Optimization of routing and scheduling of vessels to perform maintenance operations at offshore wind farms

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Abstract

We study the problem of finding the optimal routes and schedules for a fleet of vessels that are to perform maintenance tasks at an offshore wind farm. To solve the problem two alternative models are presented: an arc-flow and a path-flow formulation. Both models are tested on instances of varying numbers of vessels and maintenance tasks. The arc-flow model is solved with commercial software using branch-and-bound. The path-flow model is solved heuristically by generating a subset of the possible routes and schedules, but produces close to optimal solutions using a lot less computing time than the exact arc-flow model.

Problem description

The need for maintenance activities at an offshore wind farm change continuously over time, as new failures occur and old ones are fixed. We study the problem of deciding which maintenance tasks should be performed on a given day, and which vessels should be assigned to which task and in what order they should be executed. Figure 1illustrates the problem faced on a given day. There are some turbines in need of repair, some that needs parts replaced, and some that are in need of an inspection. Each maintenance task is described by its duration, the number of technicians and the weight/volume of the spare parts needed, and finally a down-time cost that is incurred until the task is performed.

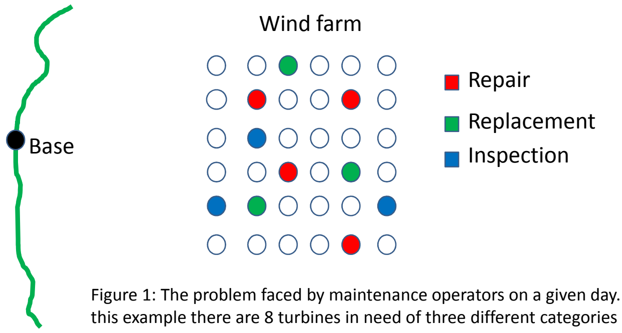

Figure 1: The problem faced by maintenance operators on a given day. In this example there are 8 turbines in need of three different categories of maintenance

To perform the maintenance tasks we have a fleet of vessels available at an onshore base. The vessels are described by their fuel cost, personnel capacity, weight/volume capacity, the access and transfer time, and their wave criteria. We assume that the weather on the planning day is known, and this, together with the wave criteria of the vessel can be used to calculate a weather window for each vessel.

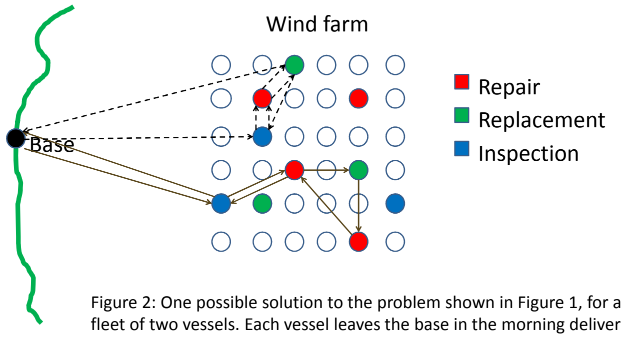

Figure 2: One possible solution to the problem shown in Figure 1, for a fleet of two vessels. Each vessel leaves the base in the morning delivers technicians to turbines where maintenance is needed and then pick them up again before returning to base.

Figure 2 shows one possible solution to the problem for a fleet of two vessels. The objective is to find the route sailed by each vessel, and the time each turbine is visited. Normally, each turbine is visited twice, once to let the technicians off the vessel and once to pick them up again. It is important that the time between these two visits to the same turbine is separated by at least the time it takes to perform the maintenance task.

Solution method

The problem is solved using a path-flow model, where the most promising routes and schedules are generated a priori. Before presenting the model, some additional notation must be defined. Let I be the set of all maintenance tasks i, R the set of all feasible routes r, and R_v the subset of routes compatible with vessel v. Further, let C_{vr} be the cost, including downtime cost, of sailing route r with vessel v, and let A_{ivr} be equal to one if vessel v performs maintenance task i on route r, and zero otherwise. Finally, we define the variables λ_{vr} which are equal to one if vessel v sails route r, and zero otherwise, while y_i is equal to one if maintenance task i is not performed within the planning horizon and zero otherwise. With this notation we may formulate the path-flow model as follows:

$$
\begin{aligned}
& min \sum_{v \in V} \sum_{r \in R} C_{vr} \lambda_{vr} + \sum_{i \in I^D} S_i y_i, & \\
& \sum_{v \in V} \sum_{r \in R} A_{ivr} \lambda_{vr} + y_i = 1, & i \in I, \\
& \sum_{r \in R_v} \lambda_{vr} = 1, & v \in V, \\
& y_i \in \{0,1\}, & i \in I, \\
& \lambda_{vr} \in \{0,1\}, & v \in V, r \in R.
\end{aligned}
$$

The objective function minimizes the sum of the sailing costs and the penalty costs associated with not performing maintenance. The first set of constraints state the all maintenance tasks have to be performed, or incurs a penalty cost if it is not, while the second set of constraints ensure that each vessel sails exactly one route. Finally, all variables are required to be binary.

Essential for this solution method is to have an efficient way of generating the set of routes R. This is done using a dynamic programming algorithm where inefficient partial routes are removed during the generation process, so that the final set R contains only the most promising routes. Due to the complex nature of the routing and scheduling decisions of this problem, the removal of inefficient partial routes is done using heuristic dominance rules and the resulting solution methodology must therefore strictly speaking be classified as a heuristic.

Results

The solution methodology has been tested on a set of randomly generated instances consisting of between 2 and 5 vessels, and 2 and 8 maintenance tasks. The computational results show that all instances can be solved to optimality in less than 1000 seconds, and most instances within 100 seconds. When compared with an arc-flow model implementation of the same problem, the results show that the path-flow model is much faster when the number of maintenance tasks and vessels increase.