Vessel fleet analysis for operation and maintenance activities at offshore wind farms

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Outline

1. Motivation
2. Problem description
3. Mathematical model formulation
4. Some numerical results
5. Conclusions and further research
Motivation

• EU's 20-20-20 target – to be meet by 2020
  - A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels
  - 20% of EU energy consumption to come from renewable resources
  - A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency

• 25-30 % of the cost from producing energy from offshore wind farm comes from the operation and maintenance (O&M) activities

• Vessels to support O&M activities – one of the most costly resources in the supply chain
Motivation
Problem description

- One or more wind farms has a number of wind turbines that require maintenance operations during a planning horizon

- Vessel resources and maintenance infrastructure can be shared between the wind farms
  - Maintenance infrastructure/bases can be onshore ports, offshore installations, mother vessel concepts...
  - Vessel resources can be purchased or chartered and can be CTVs, supply vessels, crane vessels, helicopters...
Problem description

• Maintenance bases can have investment costs and have a maximum vessel capacity
• Vessel resources are associated with a given maintenance base
• Each vessel resource has:
  – investment cost or time charter cost
  – variable cost
  – service speed
  – deck load
  – deck size
  – crew capacity
  – operational and safety weather requirements
Problem description

• Vessel fleet and maintenance infrastructure need to support the wind farm(s) need for preventive and corrective maintenance operations
• Preventive maintenance operations are executed to extend the life of a wind turbine and keep the number of failures down
  - Scheduled according to the wind farm operator's maintenance strategy
• Corrective maintenance operations are executed due to unforeseen failures to the system
• Each maintenance operation is divided into up to three maintenance activities
Problem description

- Preventive maintenance activities will have a soft and a hard time window for execution.
- Corrective maintenance activities always have a penalty cost based on the real downtime cost the failure cases.
- Activities can be delayed until next planning horizon at a penalty cost.
Problem description

• Several uncertain parameters:
  – Weather conditions: Wind speed and direction, wave heights and directions, current...
  – Determines when operations can be executed and when vessels need to return to a safe haven
  – Wind speed and direction also determine the power production
  – Electricity prices determine the revenue from the wind farm
  – Spot prices of time charter contracts determine the cost of charter vessels
  – Number of failures and when they occur determines the corrective maintenance activities

• Deterministic modeling approach: All uncertain parameters are treated as known
Problem description

Objective:

Determine the minimum cost fleet and maintenance infrastructure that can execute all, or most, of the maintenance activities during the planning horizon
Mathematical model formulation – objective function

\textit{Minimize}

\begin{itemize}
  \item Cost of maintenance bases +
  \item Fixed cost of vessels +
  \item Variable cost of using vessels to execute maintenance activities +
  \item Penalty cost for maintenance activities executed outside their soft time window +
  \item Penalty cost for not executed maintenance activities +
  \item Travel cost for vessels
\end{itemize}
Mathematical model formulation – constraints

Restricting the number of vessels that can be based at a maintenance base
Budget constraint restricting the investment in vessels and bases
Maintenance activities are either executed within their hard time windows or postponed until next planning horizon
Only one vessel can be used to execute a maintenance activity at the same time
Determining the number of vessels that need to be purchased or chartered
Operational constraints - weather
Safety constraints - weather
Balancing constraints and flow conservation constraints
Binary, integer and non-negativity requirements
Numerical results

• Mathematical model formulation implemented in Xpress-IVE

• 15 problem instances
• Planning horizon of one year (360 days)
• 2 maintenance bases – one port and one offshore installation
• 9 vessel types: 3 CTVs, 2 supply vessels, 2 helicopters, one multipurpose vessel, one jack-up rig
• 1-3 wind farms
• 20-200 wind turbines per farm
### Numerical results

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<tr>
<th>Problem instance</th>
<th># wind farms</th>
<th># wind turbines per wind farm</th>
<th># maintenance activities</th>
<th>CPU [s]</th>
<th>Bases</th>
<th>Vessel types</th>
<th># activities not executed</th>
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Conclusions and further research

• A deterministic optimization model has been developed for the fleet composition problem for maintenance operations at offshore wind farm
• The model is implemented in commercially available software
• Numerical results show that the model can be used to provide decision support on optimal or near-optimal vessel fleet within acceptable computational time

• Future research should focus on modifying the model to capture other relevant aspects to the problem not yet discovered
• The problems underlying uncertain nature can make it relevant to investigate ways of incorporating uncertainty into the model
  – Stochastic modelling approach
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