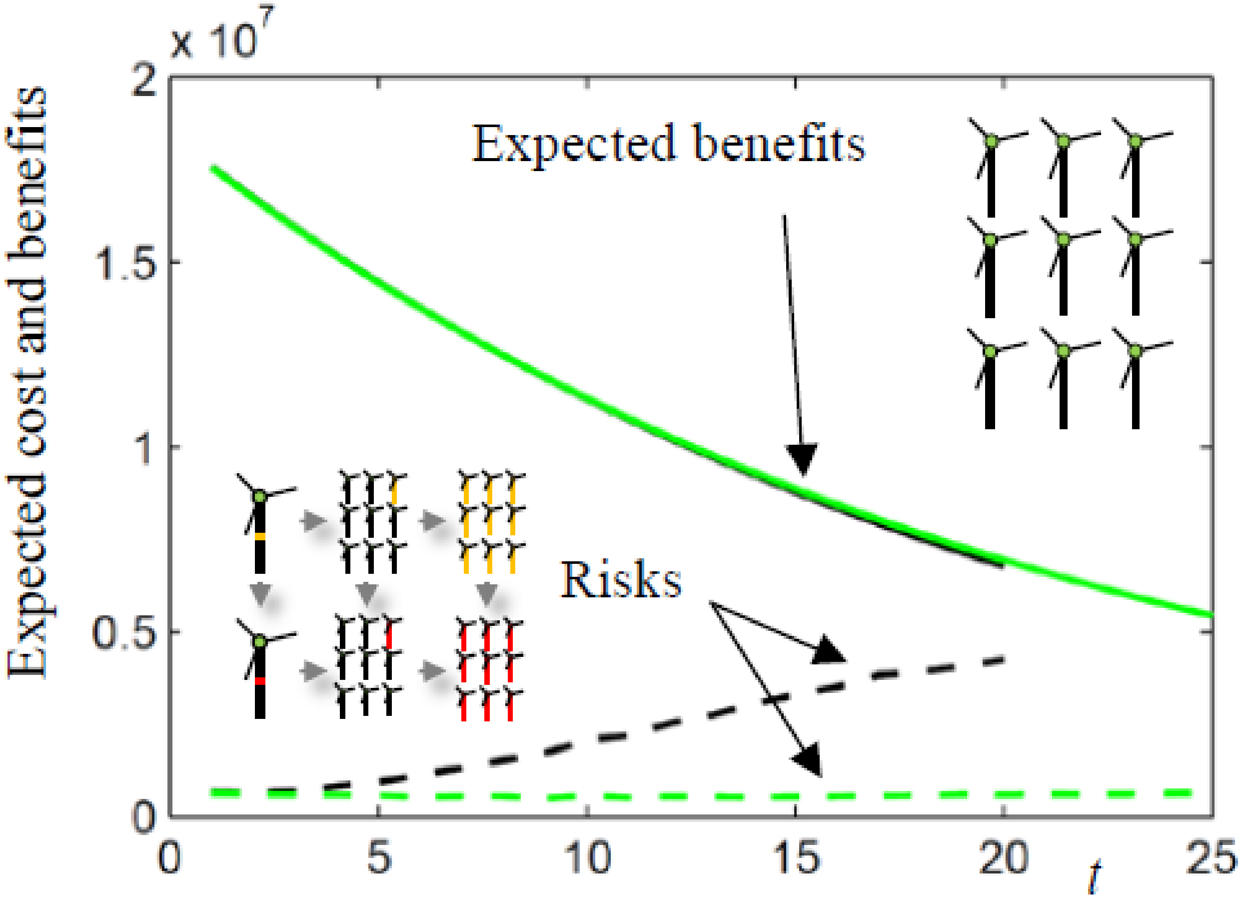
Example: Service Life Extension of a Wind Park



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Working Mode

1. Description of case study
2. Individual demonstrators
3. Adding complexity
4. Performing the case study
5. Disseminate

Thank you for your attention.