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Finding cost-optimal solutions for the maritime logistic challenges for maintenance operations at offshore wind farms

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Abstract

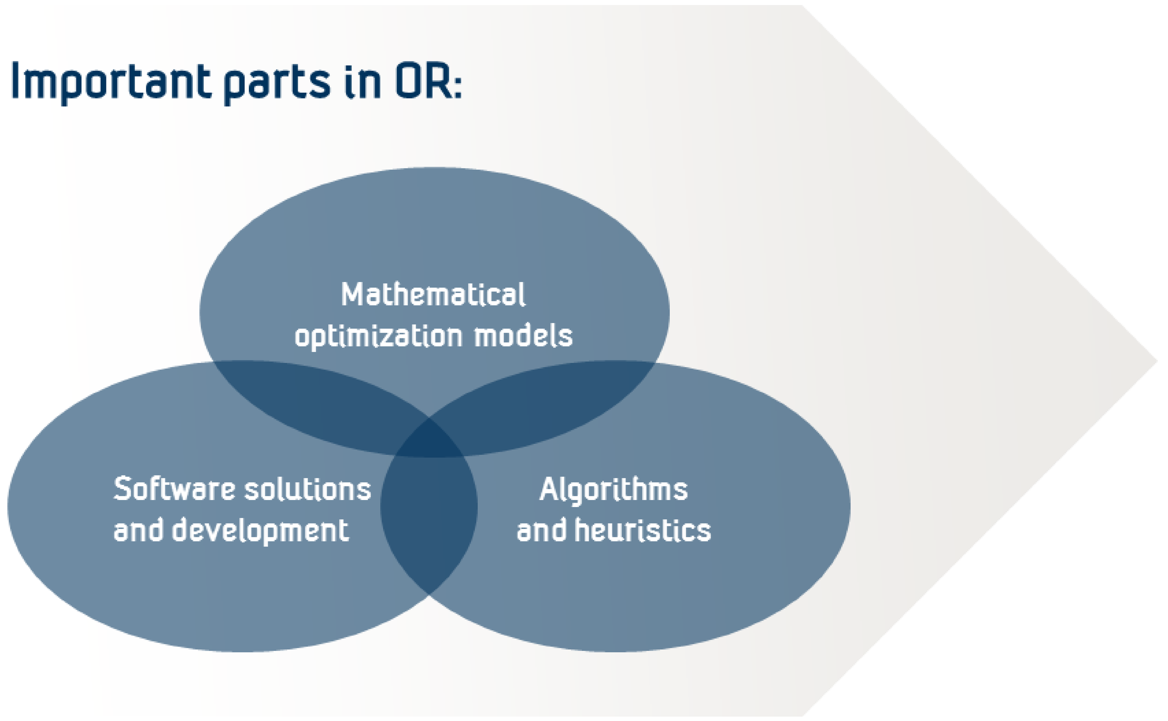
For offshore wind to be a profitable future energy source it is vital to significantly reduce the cost of energy. One way to do this is to learn from other more mature industries. **Operations research (OR)** is used for example in aviation and land based transportation systems in order to support planning experts to make better and more informed decisions based on quantitative advanced decision support tools. This can be seen as a contrast to the ad-hoc procedures that is widely used in today's young and immature offshore wind industry.

In general within offshore wind:

- *Lack of structured planning processes*.
  - Young industry that relies heavily on expert opinions and ad-hoc procedures
- *Complex operations*.
  - Exceeds human capacity to evaluate the entire solution space
- *Lack of advanced tailor-made decision support tools*.
  - In order to support experts in evaluating and finding near-optimal solutions

Operations Research (OR):
The study of how to develop mathematical models of complex engineering and management problems and the corresponding solution process.

We apply OR methodology and have developed a mathematical model that has been implemented in a decision support tool for determining cost optimal vessel fleet size and mix for maintenance operations at offshore wind farms.



Major application areas today:

- Petroleum industry
- Aviation
- Production planning
- Distribution
- Finance (portfolio optimization)
- Energy production

Objectives

Objectives for the vessel fleet size and mix optimization model:

- Minimize the investment/time charter costs of vessels and corresponding vessel bases (optimal fleet composition)
- Minimize the variable costs of using the vessels (optimal vessel deployment)
  - Variable costs are mainly related to fuel consumption
- Minimize downtime costs of the wind turbines

Evaluating all possible fleets manually is impractical or even impossible
10 vessel types, 0-3 vessels each → 2^{20} ≈ 1 million combinations!

Methods

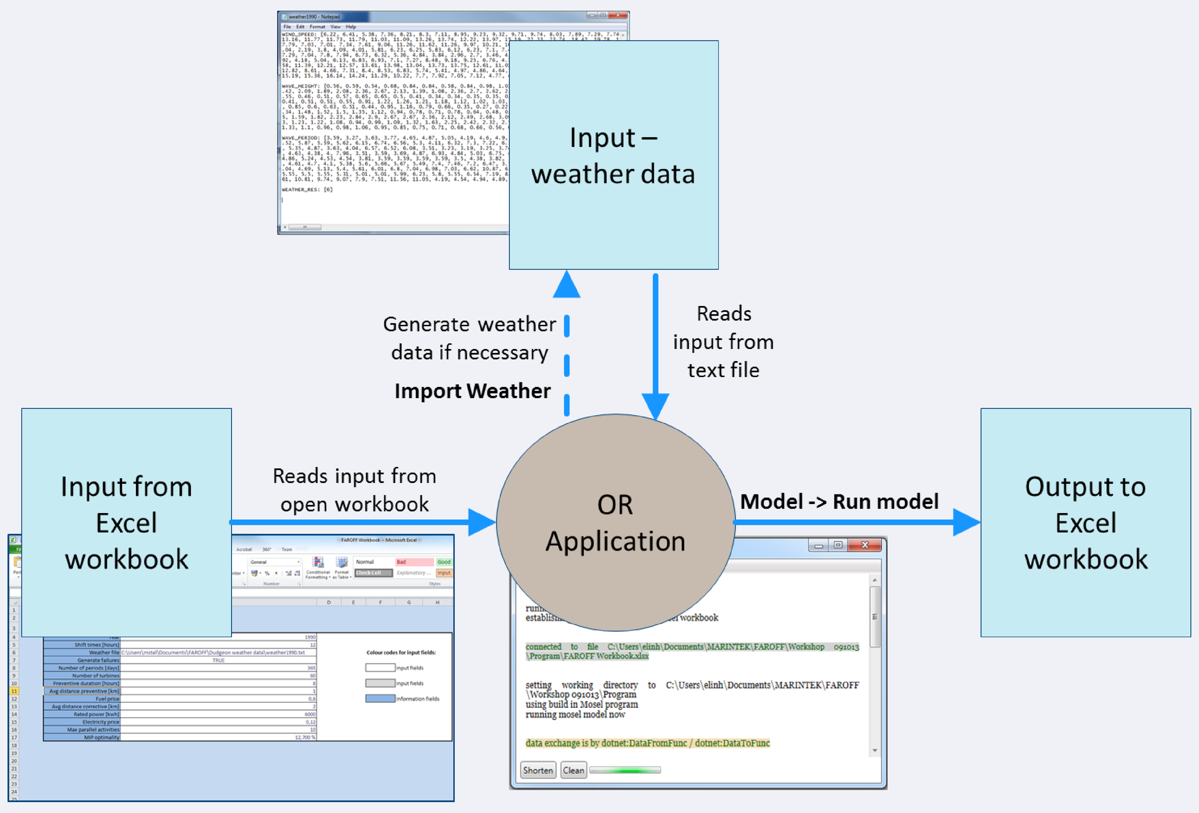
Common for many decision support tools are the use of some sort of simulation algorithm to evaluate the effects of a given solution. We are adapting a different approach where we utilize **mathematical models and optimization techniques** to select the cost-optimal vessel fleet among the options that are available for a given planning horizon. This means that while the simulation model merely calculate the cost of a given input scenario from a domain expert, the optimization model automatically searches among all possible scenarios before it provides the cost-optimal one to be validated by the domain expert.

In order to **determine a cost-optimal vessel fleet and corresponding infrastructure** the underlying optimization model also needs to correctly evaluate other relevant aspects of the logistic system. We have to consider which vessels should be used to support which maintenance activities at what time. To decide when a vessel can operate, we use the weather limitations of the vessel classes in conjunction with weather data from the wind farm's location. Weather data and electricity prices are used to determine the downtime cost. In total, output from the model is not only the cost-optimal vessel fleet and infrastructure, but also a wide range of statistics: Cost break-down, the vessel fleet's accessibility, number of working shifts per vessel, and availability of the wind farm.

Since the model also includes detailed information on other aspects of the logistic system, it can be adapted to analyse and provide insights to other interesting features. This creates **new and innovative ways for a decision maker to get valuable information** regarding the logistic system for maintenance operations at offshore wind farms. This can be e.g. to calculate the cost of increasing the availability of the wind farm, or to evaluate when it is best to execute preventive maintenance activities from a minimum cost logistic perspective. The model can be adapted to instead of taking weather limitations for a vessel class as an input parameter, evaluate which limitations that a vessel and access system should ideally have to reduce cost and increase availability of the wind farm.

$$\min \sum_{k\in K} C_k^F \delta_k + \sum_{v\in V}\sum_{k\in K} C_v^F x_{vk}^L + \sum_{v\in V}\sum_{k\in K}\sum_{s\in P^S} C_{vl}^F x_{vks}^S +$$
$$\sum_{v\in V}\sum_{i\in N_v}\sum_{j=1}^{M_i}\sum_{p\in P} C_{ijp}^D y_{vijp} + \sum_{v\in V}\sum_{w\in W}\sum_{p\in P} C_{vwp}\lambda_{kvwp} + \sum_{i\in N} C_i^P z_i$$

$$\sum_{v\in V}\sum_{w\in W}\sum_{p\in P} A_{iw}\lambda_{kvwp} + z_i = A_i, \quad \forall i \in N^P,$$
$$\sum_{v\in V_i}\sum_{p\in P_i} y_{vijp} + z_{ij} = 1, \quad \forall i \in N^C, j = 1,\ldots,M_i,$$
$$\sum_{w\in W} A_{iw}\lambda_{kvwp} - \sum_{j\in M_i} y_{vijp} = 0, \quad \forall v \in V, p \in P,$$
$$\sum_{w\in W}\sum_{p'=p-S_w}^{p} \lambda_{kvwp'} \leq x_{kv}^L + x_{kvs}^S, \quad \forall k \in K, v \in V, p \in P \mid p \in s$$
$$x_{kv}^L + x_{kvs}^S \leq Q_{kv}\delta_k, \quad \forall k \in K, v \in V, s \in S$$



Conclusions

The vessel fleet size and mix optimization problem describes the logistic challenge of executing operation and maintenance (O&M) activities during the operational phase of an offshore wind farm. The optimization model determines the *number and type of vessels and* the corresponding *infrastructure (bases, platform, mother ship)* needed in the offshore transport system.

References

1. Magnus Stålhane, Elin E. Halvorsen-Weare, Lars Magne Nonås (2014). FAROFF Optimization Model Technical Report, MARINTEK Report MT2014 F-097.

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