Offshore Wind Farm Maintenance Decision Support

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Abstract

The main purpose of this work is to generate alternative plans for resource allocation during the maintenance phase of offshore wind farms. Furthermore, these plans are automatically evaluated with respect to success probability and costs. This approach should furnish the management with additional information on costs and risks of possible resource plans. Such plans will be presented in the form of daily, weekly and monthly plans. On this basis, the management should be able to make decisions regarding planning of the activities, personnel, and means of transport while the costs and risks are optimized. This work is the Informatics part of a funded comprehensive interdisciplinary research project with several academic and industrial partners.

1. Motivation

During the maintenance phase of offshore wind farms (OWFs), all activities, personnel, and means of transport are planned under permanent time and cost pressure. The resource planning decisions in the management of the OWF Alpha Ventus, for instance, are made based on experiential values which are not always documented or verified. Furthermore, since only individual staff have the required expertise, decision making inevitably depends on them **[1]**.

Automated resource planning can not only produce optimal suggestions, but also facilitate the process of decision making and reduce the overall pressure on decision makers. Since providing a sequence and an approximate execution time for the planned activities contrasts to the current practice in German OWFs **[1]**, an optimized establishment can yield in time and cost efficiently utilization of the resources.

2. Challenges

In order to provide optimized maintenance resource planning following questions shall be addressed:

- How should personnel be divided into teams? (efficient team allocation)
- When, in which order, and by which team should each of the planned activities be carried out? (efficient activity allocation)
- In which order and by which means of transportation should teams travel within the wind farm? (efficient transport routing)

These partial problems will be discussed in more detail in the next sections.

2.1. Efficient Team Allocation

The personnel of OWFs operators who work on sites are always arranged in teams, which, depending on the security policies in the wind farm, must have a minimum size. Moreover, team building is done based on the personnel's qualifications, which entitle them to carry out specific activities. In the most complex scenario, each employee has a unique combination of qualifications. In this case, for example, arranging 24 employees into teams of three, results already in nine trillion combinations. Therefore, team building is a problem of combinatorial explosion. However, the complexity of the problem gets reduced if more employees own an exactly identical combination of qualifications. Finding a suitable algorithm for building the teams, which enables the most efficient processing of the activities, is one of the goals of this work.

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2.2. Efficient Activity Allocation

Besides its size and members, each team has a limited working time window. The use of this time window should be as efficient as possible, so that the overall resource utilization is maximized.

This partial problem, which is similar to Knapsack Problem and therefore most likely of NP-equivalent complexity, is aggravated by two aspects:

1) Different arrangement of teams enables them to perform different activities due to the changed set of qualifications.

2) The duration and spatial configuration of the necessary transports before and after an activity depends on the sequence, in which the activities on different platforms are carried out.

The focus of this work is on both long-term planned missions (when the annual maintenance of wind turbines, foundation structures, etc. can be done), as well as short-term additional actions, with a time horizon of one day to a few weeks. Moreover, the activities, which are planned for more distant future up to one year (in particular as long as major logistics is needed), are also considered early on, provided that this allows for improved resource allocation.

2.3. Efficient Transport Routing

The order of approaching the wind turbines for dropping off the teams to carry out the activities, is another point for potential optimization. Minimizing the transport times can potentially maximize resource utilization and reduce the total costs of carrying out the given activities. Such a problem is generally declared as asymmetric Traveling Salesman Problem (TSP), which is assumed to be of NP-equivalent complexity. In the context of OWFs, however, there is a more complex TSP version since each location should at least be visited for the second time for picking up the teams. Moreover, the activities' durations introduce mandatory waiting times into transport scheduling. Therefore, bringing the personnel time and cost efficiently to the workplace can potentially lower the overall costs and risks of scheduled plans.

3. Approach

The focal areas of this work therefore concentrate on developing a suitable OWF maintenance scheduling algorithm (Section 3.1) and a simulation environment to evaluate plans proposed by this algorithm (Section 3.2).

3.1. Scheduling

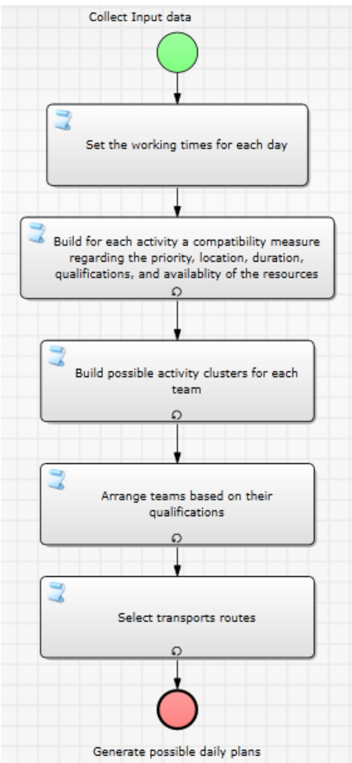

Figure 1: Scheduling process schema

On account of existing feedbacks between them, none of the above mentioned partial problems should be considered separately. In order to generate the best possible optimal planning proposals, according to the required indicators (cost and risk), a heuristic algorithm which reckons all these partial problems at the same time will be implemented.

A Top-Down approach based on the process representations can simplify the difficulty of designing such a heuristic. Besides, tackling partial problems in different orders leads to slightly different versions of the algorithm. Figure 1 shows one variation of scheduling process representation.

In this schema, after collecting the necessary input data, the working time window of the day is set as the limiting time frame for all activities. In the next step, for each activity, a compatibility measure regarding the priority, duration and location of the activity, required qualifications of the personnel for performing this activity, and availability and temporal compatibility of the required resources will be built.

With the help of this measure, activities can be clustered, for example such that opportunity costs are minimized, i.e. not necessarily matching activities yielding the best fit, but such that each activity obtains "partner activities" that do not leave outliers without a suitable "partner activity". Ideally, each cluster consists of the activities with highest priorities, which are planned to be performed on the geographically close locations and require similar qualifications. The duration of all activities in each cluster must also not exceed the working day.

After that, personnel will be divided into teams based on their qualifications and the clustered activities will be assigned to them. Finally, finding an optimal route for transportation within the wind farm and assigning teams to them will be done in the next step. In the end, the algorithm will generate several suggestions for daily resource planning.

3.2. Simulation

Simulation is a well-known method for resource allocation optimization in the Logistics domain **[2]**. A heuristic scheduling algorithm reduces the search space for finding optimal suggestions for resource planning. With the help of simulation techniques, the generated alternatives can be evaluated with respect to costs and risks indicators.

Costs indicators consist of the costs of main resources such as personnel and means of transport. Risks indicators include successfully execution probability of the plans. The following questions will be addressed by simulation: How likely is it for a plan to be executed successfully? Are time slots large enough to counteract the stochastic fluctuations in the execution? Are plans potentially vulnerable to fail entirely?

4. Results

The alternative plans generated by the scheduling algorithm should be finally well presented to enable the management to select suitable plans. Figure 2 shows a sample Gantt chart which represents a sample schedule of one day. The means of transportation and employed teams are shown in the first column of the Gantt chart. The main body of the chart shows when teams work on which activities and by which means of transport they travel through the wind farm. There are several daily alternatives each of which is rated by costs, risks and execution probability. Each plan can be modified by the user and automatically after that, there will be a reassessment of the relevant indicators by means of simulation techniques. Manually created version of the plan will be listed as another possible alternative.

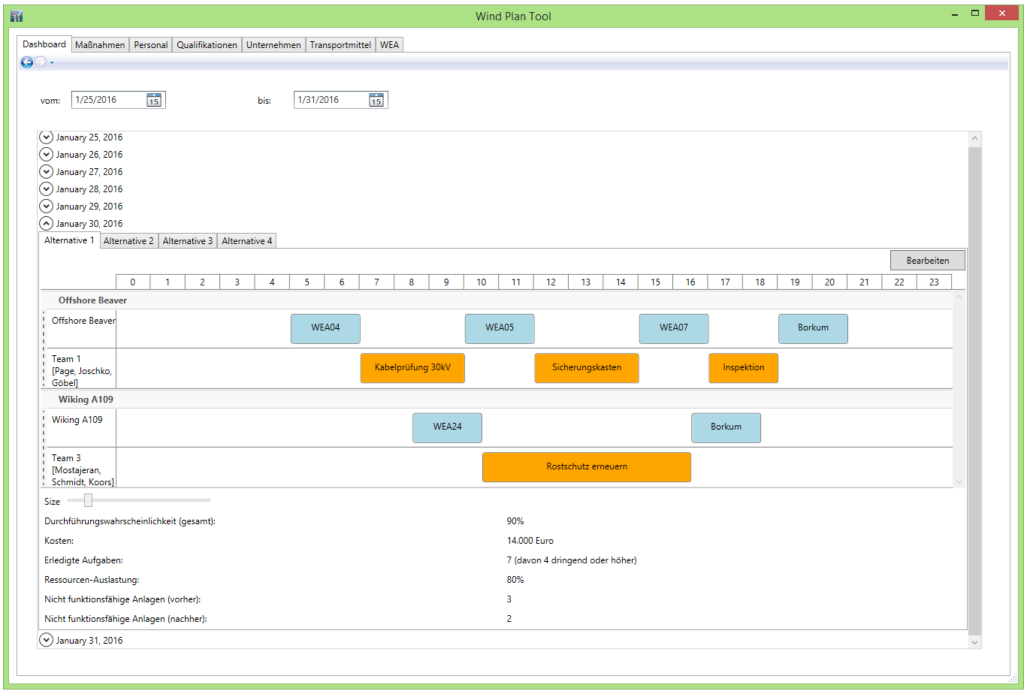

Figure 2: Sample resource allocation output

5. KrOW! as the underlying research project

This work is part of the comprehensive research project "KrOW! - Kosten- und risikogesteuerter Betrieb von Offshore Windparks" (Cost and Risk Controlled Operation of Offshore Wind Farms) funded by Federal Minister of Economic Affairs and Energy in the research program "Renewable Energies' Wind" (2014-2017). Figure 3 shows an overview of KrOW! sub-projects, some of which will be briefly introduced in this section.

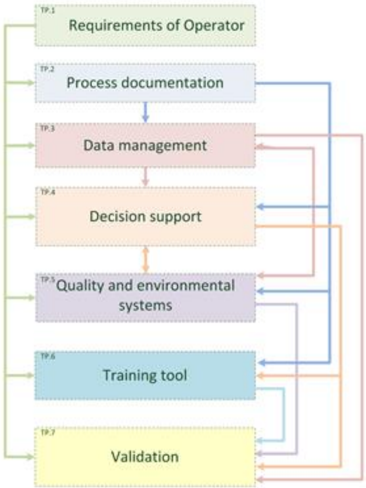

Figure 3: KrOW! subprojects

5.1. Quality and environmental systems[4]

In order to fulfill requirements of quality management systems according to ISO 9001:2015 and to support proof of environmental obligations, business processes are connected with documented information. Processes selected regarding operational procedures of the maintenance of OWFs. Flows of documents are illustrated within the models and key performance indicators (KPIs) are linked to the processes. Quality Management KPIs allow to monitor and control these business processes. Environmental KPIs enable measurement and surveillance of environmental performances and impacts of OWFs.

5.2. Process documentation[4]

Business processes of operational management of OWFs are documented, parametrized and modelled. Operational processes that visualize tasks and decisions involved in the execution of maintenance actions are modelled using the OMG[5]-Standard Business Process Model and Notation (BPMN). Documents and IT-Systems are illustrated in the models and KPIs are linked to the processes. Further relevant information and data that is not electronically available is gathered and integrated in the *KrOW!* Database.

5.3. Training tool[4]

The development of a concept for an e-learning environment aims to support training of employees of the operational and strategic management. New employees of the operating company can use this training tool in order to quickly acquaint themselves with their tasks of every-day business. Being part of this, it also comprises tutoring in the use of the scheduling tool as well as interpretation of the alternative plans and choice of optimal routing. Finally, the training tool will enable employees of strategic management to appraise and construe KPIs that will assist them to optimize operational management of OWFs.

5.4. Evaluation models for strategic planning of preventive maintenance tasks and risk analyses of maintenance related processes[6]

For the strategic planning of preventive maintenance tasks in a wind farm, an evaluation model that offers suggestions for choosing a suitable maintenance policy depending on different performance criteria like availability, failure frequency and costs will be developed. In particular different types of preventive maintenance strategies such as condition-based, time or mileage dependent, run-to-failure will be analyzed. The resulting prearranged maintenance tasks will be considered within the scope of operative scheduling.

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The risk analysis of the operation and maintenance processes shall identify and assess hazards that are related to their main activities and sub-processes. For this purpose an additional evaluation model including the following risk dimensions will be developed:

1. Delayed restoration of the wind turbine,
2. Additional maintenance costs,
3. Non-fulfilment of the planned mission.

Basis for the analysis shall be process structures and event data stored in a dedicated data base. These data shall be statistically analyzed in order to generate statements about the risks and critical items.

6. Conclusion

In this work we outlined an approach for providing faster and more efficient resource plans with a higher resource utilization rate and consequently lower costs and risks during the maintenance phase of OWFs.

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