Innovative Framework for Risk-Based Maintenance Optimization of Offshore Wind Substructures

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Introduction

Context: Wind farms further from shore
Complicated maintenance tasks

Research Aim: To identify the optimal maintenance strategy

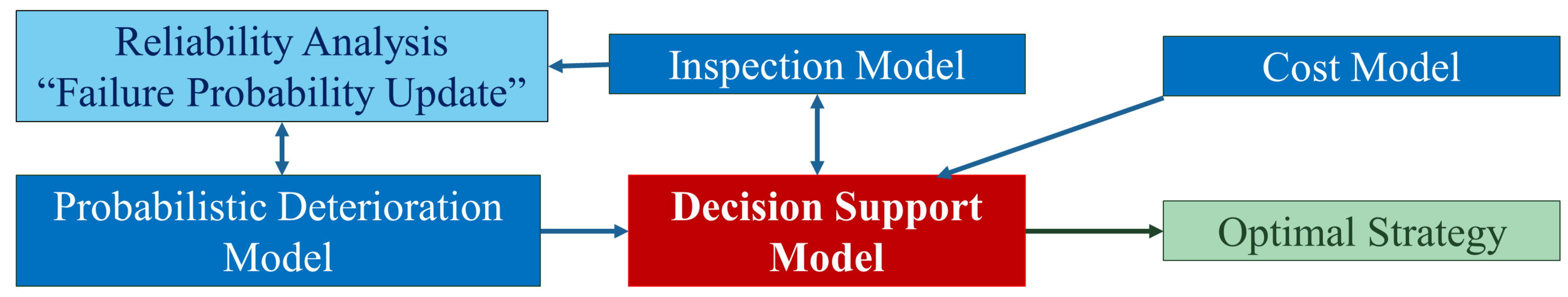
Impact: ↓O&M cost (≈ 25% LCOE)
Lifetime Extension

Approach

Level IV Reliability Analysis: Failure Probability + Costs

- Input: Damage, inspection and cost model
- Output: Optimal strategy (when to go for inspection)

*Information from inspections and monitoring is used to update the reliability



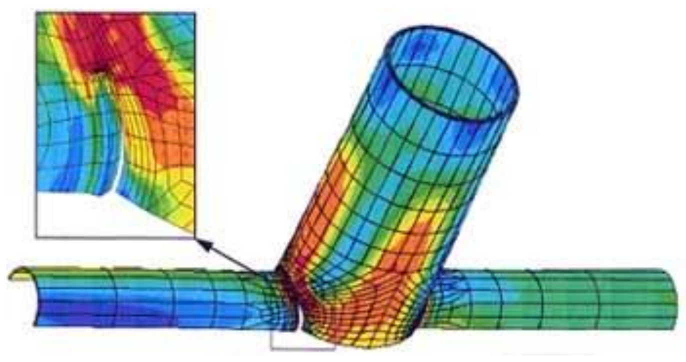
Deterioration & Inspection Models

Probabilistic Fracture Mechanics Model

The main failure mode to be considered in offshore structures is fatigue. A probabilistic damage model is built. The crack growth is estimated by using **Paris-Erdogan's Law** for each sample considered.

$$\frac{da}{dN} = C\left(\sqrt{\pi a}\,\Delta\sigma\, Y_a\right)^m$$

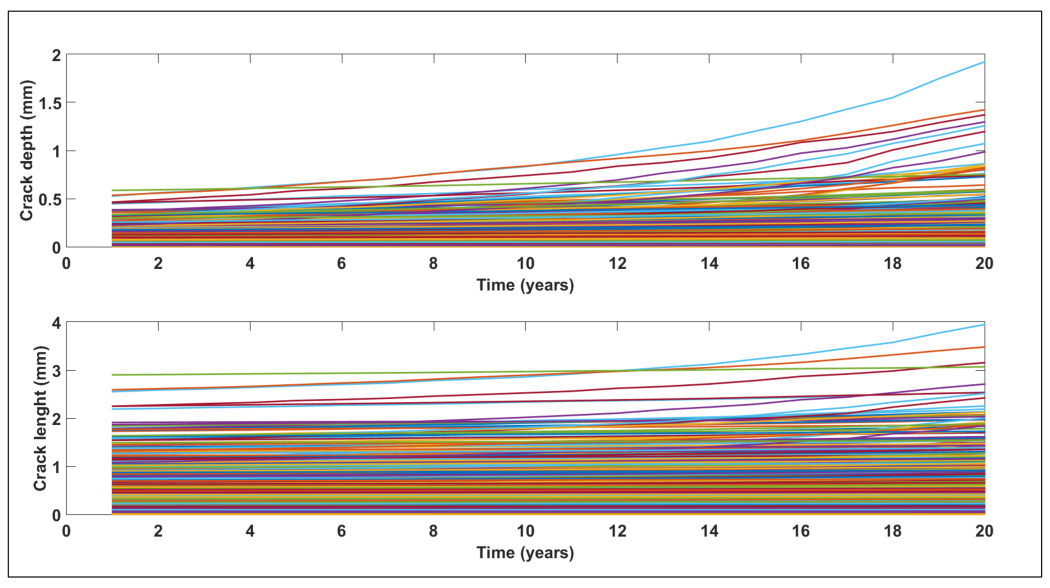
$$\frac{dc}{dN} = C\left(\sqrt{\pi a}\,\Delta\sigma\, Y_c\right)^m$$



Fracture Mechanics Parameters

Variable	Distribution	Parameters	
a_i	Exponential	μ=0.044	
C_i/a_i	Deterministic	0.2	
$logC$	Lognormal	μ=-12.74	σ=0.2
$\Delta\sigma$	Weibull	k=0.8	λ=8.3564
Y	Deterministic	1	
v	Deterministic	5045760	
m	Deterministic	3	

Coupled crack growth:

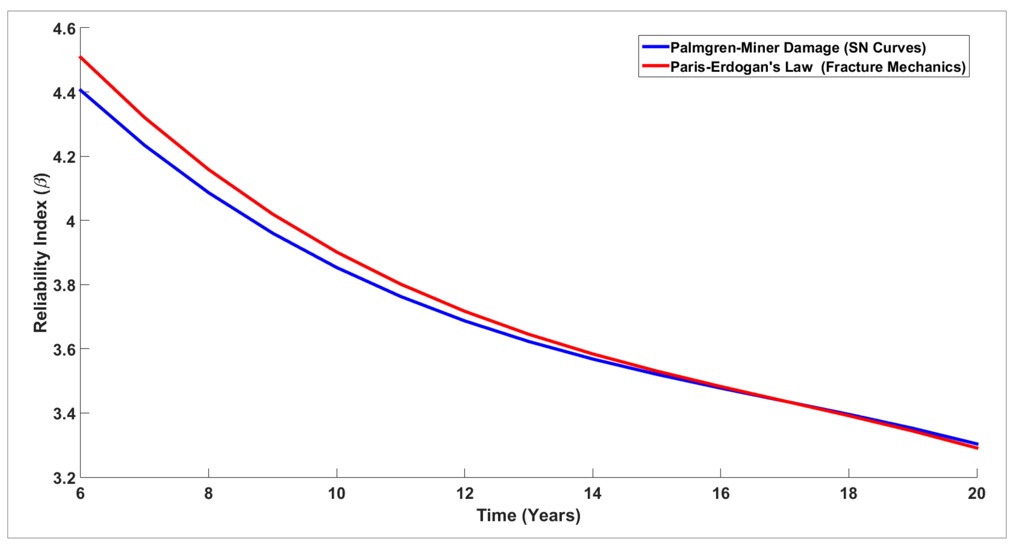


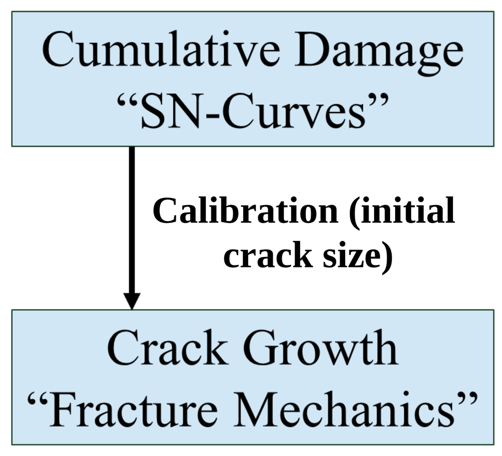
Cumulative Damage Parameters

Variable	Distribution	Parameters	
$m1$	Deterministic	3	
$m2$	Deterministic	5	
$log10(a1)$	Normal	μ=12.88	σ=0.2
Δ	Lognormal	μ=1	CoV=0.3
$\Delta\sigma$	Weibull	k=0.8	λ=8.3564
v	Deterministic	5045760	

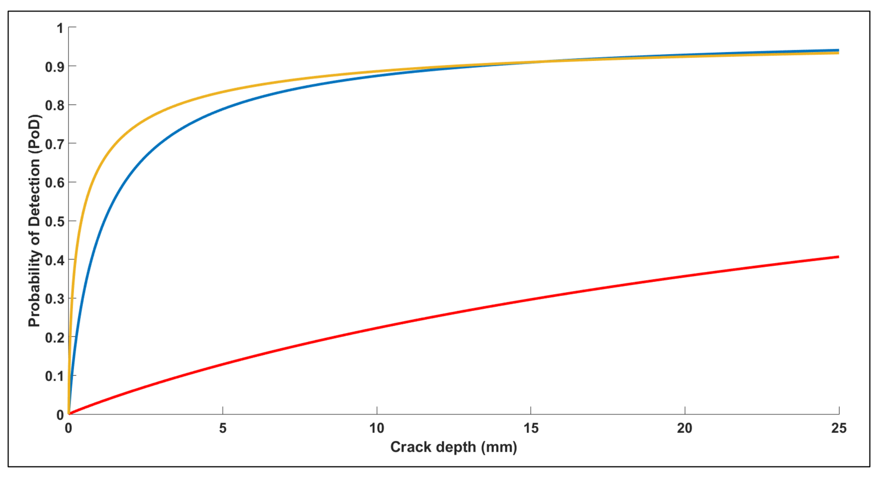
Fracture Mechanics Model Calibration

The initial crack size is calibrated to obtain similar damage as "Cumulative damage" using empirical SN curves. Thus, it is ensured that deterioration model is realistic.





"Probability of Detection" (PoD)



Different inspection techniques

- Ultrasonic Testing
- Eddy current
- Visual Inspection

Decision Support Model – "Partially Observable Markov Decision Process"

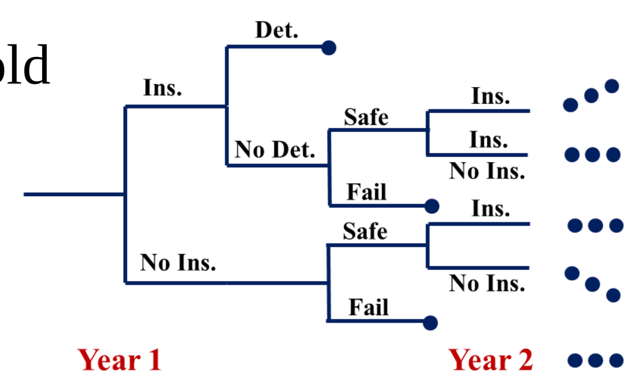
Before --> Now

Traditional Risk-Based Inspection Methods

Limitations are imposed to solve the decision problem:

- Equidistant inspections
- Probability of Failure Threshold

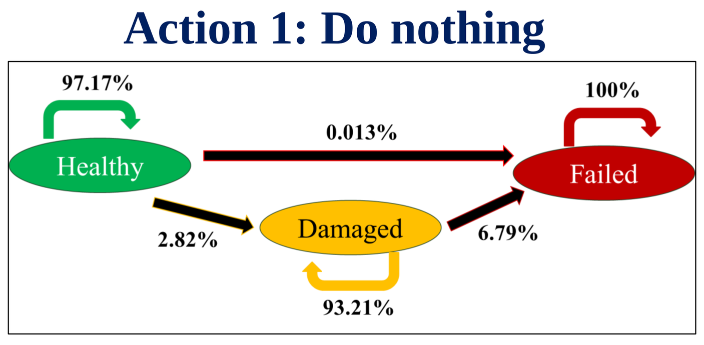
Otherwise, it cannot be solved within a reasonable CPU time



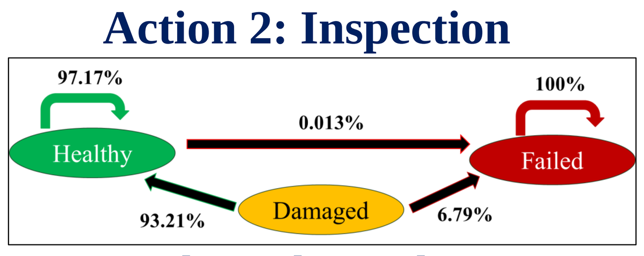
Innovative Risk-Based Maintenance Method

- Dynamic maintenance policies - POMDP
- Example: 3 States – 2 Actions

Action 1: Do nothing



Action 2: Inspection



- Crack not detected
- Crack detected and repaired

Results

O&M Strategy for a simple tubular joint (10million samples)

- Lifetime: 30 years
- Limit state: $g = a - a_c\,;\, a_c = 25\,mm$
- Repair rule: Crack detected & repaired
- Inspection cost: 2,000,000 €
- Repair cost: 50,000 €
- Failure cost: 5,000 €

Equidistant inspections

- Insp. at years: 9, 18, 27
- **CPU time: 3 hours**
- E [Repair+Ins Cost]: 7,060 €
- E [Failure Cost]: 15,360 €
- **E [Total Cost]: 22,420 €**

POMPD

- Insp. at years: 14, 24
- **CPU time: 40 min (78% Reduction)**
- E [Repair+Ins Cost]: 4,630 €
- E [Failure Cost]: 16,500 €
- **E[Total Cost]: 21,130 € (6% Reduction)**

Perspectives

- **Include system effects**
  - Investigate dependencies (stochastic/functional) between components
- **Incorporate monitoring information**
  - Reliability update / Assess the "Value of Information"

Publication

Pablo G. Morato, Quang. A. Mai, Jannie S. Nielsen, Philippe Rigo (2018). **"Point-Based POMDP" Risk Based Inspection of Offshore Wind Substructures.** *International Symposium on Life-Cycle Civil Engineering*, Ghent (Belgium).

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