# An Integrated Performance and Condition Based Approach to Maintenance Decision Making for Wind Turbine Support Structures

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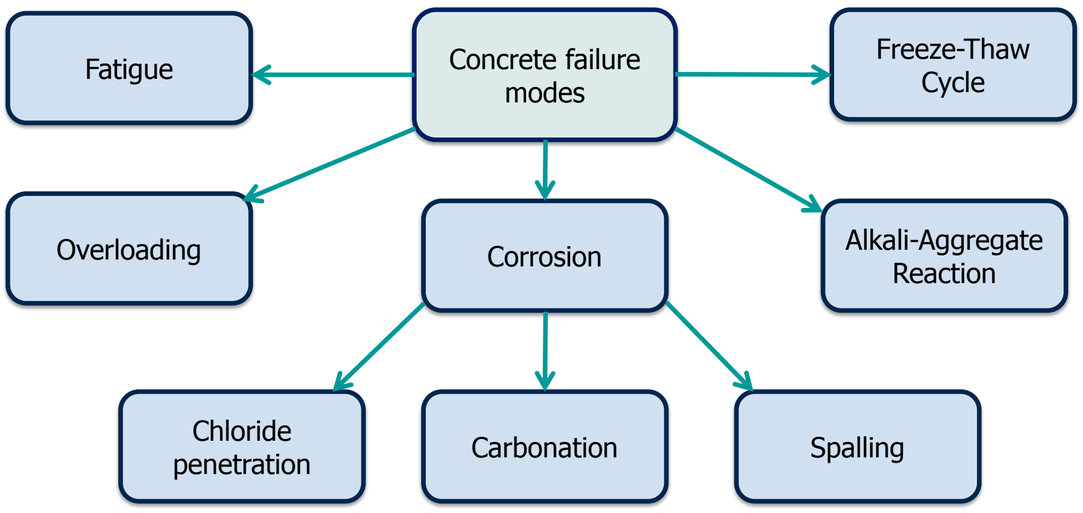
## Research Objectives

The aim of this project is to develop and validate a condition-based maintenance model that uses historical failure data, engineering judgement, real-time health and performance data to identify the optimum maintenance and inspection actions and intervals for engineering systems, with an initial focus on support structures.
As a result, the model should be able to:

- Assess the economic value of different sources of information, capturing correlations and dependencies between information sources
- Minimise maintenance while maximising availability by identifying optimal repair, replacement and inspect decisions

## Reinforced Concrete Structures

Damage to wind turbine support structures can be caused by a number of different deterioration processes/failure modes, some of which are highlighted below:




A number of maintenance actions can be undertaken to identify and slow down/prevent the deterioration process:

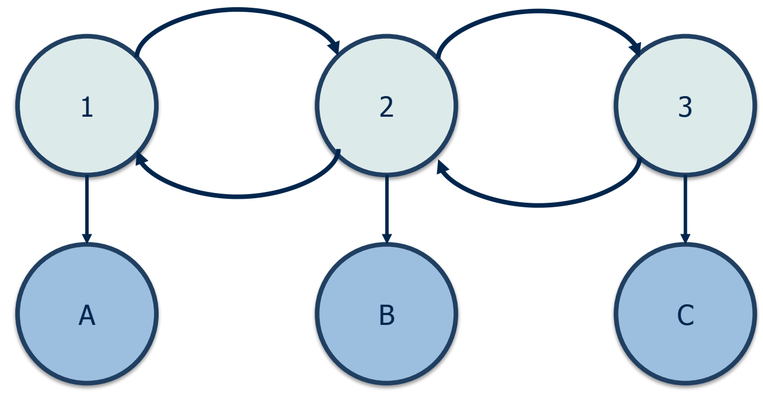
- Re-coating/painting to prevent corrosion
- Cleaning/de-greasing
- X-ray examination
- Visual examination
- Microscopy and other non destructive tests

In order to make a decision on when, and which maintenance actions to take, the condition of the condition of the tower needs to be monitored. Another factor that needs to be considered is the interaction between different failure mechanisms – for example the combined effect of freeze-thaw cycles and fatigue cracking can lead to accelerated deterioration as water seeps deeper into concrete causing more damage with each cycle.

Having a model which can approximate the current state of the structure would be of great help in increasing in the structure's overall lifetime, while decreasing the maintenance costs. The model that will be developed in this research will be based on failure rate values for given deterioration processes, which will be used in a Partially Observable Markov Decision Processes (POMPD) model to aid maintenance decision making.

## Methods

Condition monitoring systems provide information about the structure to it's operator, however, they do not indicate the state of the system with 100% accuracy. One way of dealing with this uncertainty is by utilising Hidden Markov Model, such as the one shown below:




- 1,2, and 3 are hidden states, while A,B and C are observable states, which provide an insight into the actual state of the system
- The arrows represent the transitions between states, which, in the context of this project, would be failure and repair rates
- The failure rates are likely to vary with time, meaning the actual system would be a semi-Markov process
- Different failure/deterioration modes can be represented by different Markov Chains, or be merged into one
- Problems as complex as this are solved iteratively, using methods such as Monte Carlo Modelling, which can be computationally intensive for large systems
- The model will be able to make maintenance decisions based on the risk of failure and the cost of such failure versus a cost of a maintenance action and it's potential return

Research to date shows that Hidden/Partially Observable Markov Decision Processes (HMDP/POMDP) can be used to predict the component's deterioration process, as shown in Figure 1. It is worth noting how observations (marked by a red cross) can be used to update system's belief state, which results in narrowing the grey area.

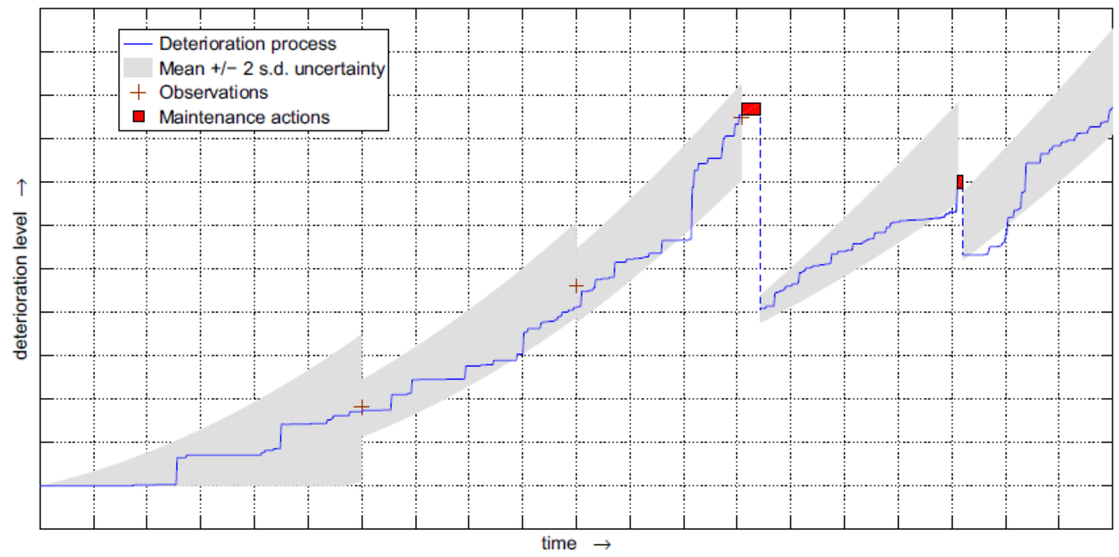



Figure 1. Model's prediction vs. actual deterioration [1].

There has been a significant amount of research on the subject, however, it is often purely theoretical. This project aims to apply the POMPD methodology in a real life scenario, in cooperation with an appropriate industrial partner.

## References

[1] Papakonstantinou, K. and M. Shinozuka, "Planning structural inspection and maintenance policies via dynamic programming and Markov processes. Part I: Theory.", Reliability Engineering & System Safety, 2014.

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