VESSEL SELECTION GUIDELINE FOR THE INSTALLATION OF OFFSHORE WIND FARMS

Fiona D. Lüdecke[1,2,3], Gerrit Wolken-Möhlmann[1,4], Thrasyvoulos Panteleon[1], Antonio Hurtado[2]
[1]: Fraunhofer IWES, Am Seedeich 45, 27572 Bremerhaven, Germany
[2]: Technische Universität Dresden, George-Bähr-Strasse 3b, 01069, Dresden, Germany
[3]: Universität Stuttgart, Allmandring 5b, 70569 Stuttgart, Germany
[4]: Tufts University, 200 College Avenue, Medford, MA 02155, USA

Abstract
Weather uncertainties during offshore wind farm installations cause difficulties in vessel type selection in the planning phase. Therefore, the development of a general guideline to determine appropriate vessel requirements in the early stage of project planning is desired. A possible approach to develop such a guideline is a statistical analysis. That is why the main objective of this paper is the investigation of the statistical contingency between on-site weather conditions and required vessel restrictions for offshore wind farm installation processes. A method to generalise the choice of the necessary vessels considering its weather restrictions is presented. An optimisation algorithm is developed, based on the existing Fraunhofer IWES COAST tool. The algorithm analyses the dependency of the optimised vessel's weather restriction on the expected weather conditions at the installation site under varying on-site conditions. As a result, a functional relation between the expected weather conditions and the required minimal vessel weather restrictions is found. The identified relationship provides a rapid assessment of required vessel operational limits given the expected on-site weather conditions.

1. Introduction

Recent offshore wind energy projects tend to focus on locations with increased water depth and distance to shore for enhanced and more constant energy yield [1]. However, the installation of offshore wind farms is subject to vessel and crane limitations in combination with the local weather conditions, i.e. significant wave height (H_s) or mean wind speed (U). Therefore, the installation process comprises a certain risk (e.g. delays, idle times, etc.) with respect to monetary expenses and project duration. Hence an economic optimisation of the project planning is desirable. In the past, a variety of optimisation tools have been developed and applied, e.g. [2], [3]. The tools are based on mathematical methods, statistical analysis or Discrete Event Simulation (DES). An example for a mathematical tool is introduced by Irawan et al. [2], which minimises the project costs and duration. A statistical analysis is used by Scholz-Reiter et al. [4] to minimise the project duration. Scholz-Reiter et al. assume that the duration is proportional to the mean project costs. Muhabie et al. [5] minimise the project duration using DES. Beside the scientific tools, several commercial tools are available, e.g. "Mermaid" [6] and DNV-GL's "O2C-Tool" [7]. All these tools use either weather statistics, weather forecast data or simulated weather time series. They generate an optimised project plan including time schedule and the weather restrictions of the chartered vessels and cranes. However, their utilisation can be laborious and time consuming. Hence, a general and easy-to-use planning guideline is favourable, especially in the early stages of the project's planning phase, which is the aim of this paper.

2. Method

2.1. Input data

For the scope of this study, eleven sites in the North Sea are chosen as potential installation sites. The sites differ in their annual mean value of H_s using hindcast weather data of the coastDat project [8]. The different annual mean values ensure that the analysis of each site creates a different scenario. A basic project plan is defined assuming the installation of four turbines with single blade installation, transporting the tower in one piece and using monopiles as foundation structure. To determine the project duration at the different sites, the analysis tool COAST developed by Fraunhofer IWES Nordwest is used [9]. COAST determines the project duration for varying project start dates in order to obtain a distribution of installation durations. For each start date, the project duration is calculated. As indicated in Fig. 1, COAST tests, whether a specific task (e.g. jacking up) can be carried out by a vessel, considering the vessel's weather restrictions and the present weather conditions. If the task

cannot be executed, it is delayed until a suitable weather window occurs.

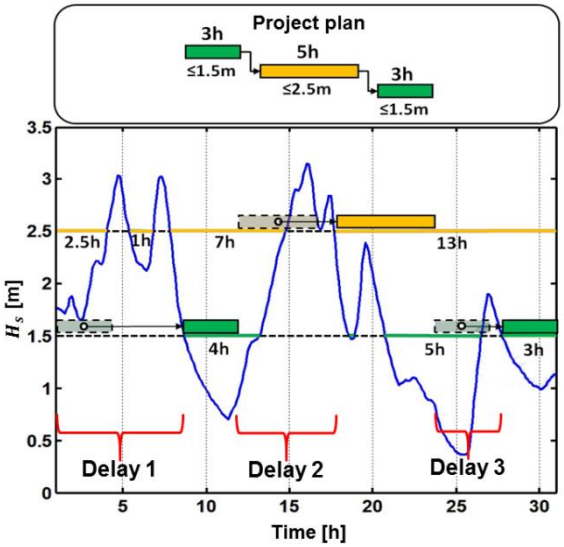

Fig. 1 Principle of COAST [9]

Thereby a distribution of project durations and start date periods is established. The distribution will be analysed with respect to percentiles for the project duration. Because of the chosen shift of the start date, in total about 2500 simulation runs with different start dates are used for each analysis.

2.2. Pre-analysis

The results from COAST are used as input for a self-developed optimisation tool (see [10]). Optimising the weather restrictions is necessary as a less robust ship is expected to cause the highest delay but is less expensive. On the other hand, the most robust ship causes the minimum delay but is most expensive. To prevent the results from being influenced by dependencies between two restriction-parameters each parameter is analysed separately. Hence either H_s or U is restricted and the other is not. The optimisation tool is working as follows:

Initially each task's weather restriction is set to a strict value (e.g. $H_s = 0.9\,\mathrm{m}$ or $U = 7\,\mathrm{m/s}$) and the entire project is simulated with COAST. Subsequently, the task causing the most significant delays is determined. For this task, the weather restriction is increased in a stepwise manner until a convergence criterion is met. In this work, convergence is defined when the simulated project duration is between 120 % and 150 % of the ideal project duration (i.e. project duration without weather influence). This range results from the necessity to have a minimum project delay without using the most expensive and robust vessel. For the convergence, the decrease in the project duration must be less than 0.1 % of the ideal project duration within one simulation step (i.e. insignificant time gain by more iteration steps). The weather restrictions determined with this method are used for the statistical analyses described in 2.3. The weather restrictions and the month the task takes place are stored in an array.

2.3. Statistical analysis

A premise for establishing a general guideline for vessel requirements is to study the statistical correlation between optimum weather restrictions and mean weather conditions on the installation site. For each installation site, the used hindcast weather data is sorted in periods of months. For each month the mean value over 50 years (January 1958 to December 2007) is calculated. These weather mean values are combined with the optimum weather restrictions from 2.2 to form pairs of values. These pairs of values are tested for statistical independence by a chi-square test. Additionally, the arithmetic means of the found weather restrictions and their confidence intervals are calculated. Ultimately, a linear and a logistic regression are performed (eq. (2-1) and (2-2)) with WR_{opt} as optimised weather restriction and MW as mean value of the weather conditions. A, B and C are parameters of the functions.

$$WR_{\mathrm{opt}} = A \cdot MW + B \qquad (2\text{-}1)$$

$$WR_{\mathrm{opt}} = \frac{C}{1 + e^{A \cdot MW + B}} \qquad (2\text{-}2)$$

For a visual assessment of the quality of the regression, the found functions are plotted along with a Box-Whisker-Plot, see Fig. 2 and Fig. 3.

3. Results

3.1. General

For both parameters H_s and U, the chi-square test rejects the independence of the pairs of values, i.e. a correlation between optimum weather restrictions and mean weather conditions is likely. The validation of the arithmetic mean value using the confidence interval (see 2.3.) showed good agreement: the confidence intervals are in a range of less than ± 0.2 % of the arithmetic mean, i.e. the variance is considered acceptably low.

3.2. Significant wave height H_s

The result for H_s is shown in Fig. 2. The linear regression function (green) captures the main tendency, yet near the upper and lower bounds

it does not cover the medium 50 % interval (i.e. range of the 25 % to 75 % of the pairs of values). In contrast, the logistic regression function (orange) captures the effects near the interval's bounds and therefore appears more favourable to describe the data. This leads to the determination of a degressive increase in the correlation. This could be due to high monthly mean values for the weather conditions appearing far offshore and in winter when the weather is highly variable, resulting in short weather windows. To assess the impact of the varying weather conditions on the results of the relationship further research needs to be conducted.

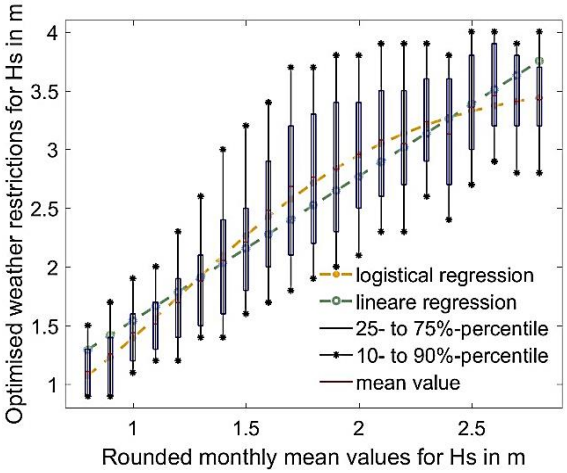

Fig. 2 Recorded statistical relationship for H_s

3.3. Mean wind speed U

The result for U is shown in Fig. 3. Both regression functions, linear (green) and logistic (orange), capture the tendency of the mean values without leaving the medium 50 % of the pairs of values. Therefore, both regression functions describe the data equally well and for simplicity only the linear regression function is used.

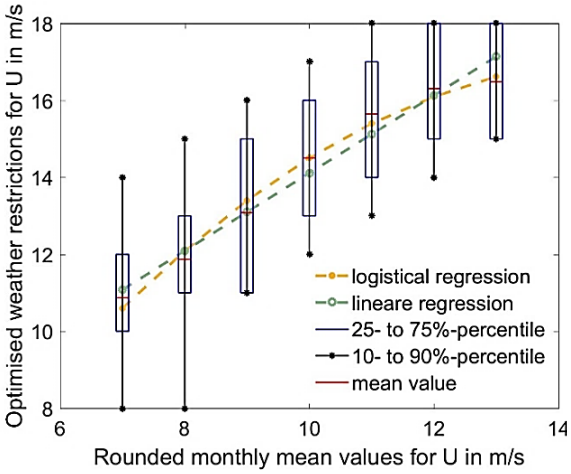

Fig. 3 Recorded statistical relationship for U

3.4 Application in planning process

During the planning process, the expected on-site weather conditions (e.g. monthly mean value of H_s) are used as input for the regression function. The function then defines the near-optimum (i.e. minimum) vessel weather restriction WR_{opt} to execute a specific task (e.g. jacking-up) with minimum delay.

4. Conclusion

The presented method to identify a planning suggestion for offshore operations shows promising results for the North Sea area. It allows for the prediction of near-optimum weather restrictions without the need for additional optimisation tools. Based on the sites used for this study, the vessel weather restriction for the significant wave height H_s correlates best with the monthly mean value of the significant wave height at the installation site with a logistic correlation. On the other hand, the mean wind speed U implies a linear correlation between the vessel weather restriction and the monthly mean value at the installation site. To generalise the method further research needs to be conducted including more installation scenarios (e.g. alternative installation sites).

It is expected that such a general planning suggestion will dramatically reduce the effort required during the complex planning phase of wind farm installations. Thereby a contribution towards a lean and economic project management can be achieved.

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6. Contact

For further information please contact:
Fiona D. Lüdecke luedecke@ifb.uni-stuttgart.de

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