BAM

Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

29.05.2017

Case study idea – Offshore wind park

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Motivation

Offshore wind parks consist of many equivalent turbine support structures

Their performance is significantly correlated due to:

- Series production
- Similar geometry
- Similar material properties
- Similar production processes
- Similar quality standards

Motivation

Turbine support structures are exposed to:

- Same deterioration processes
- Similar loading conditions

BMU-Forschungsplattform FINO 1, ©Germanischer Lloyd

Motivation

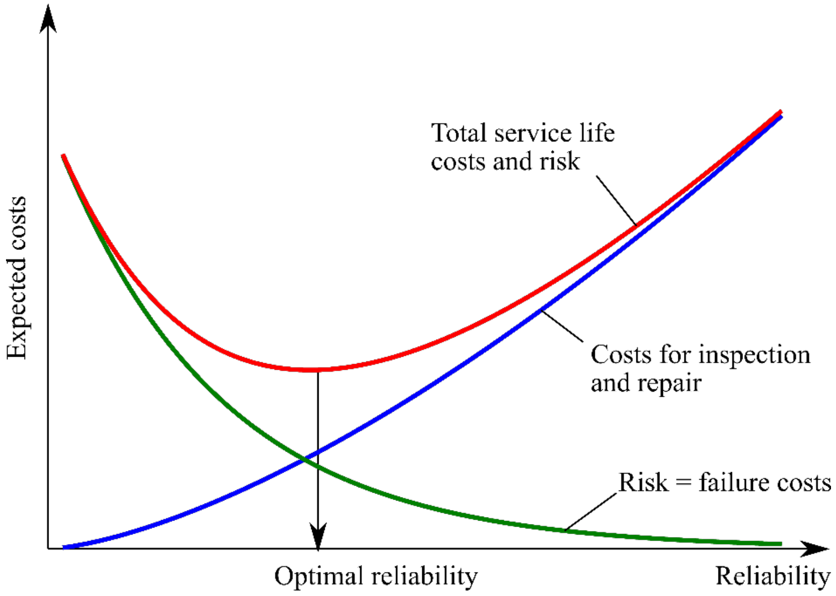
System effects enable:

- Inference of the condition of all structures by inspecting and monitoring a few
- Optimized planning of inspection, monitoring and repair

Optimal planning of inspection and repair without SHM

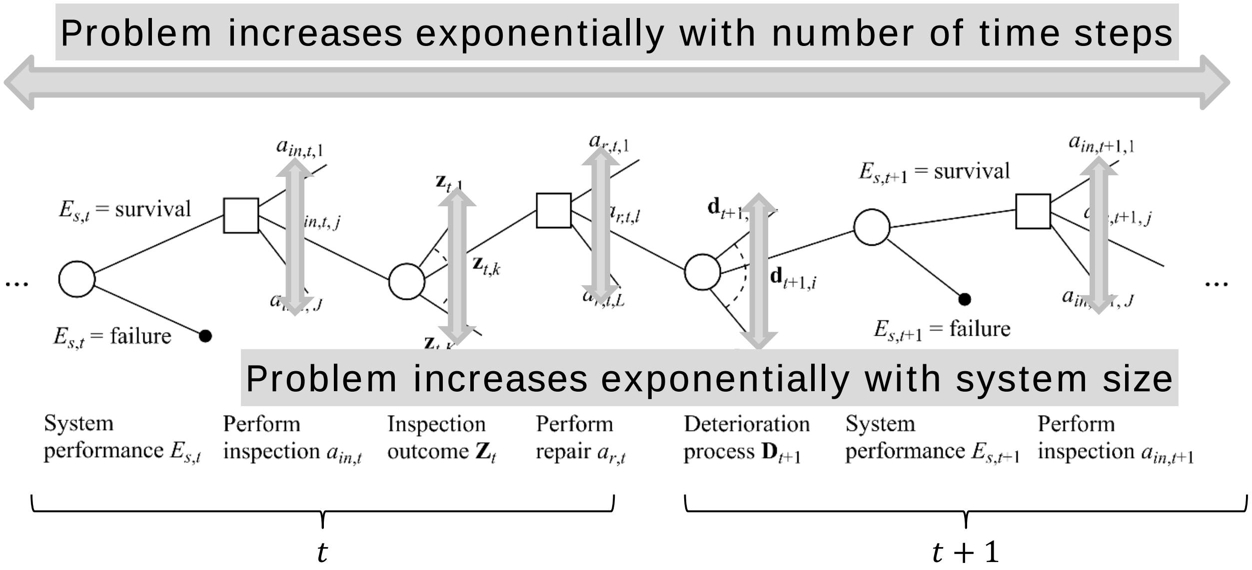
Objective

- Minimize expected total service life costs and risk



Decision tree – graphical model of the decision problem

Sequential decision problem + system analysis



Identifying the optimal inspection and repair strategy

Proposed solution (Bismuth et al. 2017 – WG3 of TU1402):

1. Apply heuristics to reduce the number of possible inspection and repair strategies.
2. Evaluate total service life costs and risk associated with a strategy and corresponding inspection outcomes and repairs.
3. Use Monte Carlo approach to compute expected total service life costs and risk of a strategy.
4. Optimal strategy minimizes expected total service life costs and risk

Formulation of the optimization problem

(Bismuth et al. 2017)

Service life risk:

$$R_F(\mathcal{S},\mathbf{z}) = \sum_{t=1}^{T} c_F(t) \cdot \Pr(F_t|\mathcal{S},\mathbf{Z}_{0:t-1} = \mathbf{z}_{0:t-1})$$

Total service life costs:

$$C_T(\mathcal{S},\mathbf{z}) = C_C(\mathcal{S},\mathbf{z}) + C_I(\mathcal{S},\mathbf{z}) + C_R(\mathcal{S},\mathbf{z}) + R_F(\mathcal{S},\mathbf{z})$$

Expected total service life costs and risk:

$$E[C_T|\mathcal{S}] = \int_{D_{\mathbf{Z}}(\mathcal{S})} C_T(\mathcal{S},\mathbf{z})\, f_{\mathbf{Z}}(\mathbf{z})\, d\mathbf{z}$$

Optimal inspection and repair strategy:

$$\mathcal{S}_{opt} = \arg\min_{\mathcal{S}} E[C_T|\mathcal{S}]$$

An example of heuristics at system level

(Bismuth et al. 2017)

1. Inspection campaigns are performed at fixed intervals ΔT.
2. The minimum number of inspected hotspots in each campaign is n_I.
3. Hotspots are selected for inspection as a function of their fatigue reliability and structural importance.
4. If a threshold on the system failure probability p_{th} is exceeded, an additional hotspot is inspected. If no inspection campaign was planned at that time, an additional inspection campaign is launched.
5. Repairs are performed, if a fatigue crack is indicated and measured to be larger than a repair criterion d_R.

Value of SHM analysis

SHM system

One possible SHM system:

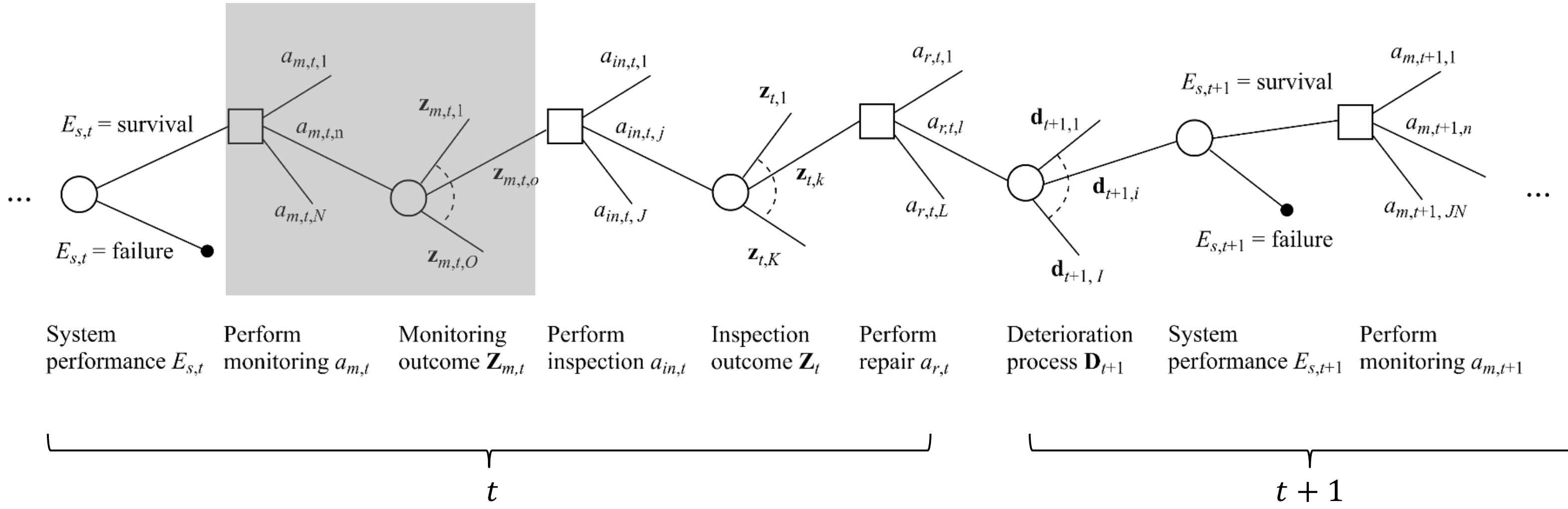
- Measures vibration response data
- Data is processed by a suitable algorithm
- SHM outcome: damage/no-damage indication

SHM system may, for example, trigger:

- Turbine shutdown, and
- Additional inspections

Example of an extended decision tree including SHM

Decision on performing SHM
at time t and its outcome



Possible evaluation of the value of the SHM system

$$net\ VoI = E\left[C_T \middle| \mathcal{S}_{opt,without\ SHM}\right] - E\left[C_T \middle| \mathcal{S}_{opt,with\ SHM}\right]$$

References

Bismuth, E., J. Luque, D. Straub (2017). Optimal prioritization of inspections in structural systems considering component interactions and interdependence, ICOSSAR 2017, Vienna, Austria