RISK-BASED MAINTENANCE OPTIMIZATION OF OFFSHORE WIND SUBSTRUCTURES

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Introduction

Pablo is a Maritime Engineer...

... specialized in Offshore Renewable Energy...

... and Advanced Design of Offshore Structures...

Now?... PhD in Risk-Based Maintenance of Offshore Wind Substructures
Context: Offshore Wind

Far away from shore

...Complex O&M tasks
Reduce LCOE...

Information available

....Inspections
Monitoring...

Source: https://www.researchgate.net/figure/Optical-strain-gauges-as-installed-at-a-Belwind-and-b-Northwind


Source: EYReport. Offshore wind in Europe
Walking the tightrope to success

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Aim: Decision Support

‘Taking the right decision under uncertainty’

Reliability Analysis
“Failure Probability Update”

Probabilistic Deterioration Model

Inspection Model

Cost Model

Decision Support Model

Optimal Strategy

Repair?

Inspection?

Will it FAIL?

Monitoring?
Uncertainties Modeling

Uncertainties?

Physical

Model

Statistical

Measurement

Uncertainties Modeling

Structural Reliability: Bayesian Inference

Physical

Model

Statistical

Measurement

Physical

Model

Statistical

Measurement

Structural Reliability: Bayesian Inference

Knowledge

Design

Production

Operation

Decommissioning

Source: https://www.theguardian.com/sustainable-business/microsoft-walmart-google-renewable-energy-wind-farm-solar
Deterioration Model - Fatigue

Why fatigue?

Combined action of wind & waves \( \sim 10^8 \text{ cycles/lifetime} \)

Fracture Mechanics Calibration

- Fracture Mechanics
- Similar Reliability
- SN Curves

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Optimization: \( \text{RISK} = \text{Probability} \times \text{Consequence} \)

- **Inspection technique:**
  - Ultrasonic
  - Eddy current
  - Visual

- **Inspection result:**
  - No detected
  - Detected & repair
  - Detected & no-repair
Utilizing Monitoring Data

Optimization: \( \text{RISK} = \text{Probability} \times \text{Consequence} \)

‘Dynamic Bayesian Network (DBN)’

Monitoring

Stress Range

Crack size

Inspection

\( M_0 \to S_1 \to A_1 \to I_1 \)

\( M_0 \to S_2 \to A_2 \to I_2 \)

\( M_0 \to S_n \to A_n \to I_n \)
Cost Optimization

Optimization: \( \text{RISK} = \text{Probability} \times \text{Consequence} \)

Expected Costs (€)

Maintenance Efforts

Failure Event

Inspection cost

Repair cost

Optimal

Failure cost
Decision Problem (II)

‘Pre-posterior Decision Analysis’… $12^{20}=3.8e21$ branches
1 second per branch = 1.24e14 years

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Simplification to Decision Problem

Heuristic Rule: ‘Constant intervals of time’

Year 0

Every 6 years

- Y6

Every 5 years

- Y5

Year 20

- Y20

- Y10

- Y15

- Y12

- Y18

More simplifications…

- Perfect inspections
- Repair if detected
Dynamic Approach for Maintenance Planning

**MARKOV Models**

- **State 0**: Healthy
  - No repair
  - Repair

- **State 1**: No repair

- **State 2**: No repair
  - Repair

- **State n**: Failure

Inspection/Monitoring \(\rightarrow\) Improves the belief state

**Partially Observable** Markov Decision Processes (POMDP)

- Point-based algorithms \(\rightarrow\) Reduces CPU time significantly
- 60-states POMDP including 3 combined actions \(\rightarrow\) Only 0.32 seconds of CPU time
System Effects for Planning

**Where to perform inspections?**

**Past...**
Components analyzed separately

**Future...**
Considering **Dependencies**
Shared epistemic uncertainty

- Similar manufacturing
- Similar loading

‘Lower costs can be attained’
Impact: Life extension

Fixed-Offshore Wind Farms…

… Lifetime Reassessment

Life extension

… Utilize gathered data

Inspections / SCADA

Source: https://corporate.vattenfall.co.uk/projects/
Impact: Design Optimization

Floating Offshore Wind Farms...

... Probabilistic Design
Reduce Safety Design Factor

... Utilize information
Optimize resources

Conclusion

• Decision support under uncertainty

• Utilizing available DATA

• Engineering: Optimization of the resources!

*Contact me for more info 😊