Economic Analysis of Condition Monitoring Systems for Wind Turbine Sub-Systems

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Introduction

The growth of the number and size of turbines installed worldwide has been large in recent years. The capital costs involved in the development and installation of wind farms have also increased.

To ensure the maximum return on investment, operators are looking to maximise turbine availability and minimise Operation and Maintenance (O&M) costs. Condition Monitoring (CM) systems and Supervisory Control and Data Acquisition (SCADA) systems allow Condition Based Maintenance plans (CbM) to be used which offer possible O&M savings over both Failure based Maintenance (FbM) and Preventive Maintenance (PM) strategies.

Fault Classification

Faults are classified as 'Major' and 'Minor' where minor faults takes less than 24 hours to clear. An FMEA is used to determine where a CMS may allow for a major fault to be repaired at a lower cost – for example, detecting bearing wear in the gearbox before damage to the gears or shafts occurs, leading to fewer replacement parts

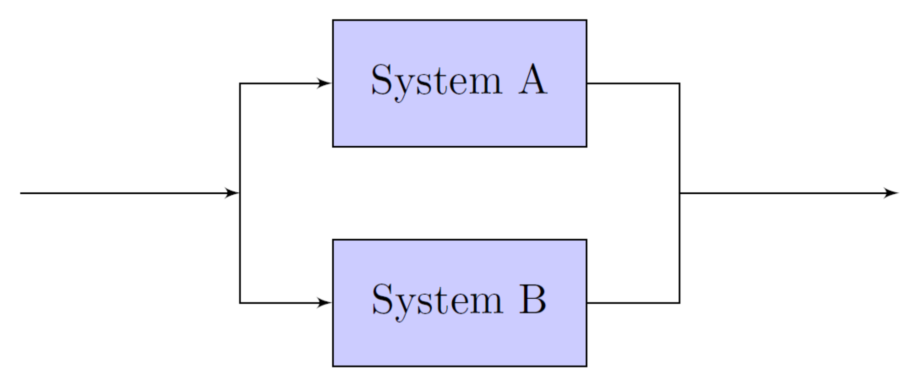
Additionally, faults are assigned one of six logistics classes that shows the type of vessel (Crew Transfer Vessel, Field Support Vessel or Crane Vessel), number of crew and billable hours required to complete a repair.

Condition Monitoring Systems

Vibration based condition monitoring systems on the drive train, gearbox and generator are common, however many other types are also available. Generic costs have been anonymised and averaged from an array of vendors.

When multiple CM systems that observe different properties are added to the same sub-system the chance of fault detection increases. These have been modelled as parallel systems. This is shown below.

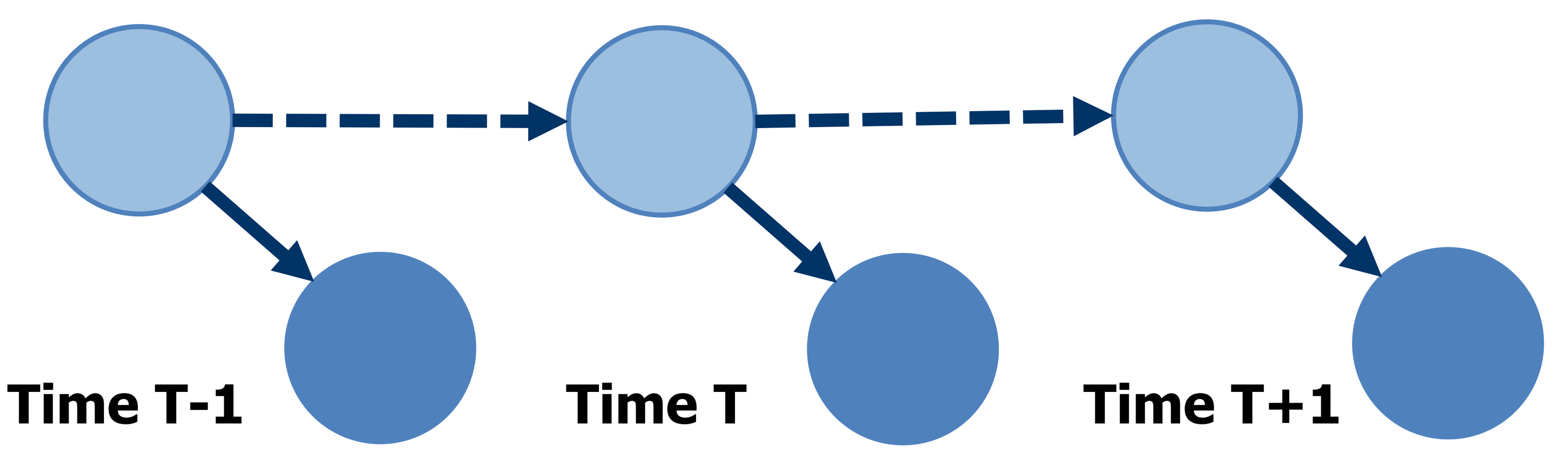
$$R_p = 1 - \Pi R_i$$



Modelling Turbine Deterioration

Dynamic Bayesian Networks (DBNs) are used to simulate the deterioration of components within the turbine. A DBN is a probabilistic graphical model representing variables and their relationships, where one or more of the variables have a dependency on a state at a different time.

Variables can be used represent a mechanical system. The light blue nodes represent the actual state of the components which update through time. The dark blue nodes represent the condition monitoring output, which is linked directly to the actual state of the component. Exponential decay can be achieved using appropriate probability tables.



Results

A vibration CM system offers potential lifetime savings of over £4m. The addition of either oil sensors or an AE system reduce the lifetime savings. This indicates that the additional O&M cost reductions found from adding CM systems are outstripped by the cost of the CM systems themselves. This may diminish as the turbines increase in size and the financial implications of failures increase.

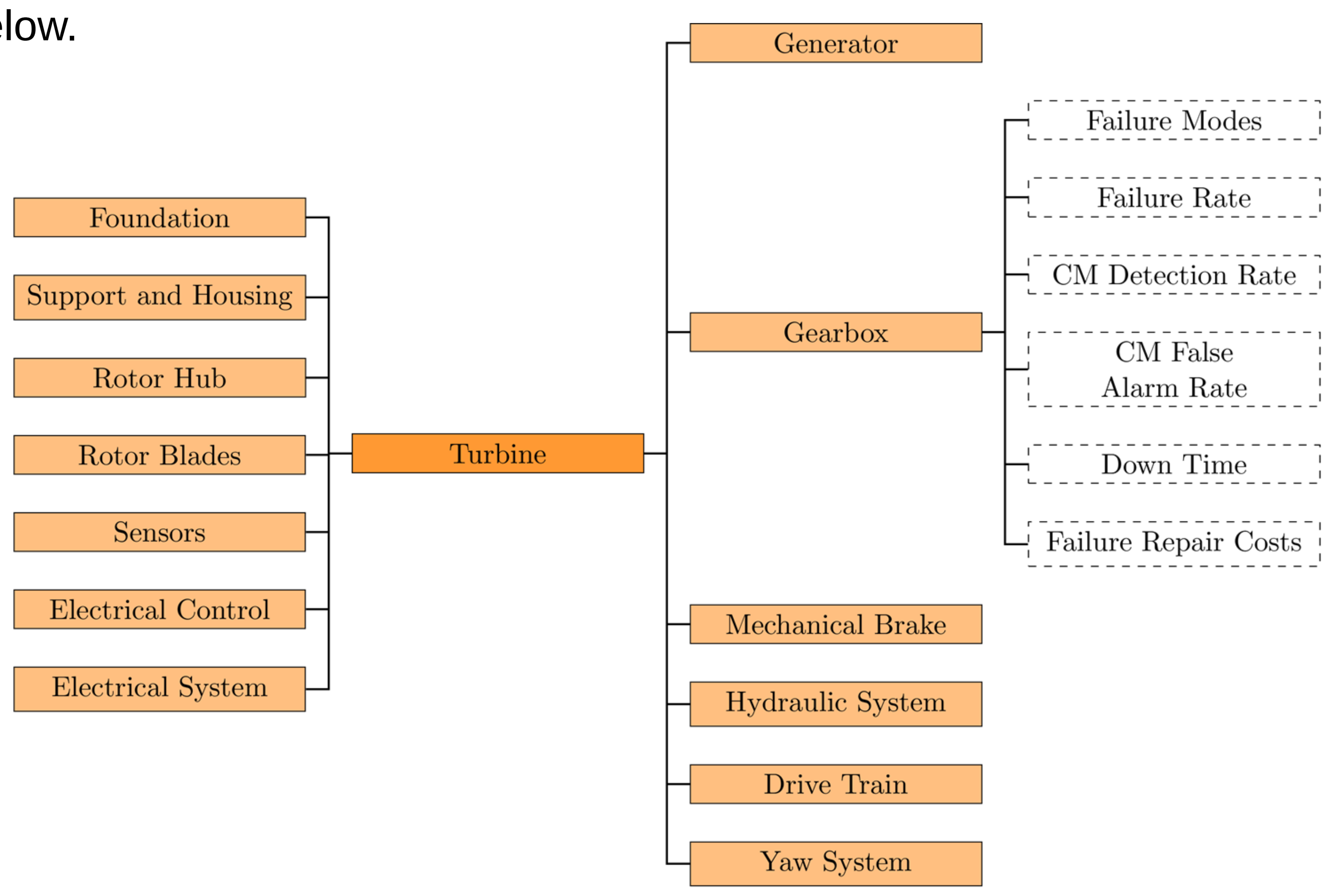
Drive Train CMS	Lifetime Saving Over PM
Vibration	£4,266,000
Vibration & Oil Sensor	£4,157,000
Vibration & AE	£4,160,000
Vibration, Oil Sensor & AE	£4,059,000

A CM system was specified to include: a vibration drive train CMS, a tower vibration SHM and a vibration monitoring foundation system. The efficacy (detection rate) of the two SHM systems was varied and the effect on savings is shown below.

Detection Rate	Lifetime Saving over PM
60%	£4,151,000
70%	£4,193,000
80%	£4,229,000
90%	£4,250,000

The Turbine Model

The model consists of 13 sub systems each containing the required information on the failures and the attached CM system. This is shown below.



The model is solved in Matlab using simulation and generates an observed and hidden state for every turbine in a wind farm for each month of its operational life. An algorithm then compares the two parameters and notes any differences. O&M costs for both a PM and CBM are calculated from the subsystem failures.

$$C_{CBM} = C_{SPP} + C_{LP} + C_{CMSPP} + C_{FA} + C_{CM}$$

Future Work

Limit state functions will be used to improve the representation of the structural components in the model and their maintenance costs. DBNs can be used to examine the uncertainties in the design loads and show the changing probability of failure over time of the structure. This will allow for risk based costs to be included in the model.

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