Logistic Efficiencies And Naval architecture for Wind Installations with Novel Developments

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Definitions

Acronym	Description
AI	Artificial Intelligence
ANN	Artificial neural networks
API	Application programming interface
BoP	Balance of plant
BP	Back Propagation
CBM	Condition-based maintenance
CCNN	Correlation Coefficient Neural Networks
CM	Condition monitoring
DBN	Dynamic Bayesian networks
DX.X	Deliverable number X.X in the LEANWIND project
ESN	Echo state Networks
ESP	Engine System Prognosis
FCTV	Fast Crew Transfer Vessel
FEA	Finite element analysis
FFANN	Feed Forward Artificial Neural Networks
FFT	Fast-Fourier Transform
FMEA	Failure Modes Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
HMM	Hidden Markov model
HSMM	Hidden Semi-Markov model
I2C+SPI	Inter-Integrated Circuit + Serial Peripheral Interface

IDPS	Integrated Diagnosis and Prognosis System
LCOE	Levelized cost of energy
LED	Light-emitting diode
LPM	Logistics planning module
MAS	Moving Averaged Spectral
MILP	Mixed integer linear problem
MRM	Maintenance Routing Model
MSM	Maintenance Scheduling Model
MTTF	Mean time to failure
NAN	Not a number
NN	Neural networks
NPC	Nominal Power Classification
O&M	Operation and maintenance
OSV	Offshore Service Vessel
PDF	Probability density function
PM	Preventive maintenance
POD	Probability of detection
RAMS	Reliability, Availability, Maintainability and Safety
RMS	Root Mean Square
ROV	Remotely Operated underwater Vehicle
RPM	Revolutions per minute
RPN	Risk priority number
RUL	Remaining useful life
SCADA	Supervisory control and data acquisition
SMC	Sequential Monte Carlo
SPC	Statistical Process Control
SVP	Support vector machine
SWATH	Small Waterplane Area Twin Hull
TCI	Technical condition indices
TCM	Technical condition management module
TeCoLog	Technical condition based logistic planner
TeCoMan	Technical condition manager
W2W	Walk to work
WP	Work package

Executive Summary

This deliverable is the final deliverable within work package (WP) 4 'Operation and Maintenance strategies' with the title "O&M; Integration of tools and systems". Several tools, models, methodologies, concepts (henceforth simply referred to as "solutions") have been designed, developed, applied, or identified with the aim of optimizing O&M for offshore wind turbines. Each solution considers a limited part of the complex optimization problem, and the aim of this deliverable is to describe how the solutions can be used in combination, and how they can be integrated to increase the level of detail and capture effects not included in each solution originally. In summary the deliverable demonstrates that one by integrating different tools can increase the accuracy of the results solve problems that one could not previously solve in an adequate manner using each tool in isolation.

The solutions considered in this deliverable are:

1. **Reliability-based design and degradation modelling**: application of existing methods for identification of critical components (e.g. FMECA and RAMS), web-based tool for reliability based design, and description of degradation modelling.
2. **Degradation modelling through Fault Diagnosis and RUL prognosis**: description of approaches for fault diagnosis and RUL prognosis.
3. **O&M access**: input data describing O&M access solutions including transfer limits.
4. **O&M Strategy model**: simulation based tool for strategy optimization regarding e.g. O&M vessel fleet composition and jack-up vessel charter strategy.
5. **Risk-based O&M model**: tool for optimization of inspection and repair strategy considering probabilistic models for deterioration and inspections.
6. **Remote Presence system**: prototype of robot on rails to be used inside the nacelle for remote inspections using high definition photos, thermography, and audio recording.
7. **IDPS Web Service:** web service for condition monitoring and diagnostics.
8. **A Dynamic Scheduling Framework**: tools for dynamic scheduling and routing of preventive and corrective maintenance tasks.
9. **TeCoLog (technical condition based logistic planner)**: a concept using existing tools for an operational/tactical logistics decision support system for planning and scheduling of O&M activities using technical condition indexing.

Solutions 4, 5, 8. and 9. are decision support tools for O&M planning, the remaining ones can be considered as providing input to the decision support tools. The O&M Strategy model (4.) and the Risk-based O&M model (5.) are strategic decision support tools, to be used for long-term planning, and the Dynamic Scheduling Framework (8.) and TeCoLog (9.) are tools for tactical and operational decisions on shorter time scales.

The two strategic decision support tools have different strengths and weaknesses. For example, the O&M Strategy model is most applicable to decisions relating to maintenance logistics (e.g. vessel fleet composition and jack-up vessel charter strategy), as these aspects are modelled accurately. In contrast, the Risk-based O&M model is most applicable to optimization of the condition monitoring, inspection, and repair strategy, as the effect of this strategy on failure rates is modelled explicitly. The strategy tool considers condition-based maintenance only through high level performance data, whereas the Risk-based O&M model considers vessel strategies only through the costs.

Due to these differences, the two tools are to some extent complementary. Thus, the tools can be used together to provide more accurate results.

Both the Dynamic Scheduling Framework and TeCoLog can make an optimal maintenance schedule with the objective of reducing the maintenance costs. TeCoLog includes a module for suggesting maintenance tasks based on condition monitoring information, whereas the Dynamic Scheduling Framework need the list of maintenance tasks, which could be provided by the Risk-based O&M model. The dynamic scheduling model considers optimal routing of each vessel, whereas TeCoLog consider which maintenance task to be made when by which vessel considering location and need for equipment.

In addition to describing the principles of how integration and combined use of WP4 tools can be done and add value, this deliverable includes four case studies demonstrating different levels of integration between tools.

Case study 1 concerns approaches for integration of deterioration models and risk-based decisions in the O&M strategy model. These approaches make it possible to include the effect of inspection and repair strategy on the need for repairs and failures in the O&M strategy model. Three approaches are considered: full code integration (accurate but time consuming), "loose" integration through setting up data interfaces (simple and flexible but without correct distribution of repairs and failures in time), and a Bayesian network based approach using data interfacing (computationally efficient and with correct distribution of events in time).

Case study 2 presents a cost-benefit analysis of condition monitoring systems. The analysis was performed with the O&M Strategy model and data from an industrial partner was used. The case study shows how the value of condition monitoring can be estimated based on high level performance data of the condition monitoring system.

Case study 3 presents the architecture and methodology of three models for remaining useful life (RUL) estimation for main bearings. One model proposal is physics based using a multi-sensor condition monitoring system, and two model proposals are data driven using vibration monitoring and temperature monitoring respectively. The vibration based model has been implemented and applies the spectral kurtosis for diagnosis. The model is demonstrated using vibration data, but the data available was not sufficient to validate the approach.

Case study 4 presents a purpose-built simulation-based tool for estimating the costs of repairs/exchanges requiring jack-up vessels. This tool is to be used in combination with the Risk-based O&M model. Also, the effect of jack-up contract and strategy (fix-on-failure or campaign) can be estimated. Alone, the Risk-based O&M model assumes that mobilization costs are paid for each repair, but when used in combination with this tool, mobilization costs can be shared between more repairs. For a case study with blade exchanges, the expected costs per blade exchange could be reduced by up to 44 % using a more detailed cost model considering bundling of repairs.