Risk and Reliability based O&M Planning of Offshore Wind Farms

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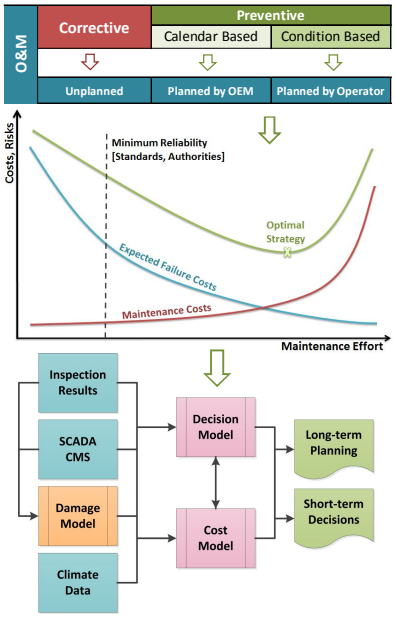
Introduction

Operational costs of offshore wind farms are one of the main contributors to the high cost of energy and can be significantly reduced by using an optimal maintenance strategy to support the wind farm operator in short-term decision making and long-term O&M planning.

During the PhD project an optimal risk and reliability O&M model is being developed to minimize the total operational costs by balancing the amount of corrective and preventive maintenance efforts, considering all system effects.

The developed O&M model consists of a risk based decision and cost model, which are using deterioration models, inspection results, SCADA data, condition monitoring data and climate data as inputs.

The model output is the long-term O&M planning of the wind farm and decision support to the wind farm operator in daily wind farm operation.

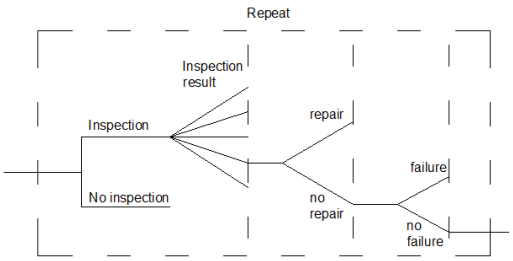


Risk based decision model

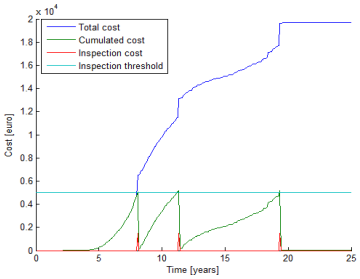
By having all the input data it's possible to develop a decision model including decision rules and criteria. The model is formulated as a Bayesian decision tree.

In predictions, unknown results from future inspections are included as the expected value in the deterioration model.

Inspection planning and decisions are chosen to minimize expected cost for the remainder of the blades lifetime



$$C_{total}(t) = \sum_{t=t_0}^{t_L}\left(\sum_{i=thr}^{5} P_i(t|IP)C_i + P_F(t|IP)C_F + P_{ins}(t|IP)C_{ins}\right)$$



Decision rules for repair threshold and for time of inspection based on cumulated cost/risk

The lifetime cost is determined as a function of the decision plan and the one leading to the minimum expected cost is chosen

After an inspection is made, the information is used to update the degradation model and the optimization is remade for the reminder of the blades life. Therefore, the maintenance policy is updated after every inspection.

Deterioration model and cost model

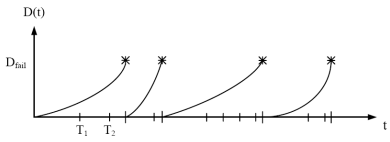
Based on an existing database of crack sizes and consultation with industry members, a cost model is set up for wind turbine blades.

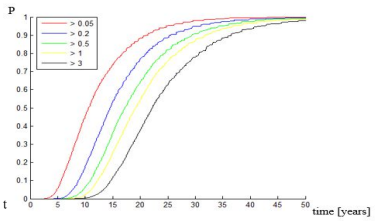
Category	Repair Priority	Blade Inspection Description/Findings	Continue to Run / Take Offline?	Action
1	None	Blade is in good working condition typical for it's age with possible signs of minor wear	Continue to Run	No action necessary
2	None	Blade shows early signs of wear or damage	Continue to Run	Monitor & Repair within 1 year
3	Low	Blade shows significant signs of wear or damage	Continue to Run	Monitor & Repair within 6 months
4	Medium	Blade shows advanced signs of wear or damage and should be scheduled to be repaired before	Continue to Run	Monitor & Repair within 3 months
5	High	Blade has failed or must be taken out of service to prevent further damage	Take Offline	Repair or Replace Immediately

Category	1	2	3	4	5	Fail
Size [m]	< 0.05	0.05 - 0.2	0.2 - 0.5	0.5 - 1	1 – 3	>3

Degradation is modeled using a continuous probabilistic fracture mechanics model, calibrated to the *guide-to-defect* database.

$$\frac{da}{dt} = \frac{A(\Delta K)^m}{(1-R)^{m(1-\lambda_W)}}$$





Demonstration of risk-based model

Using Monte Carlo simulations, the "exact" cost of maintenance over 25 a year lifetime is determined for a single blade. This is compared to traditional condition based strategies.

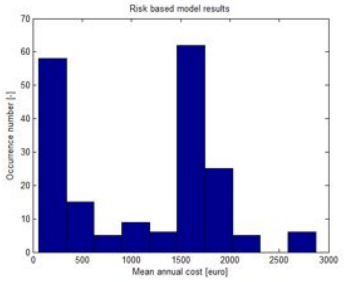
Condition based

Mean Annual O&M cost [euro]	CoV of mean cost [%]
1451	61

Risk based

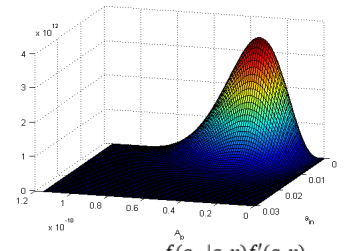
Mean Annual O&M cost [euro]	CoV of mean cost [%]
1125	71

A reduction of 22.5 [%] in expected annual cost is obtained using risk-based maintenance strategies

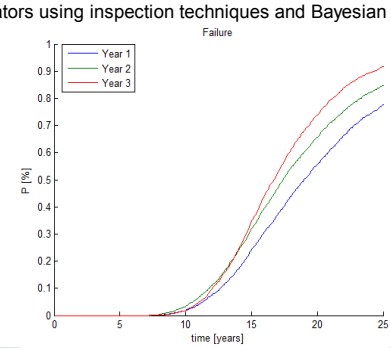


Updating the deterioration model

Since deterioration are associated with significant uncertainty, deterioration model is updated using direct information from indicators using inspection techniques and Bayesian statistics.



$$f''_{(q,v|a_m)} = \frac{f(a_m|q,v)f'(q,v)}{\int\int f(a_m|q,v)f'(q,v)\,dqdv}$$

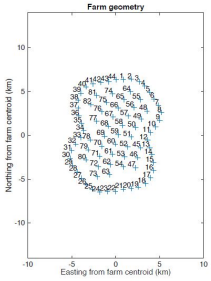


Application on NORCOWE wind farm

For demonstration of practical applicability, the risk based maintenance model for blades is included into a discrete event simulator similar to ones developed for commercial/research purposes (ECN O&M tool, NOWIcob, Maintsys™).

25 year lifetimes are simulated for the 80 turbine wind farm using 3 [h] time steps and wind/wave measurements for weather conditions

Maintenance is split in blade maintenance, using the risk model and corrective/condition based maintenance for other components.



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