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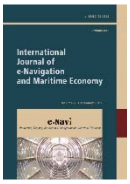

Original article

Information System for the Coordination of Offshore Wind Energy Maintenance Operations under Consideration of Dynamic Influences ☆

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Abstract

For the German energy transition, offshore wind energy is a significant factor of success. The number of installed offshore wind energy turbines is steadily increasing. Currently, the subject matter of offshore wind energy turbine maintenance and its optimization is increasingly in the focus of research and development work. The present contribution examines the logistics of offshore wind energy turbine maintenance and the impact of the actual sea state and of sea state forecasts. To this end, the coordination processes between the players involved in the planning of service operations will be presented and analysed. Based on this, the impact of the quality of wave height forecasts on operation decisions and the mean time to repair will be determined as well as the availability of the turbines at different forecast quality levels. Proceeding on the basis of these results, the concept of a decision-making support system for operative logistics planning will be presented.

Keywords: Offshore wind energy logistics, maintenance, sea state forecast, decision-making support system

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1. Introduction

This contribution examines the impact of the quality of sea state forecasts on the operative maintenance logistics of offshore wind energy turbines (OWT) as well as the resulting limitations for power generation, and provides an approach for supporting operative maintenance planning and execution. To this end, chapter 2 addresses the subject matters of maintenance and OWT maintenance logistics, as well as, the questions this paper seeks to answer. Chapter 3 presents the research approach of this contribution. Chapter 4 presents previous scientific studies in the context of operative maintenance logistics for offshore wind energy (OWE). In order to illustrate the area of application, the process of operative maintenance is presented in chapter 5 and analysed with regards to the limitations of feasible maintenance measures. The impact of the accuracy of sea state forecasts on the operative maintenance logistics is examined by means of a discrete event simulation (chapter 6). Based on the analysis and the discussion of the simulation results, the concept of a support system for the operative planning and execution of maintenance logistics is presented in chapter 7. Finally, a summary and an outlook on further research and development activities conclude this article (chapter 8).

2. Maintenance and logistics of offshore wind energy turbines

With an average annual growth rate of 29 %, OWE is one of the fastest growing industries in Europe (Shafiee, 2015). With a current installed capacity of 11 GW, the installed output has more than doubled over the last three years (Ho et al., 2016). The increasing use of OWE leads to the need to maintain the increasing number of OWTs during their operating phase. With a duration of 20-25 years, the operating phase of an OWT is the longest phase in its life cycle. The operating costs incurred during this phase amount to approximately 20 % of the overall costs incurred during the life cycle of an OWT. The costs for maintenance constitute approximately 72 % of these operating costs (Svoboda, 2013). Due to this large share of operating costs, the current challenges of the industry are cost reduction and the increase of turbine availability in order to secure efficiency and competitiveness (German Federal Ministry Economic Affairs and Energy 2015, Beinke and Quandt 2013, García Márquez et al. 2012). Due to the limited accessibility and the high transport costs and efforts connected to the maintenance of OWTs, the challenge to achieve high turbine availability, as well as, a large power output during the entire operating phase is much greater than in the case of the maintenance of wind energy turbines located on land (Oelker et al. 2016, Burkhardt 2013). The maintenance work to be performed requires both material and personnel transport which is performed with different means of transport (Oelker et al., 2013). Which means of transport are selected depend on the required transport capacities, as well as, on the actual weather conditions (Seiter et al. 2015, Franken et al. 2010). Weather conditions directly affect the usability, so maintenance work can only be performed within specific limits, which depend on the respective means of transport (Quaschning 2013, Holbach and Stanik 2012). Therefore, the quality of weather condition forecasts for the operation site and the transport route plays a decisive role during the planning of maintenance operations. In general, different approaches can be considered for carrying out maintenance activities, which specify the time, the types of measures and the frequency of implementation. The choice of the right maintenance strategy is decisive for the reliability of the system and the pertaining costs (Ryll and Freund, 2010). The selected maintenance strategy has an immediate effect on the maintenance logistics.

Based on the definition of maintenance in accordance with DIN EN 31051 which includes all technical and administrative measures for maintaining operability, according to Shafiee (2015), depending on the time frame, OWE maintenance logistics can be divided into the areas of strategic, tactical and operative dimensions. The operative dimension, which is also the subject matter of this contribution, comprises of the day-to-day business of the planning and execution of operative service missions and is characterized by short-term decisions. A large number of influences, which, among other things, include the availability of different resources (e.g. means of transport, technicians and spare parts), potential production downtimes of the wind energy turbine, as well as, the weather conditions and the sea state, need to be taken into consideration during planning (Shafiee, 2015).

The sea state is a decisive factor especially in regards to the transition from the crew transfer vessel (CTV) to the turbine. Depending on the type of vessel, the maximum numbers of the significant wave height (Hs) for the transition are between 1.5m and 3m.

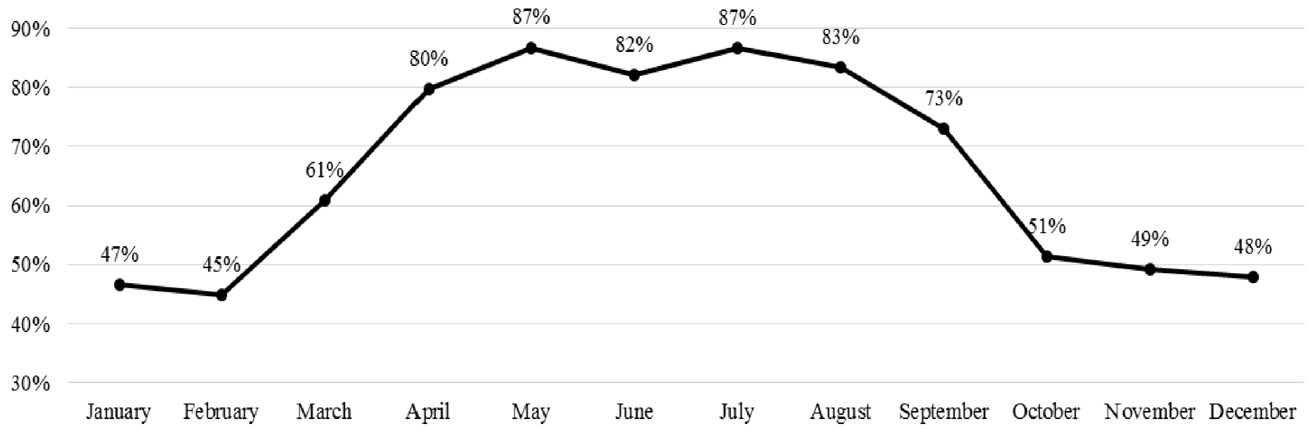

Figure 1: Relative access options at Hs ≤ 1.8m (during the years 2000-2004

Figure 1 shows the accessibility percentage distributed over one year for a catamaran with a limit of $H_s = 1.8m$. A wave forecast around the maximum value has an especially significant impact on planning, as shown in this contribution. It becomes clear that accurate wave forecasts are of great importance to the efficiency of OWTs and, therefore, justify the great costs and effort required for determining better wave forecasts.

3. Research approach

The approach of this contribution is oriented on design science research (cf. in this regard Peffers et al. 2007), and the main applied method is simulation. After the identification of the problem, which comprises an analysis of prior art and the documentation and analysis of real processes, the urgency of the identified problem is determined. This is achieved by means of a discrete event simulation. The basic idea is to generate mathematical models that are usually applied for the analysis of real processes. For complex problems, the application of mathematical models for operational studies is limited. As an alternative analysis tool simulation technique can be used. Simulation can be effectively applied for modeling processes with a different degree of detail and for supporting the decision-making process. The third step of the design science research approach comprises of the creation of a concept for the intended decision-making support system for the planning of offshore service logistics. This step is the conclusion of the research approach used in the context of this contribution.

The identification of the real planning and execution processes in service logistics was performed at a maritime service provider for OWE. Said service provider has a fleet of several vessels and is involved in the service logistics of different offshore wind parks (OWP). The processes were identified by means of semi-structured interviews. The subsequent processing and the illustration of the processes wasperformed in a detailed manner using Business Process Model and Notation 2.0. The analysis of these processes was performed by means of a cause-effect diagram. A cause-effect diagram actively supports the search for causes of a defined effect and provides approaches for solving a specific problem. The defined effect examined in the context of this contribution comprises of the limitations of OWT availability due to the limited ability to perform service operations.

Based on the problem identification, a discrete event, agent-based simulation for the determination of the impact of the quality of weather forecasts on the service logistics processes and the efficient operation of OWTs was prepared in the second step. To this end, two scenarios with different forecast qualities are described. The scenarios are compared by means of performance indicators. Ultimately, these indicators serve the goal of examining the operation of OWTs from an economic point of view. Proceeding based on this determination of the urgency of the specified problem, an approach for the improvement of the estimate of the real wave situation is provided. In the context of this contribution, the concept of a decision-making support system for the operative planning of service operations is presented as an approach to solve the problem.

Table 1: Scientific studies in the context of OWE maintenance logistics

Name and title	SB	OR	Sto	SA	IT-Tool
Besnard et al. (2011)		X			
Dai et al. (2015)		X			
Dalgic et al. (2015)	X		X		
Dinwoodie et al. (2013a)			X		
Dinwoodie et al. (2013b)			X	X	
Dowell et al. (2014)			X		
Hofmann and Sperstad (2013)	X		X		
Joschko et al. (2015)	X				X
Martin et al. (2016)	X				
Santos et al. (2015)	X		X		
Scheu et al. (2012)			X		
Stålhane et al. (2015)		X			
Van Bussel and Bierbooms (2003)	X		X		

Legend: Simulation of the operating phase (SB), operational research (OR), stochastics (Sto), system analysis (SA)

4. Previous scientific studies of operative maintenance logistics

There is a large amount of previous scientific studies in the context of decision-making in OWE maintenance logistics. Table 1 lists identified studies and classifies them based on the area they relate to and on their methodology. In the following pages, only the studies from the area of operative maintenance logistics in the OWE context shall be examined in more detail.

The work of van Bussel and Bierbooms (2003) is among the first ones in this context. The processes are examined by means of a Monte Carlo simulation. Besnard et al. (2011) analyses by means of stochastic programming an opportunistic maintenance strategy for preventive maintenance and takes into consideration vessels, as well as, helicopters and the costs for personnel, means of transport, failure and penalties in case of delay. Dai et al. (2015) presents a vehicle routing problem with pickup and delivery approaches adjusted to offshore wind energy and takes into account personnel, material, the weather window, two vessel types, vessel costs, penalty costs in case of delay, and costs of turbine failure. The entire operating phase and its maintenance measures are examined by means of a time series-dependent Monte Carlo simulation by Dalgic et al. (2015). To this end, three different vessel types, as well as, helicopters, and the duration of maintenance measures are taken into consideration. Dinwoodie et al. (2013b) presents a combined decision-making support model for the operative and strategic level based on the methods of the Bayesian network and the event tree analysis for maintenance measures. Hofmann and Sperstad (2013) uses a sequential event-based Monte Carlo simulation for developing a cost-benefit model for corrective and preventive maintenance measures. Santos et al. (2015) examines, in addition to the usual weather, transport and personnel factors, also the corresponding spare part requirements for an OWT by means of Petri nets and a Monte Carlo simulation. In their study, the authors applied an estimated weather model that used the probability of the occurrence of weather windows for an operation. Based on this information, Santos et al. estimates the waiting time for suitable weather windows. In our simulation study, we used real historical data with an hour frequency for the considered OWF location. Stålhne et al. (2015) presents a comparison of different methods. To this end, the methods arc-flow model (branch and bound) and path-flow model (heuristic) are used for examining the optimum routes and operation schedules for the maintenance vessel fleet of a wind park. Dinwoodie et al. (2013a) also compares different methods. They compare two data mining methods for the calculation of the significant wave height and the resulting weather window as well as the resulting limitations for the means of transport. Dowell et al. (2014)

uses a growth model to determine the technical availability of the turbine and identify the maximum waiting time until an operation can be performed. A planning and optimization tool for the system-wide optimization of an offshore wind park in the context of maintenance and its logistics is described by Joschko et al. (2015). In order to determine the operation planning strategy, Scheuer et al. (2012) uses a Markov chain in which the weather windows are determined with the help of the significant wave height. In addition, a differentiation is made between corrective and preventive maintenance tasks. The amount of failure costs is also taken into account. Martin et al. (2016) determines the decisive influence factors for the costs of the operating phase by means of a sensitivity analysis. In this context, they examine three wind park scenarios. In light of the above, it becomes evident that an examination of the impact of the quality of sea state forecasts on operative maintenance logistics has so far not been addressed in the scientific literature. The present contribution seeks to close this gap in the relevant research.

5. Process of operative maintenance logistics

The examinations of this contribution focuses on the CTV service provider. Other relevant players who cooperate with the service provider are the operating company, as well as, the operator of the sea port. The operative logistics process of a service operation for the performance of maintenance measures for an OWT consists of the three main processes: "operation decision", "operation preparation", and "operation execution". Once the operating company has provided an operation order, a consultation between the operating company and the captain of the CTV takes place on the day before the scheduled service operation. In this context, the weather forecast for the next day is checked. Depending on the predicted significant wave height, the operating company decides whether or not to execute the operation. Other wave characteristics, such as wave direction and wave frequency are currently only subordinated criteria for operation decisions. Yet, physical wave models including all wave characteristics are of particular importance for the operational execution (Beinke et al. 2018). The partial process of the operation decision is illustrated in detail in figure 2

After the operation decision, the operation is prepared. This includes the provision of loading equipment for loading the CTV, the provision of the material required for the offshore operation to the seaport as well as the loading of the material onto the CTV. After the operation preparation, the operative transport process or operation execution, respectively, takes place. It starts with another check of the weather conditions immediately before the CTV leaves the seaport. If this new check of the weather conditions turns out that the predicted weather conditions exceed the defined maximum values, the operation is cancelled by the captain of the CTV after a consultation with the operating company. If the weather check has a positive result, the CTV is manned by the scheduled service technicians and heads to the wind park. The technicians are taken to the turbines, cross over to the OWT and are picked up again after the completion of the operation. The CTV waits in the area of the offshore wind park for the duration of the operation and is in permanent contact with the operating company.

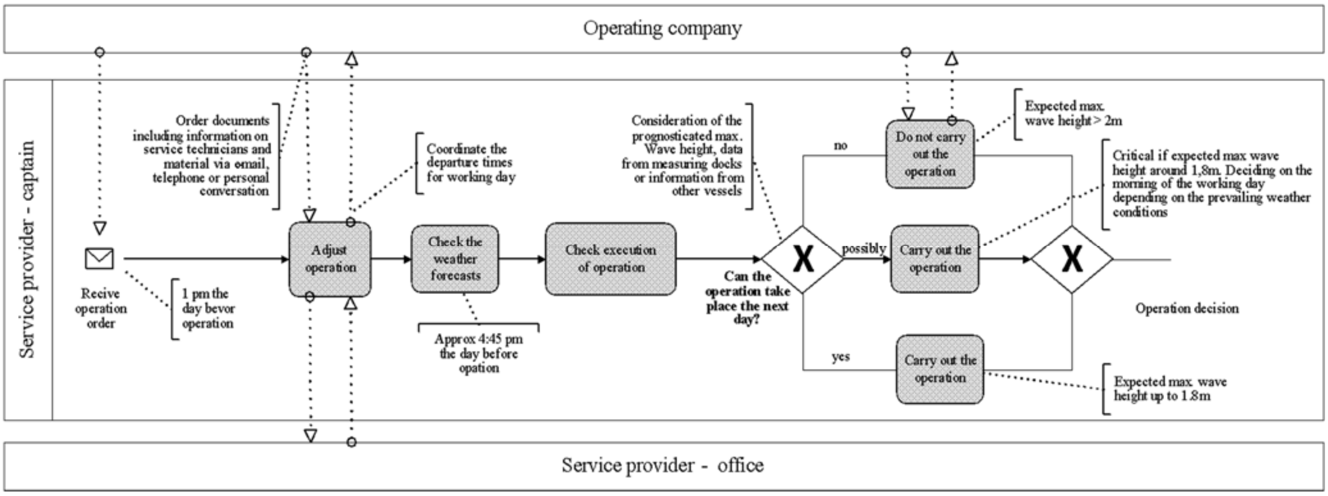

Figure 2: Main process "operation decision" in service logistics

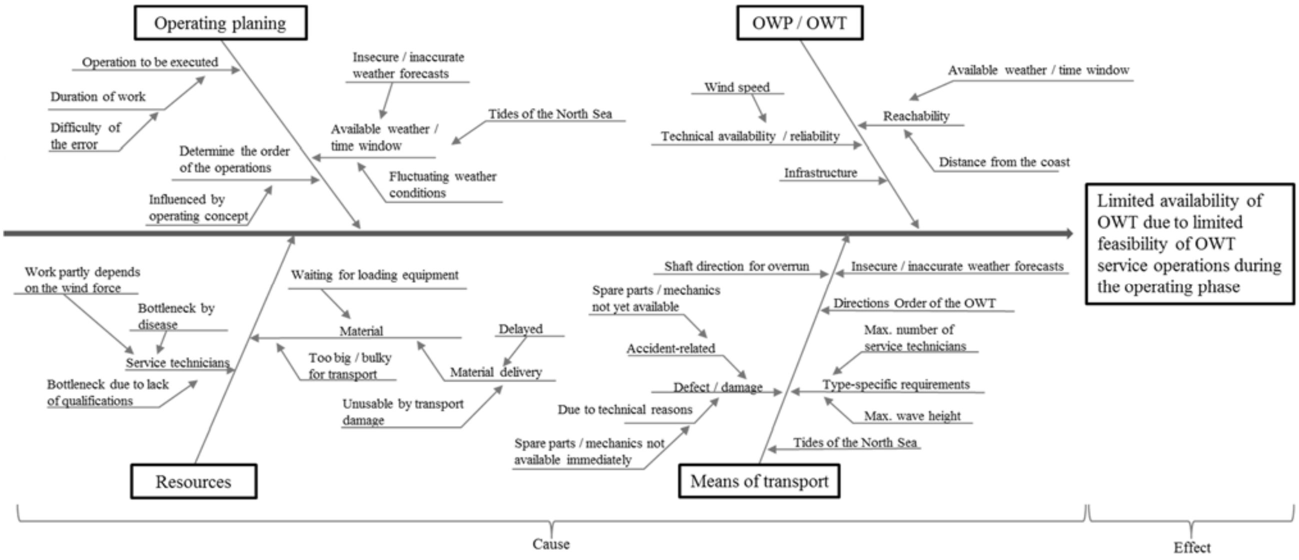

Figure 3: Cause-effect diagram of the service logistics process of maintenance

If the ongoing check of the weather conditions shows a significant deterioration of the conditions or if the CTV has technical problems, the operation will be cancelled, the service technicians will be picked up from the OWEA, and the CTV will return to the seaport.

Due to the already mentioned challenges and restrictions, the ability to perform service operations is highly limited. In the following figure, the process described above is illustrated and examined by means of a cause-effect diagram (cf. Figure 3). In this context, operation planning, the necessary personnel and material resources, the characteristics of the OWT or OWP, respectively, as well as, the means of transport used are the dominant influence factors.

Based on this closer examination, it becomes clear that a large number of influence factors affect the operative logistic process. The weather conditions are an especially decisive criterion for the feasibility of service operations. They contribute as a cause in all four main influence factors, which makes their examination a priority. While they cannot be directly influenced, weather-dependent causes play a decisive role in the planning and execution of service operations, as well as, for the accessibility of the OWT. Higher waves make it more difficult to cross over to the OWT or might even make working impossible over longer periods of time. The weather conditions must also be taken into consideration for the transport of service technicians to the OWP, since sufficiently good weather conditions in the OWP do not guarantee that the necessary conditions also exist on the transport route from the seaport to the OWP. In addition to the wave height and the wave direction, the tides also limit the period of time available for service operations involving a CTV. Due to the inaccuracy of the weather forecasts, determining a suitable weather window always entails a risk. The longer the forecast period, the more difficult and more inaccurate the estimate of the weather and sea state development will be.

6. Simulation study

As described above, the operation decision of the service vessel is made exclusively based on the available weather forecasts for the maximum wave height. Both the operating company and the captain decide on this basis regardless of whether the service operation is ultimately executed or not. Due to its importance for the operative decision-making process, the maximum wave height is used as the sole operation criterion in the following simulation. The object of the following simulation is to determine the impact of the quality of wave height forecasts on maintenance service logistics and on the efficiency of OWT. First of all, the structure and the description of the simulation scenarios are presented. Then, the simulation is specified. Finally, the simulation results are presented and discussed.

6.1. Structure of the simulation and simulations scenarios

The four players or objects, “OWT”, “weather station”, “service provider captain”, and “operating company”, which are interacting with each other, are represented in the simulation. The OWT has random defects generated in accordance with the distribution below (Table 3), and sends service requests to the operating company, and is the destination of the service provider captain. The weather station provides forecasts, which are retrieved both by the service provider captain and the operating company. The operating company restarts the turbine by means of remote maintenance, plans the annual maintenance of the turbine, performs the operation determination which includes weather forecast checks, as well as, the operation scheduling of the service technicians, and sends the service order to the service provider captain. The player service provider captain is in charge of the provision of the vessels, performs the transfer operations, and checks the weather forecast.

The simulation is a discrete event, agent-based simulation. The parameterization of the variables in each simulation run is performed by means of a Monte Carlo simulation. In the simulation model, the actuators of the supply chain are implemented as agents. This makes the exchange of news and information between the players possible. In addition, each agent has its own logic, which has been implemented with the help of a state diagram or process modeling library, respectively. Thirty-five simulation runs were performed for each scenario. For the simulation study, two scenarios were defined which make it possible to assess the impact of an improved wave forecast on the operative logistics process for OWT maintenance. Due to the different points in time at which the operating company and the service provider captain make a decision, this simulation model assumes different deviations from the actually measured wave height values for the different forecast checks. The data on the day before the operation is clearly more dispersed than on the day of the operation (cf. Table 2).

Table 2: Simulation scenarios

	Scenario α	**Scenario β**
Deviation of the forecast by the actual wave height on the previous day	$\pm 20\% \triangleq \pm 36cm$	$\pm 10\% \triangleq \pm 18cm$
Deviation of the forecast by the actual wave height on the working day	$\pm 10\% \triangleq \pm 18cm$	$\pm 5 \triangleq \pm 9cm$

The deviations have a normal distribution, wherein approximately 90 % of all values are in the range of approximately $\pm 0.3m$. Differences can be found in the probability of occurring errors. The smaller the percentages of deviation, the steeper the distribution curves. This distribution is shown in figure 4.

6.2. Simulation specification

The simulation is based on real wave data of the German North Sea from the years 2000-2004. As explained above, defects of the OWT lead to a service request. Based on the relevant literature, four error and/or maintenance classes, which are described in the following table, are taken into consideration for the simulation.

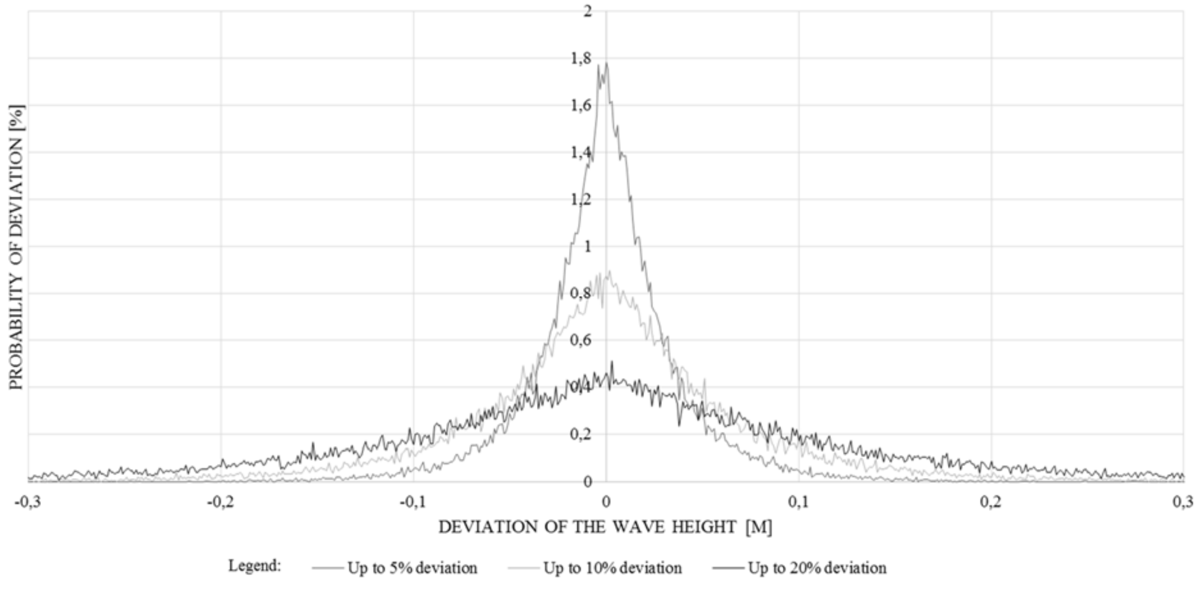

Figure 4: Deviation of the forecasts from the actual wave heights

Table 3: Error /maintenance classes of offshore wind energy turbines (Krokoszinski 2003, Rademakers et al. 2008, Oelker et al. 2016)

Class	Description	Error frequency	Repair time
1 Restart	Standstill alarm, no personnel / no material required, maintenance by restarting the OWEA, no service use	Twice per month	2 hours
2 Small error	Standstill alarm, personnel and tools required, maintenance by short corrective measures, e.g.: Clean rotor blades	Four times per year	6 hours
3 Great error	System failure, personnel, tools and spare parts, as well as a small internal crane, e.g. replacement of the pitch motor	Twice per year	1 day á 10 hours
4 Yearly maintenance	Yearly maintenance	1 time per year, due July1	4 days á 10 hours

In order to specify the simulation, parameters used, the variables and restrictions, as well as, the indicators for measuring the performance shall be presented in the following.

Parameter

N	Number of wind turbines $N = 60$.
V	Set of crew transfer vessels (CTV).
T	Set of technician's teams, with $\|T\| = 8$.
A	Maximum number of jobs to be executed during one travel of CTV, where $A = \|T\| = 8$.
E	Set of failure types. $E = [s\ ;\ b]$.
e	Index of a failure $e = \{s, b\}$
TT	Travelling time of CTV from base port to the wind farm
SB	Time of shift start, $SB = 8h$
SE	Time of the end layer, $SE = 20h$
T_{annual}	Time of annual maintenance
RT_e	Repair duration of a failure of type e, where the repair time is normal distributed.
T	Planning horizon
t	Index of the planning period where $\forall\ t \in T,\ t_{i+1} - t_i = \Delta t = 1h$
wo	Forecast window of the wind farm operator; $wo = 36h$
wc	Forecast window of the CTV captain; $wc = 12h$
LIM_{wave}	Wave limit for the travelling of a CTV
W_t	Wave height in the planning period t
$T_{Operator}$	Decision time of the wind farm operator
$T_{Captain}$	Decision time of the captain
C_e	Estimated repair cost of a failure of type e
C_v	Estimated transport cost of CTV
D_A	Duration of annual Inspection
C_A	Estimated costs of an annual inspection

Variables and Constraints

$List_t$	List of open failures at time t, where $\|List_t\| \leq N$
T_{ew}	Occurrence time of a failure of type e in the wind turbine w
WF_{to}	Wave height prediction at planning period t retrieved by wind farm operator
WF_{tc}	Wave height prediction at planning period t retrieved by captain where $\forall\ t\ \|WF_{tc} - W_t\| \leq \|WF_{to} - W_t\|$
N_A	Total number of annual inspections during the planning horizon T; $N_A = N * \frac{T}{8760}$
$GoOut_{ot}$	Binary variable which indicates if an order for the next day can be created or not based on the weather forecast for the

next time window wo at planning period t

$$\begin{cases} 1, if\ \forall\ t' \epsilon\ [t, \quad t + wo]\ WF_{t'o} \leq LIM_{wave} \\ 0, else \end{cases}$$

$GoOut_{ct}$ Binary variable, which indicates if the captain can leave the base port in direction wind farm based on the weather forecast for the next time window wc at planning period t

$$\begin{cases} 1, if\ \forall\ t' \epsilon\ [t, \quad t + wc]\ WF_{t'c} \leq LIM_{wave} \\ 0, \quad else \end{cases}$$

$DoList_t$ List of open failures to be executed at planning period t, where $|DoList_t| \leq |T| = 8$ and

$\forall\ e\ \epsilon\ DoList_t \Rightarrow e\ \epsilon\ List_t$ And if $DoList_t \neq \emptyset$ then $GoOut_{ot} = 1$

Tr_{ew} Repair time of failure e in the wind turbine w, where $Tr_{ew}\ \epsilon\ [SB, SE]$

$GClist_t$ Repair costs of the open failures, where $GClist_t = C_v + \sum_e^{DoList_t} C_e$ and $GClist_T = C_v + \sum_e^{DoList_t} C_e$

Accordingly the total repair cost is: $GClist_T = \sum_t^T GClist_t$

GD_A Total inspection duration of the annual inspections $GD_A = N_A * D_A$

GC_A Total cost of annual inspections $GC_A = \sum_w^N C_A * \frac{T}{8760}$

N_{out} Number of trips carried out by CTV

$$N_{out} = \sum_t^T GoOut_{ct}.$$

Indicators for measuring performance

Three indicators have been chosen for evaluating the simulation results. The availability of the turbines and/or the wind park gives an idea of how reliable the turbine is. In addition to the MTTF, the MTTR is among the most important parameters for the system availability and indicates how fast the turbine can be repaired after a turbine failure. The goal is to keep the MTTR as short as possible and the MTTF as long as possible. In this context, the accessibility of the turbines or the weather restrictions, respectively, play an important role for reducing the MTTR.

$MTTR$ Mean time to repair of the wind farm

$$MTTR = \sum_e^E \sum_w \frac{1}{|E|} (Tr_{ew} - T_{ew})$$

$MTTF$ Mean time to failure of the wind farm

$$MTTF = \sum_e^E \sum_w \frac{1}{|E|-1} (T_{(e+1)w} - Tr_{ew})$$

$Avail$ Availability of the wind farm

$$Avail = \frac{MTTF}{MTTF + MTTR + D_A}$$

6.3. Simulation results and discussion

For the presentation and discussion of the results, the operation decisions, the MTTR, as well as, the availability of the turbine are examined. The simulation results for the operation decisions are presented in table 4 and figure 5.

Table 4: Average number of trips and wrong decisions of the simulation

Scenario	Number of trips	Wrong decision – operation company	Wrong decision – captain
α	407,29	87,43	1,09
β	448,09	16,20	2,06

On average, the operating company issued 407.29 orders in the simulation period in Scenario α. In Scenario β, which has a higher forecast accuracy for the significant wave height, 448.09 orders and, thus, approximately 10 % more service operations were issued/initiated by the operator. With 1-2 wrong decisions by the captain after the decision of the operating company, the number of wrong decisions is very low and almost negligible. The reduction of non-initiated operation orders by approximately 78.5 % in Scenario β compared to Scenario α, clearly shows the impact of the forecast quality on the decision-making process. These unused weather windows lead to longer downtimes of the turbines and, therefore, directly to higher failure costs. The failure costs per day for a standard 5 megawatt OWT are approximately 13,000 euros (Heidmann 2015). This means that, depending on the number of OWTs for which service orders are to be executed and on the weather-dependent period of time until the execution of the next scheduled service operation, significant failure costs might be incurred even in short periods of time. This is reflected by the availability of the OWTs. In case of the examined wind park size of 60 OWTs with an average OWT operating phase of 20 years, the increase of availability of 0.79 % leads to a reduction of the failure costs by approximately 44.95 million euros.

The examination of the MTTR clearly shows precisely this fact. The average reduction by 21.68 hours per defect leads to a reduction in the downtime per turbine per year of approximately 130 hours or approximately 5.4 days, respectively. This shows that the higher quality of wave forecasts increases the maintenance logistics response time, which leads to a reduction of the OWT downtimes and of the failure costs.

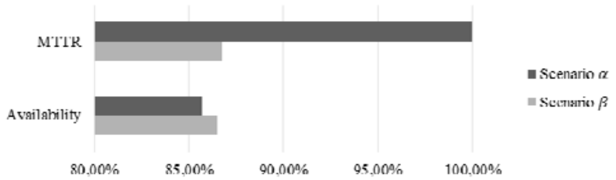

Figure 5: MTTR and availability in the examined scenario

7. Concept of a decision-making support system for operative logistics planning

In light of the simulation results, the need for an improvement of weather and sea state forecasts becomes evident. This improvement can be achieved both through the optimization of the mathematical models for forecast development and through the observation and evaluation of the forecasts, and, thus, through qualitative interpretation. The second option requires a system for the identification of the situation, the processing of the data, and the targeted visualization for the decision-making activities of the individual players in the network. Consequently, such an approach requires, in addition to the system for the presentation of the data, further systems for collecting and providing information. Figure 6 describes the system functions of the intended system (offshore control centre) which supports the operating company and the captain of the service provider in their decision-making process.

The starting point is that the user requests the wave forecasts for the site of the operation. In the next step, the system externally retrieves, based on the operation data, the wave forecasts required by the user. Based on this retrieved data, the system makes the first decision in the decision-making process. If the values of the wave forecast are within the limit, which depends on the means of transport used and is, in the context of this contribution between 1.8 and 2.2 meters of significant wave height, additional forecast parameters relevant to the operation will be automatically retrieved by the system. These parameters include the wind direction as well as the wave direction and frequency. Subsequently, the data will be processed by the system and provided to the user. Based on this, the user has to decide whether the operation decision can be made on the basis of this data or whether further information must be obtained. Such further information includes on the one hand the identification of comparable operations based on specific operation characteristics and, on the other, the inclusion of current data of the target region which is obtained by means of expert estimates of the wave height or by means of a measurement sensor system. Then, this data is processed and presented to the user for the decision-making process.

This approach allows for a successive extension of the basis for the decision, depending on the framework conditions and means that additional information is only provided if needed. However, this system is merely a decision-making support function and not a decision-making system. The reason for this, is the importance of the decision and the specific expert knowledge of the captains, which cannot be completely reproduced in an IT system.

8. Conclusion

In the context of this contribution, the impact of the wave forecast quality on the planning and execution of service logistics processes for OWT maintenance was analysed and a concept for a decision-making support system was presented. The presentation and analysis of the actual average value of a discrete event, agent-based simulation was able to prove that the improvement of the forecast quality for the significant

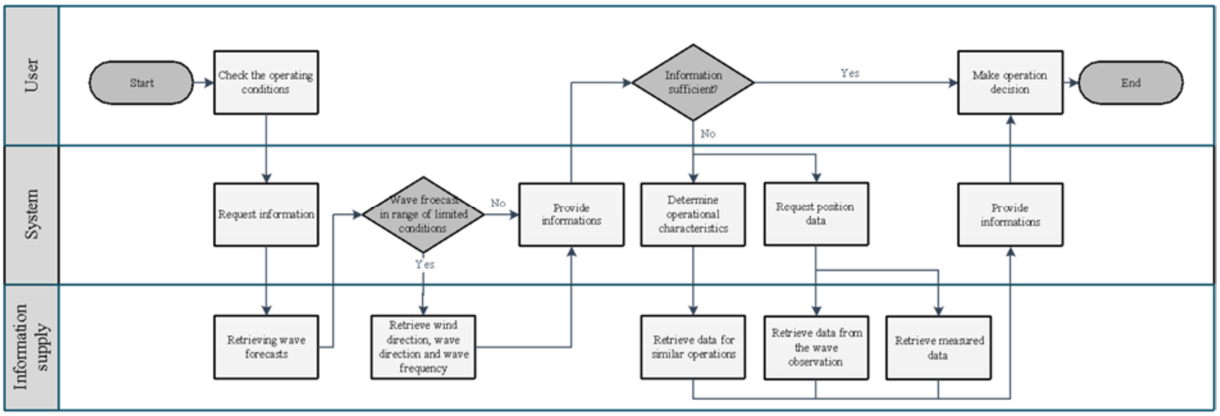

Figure 6: System functions of the offshore control center

wave height leads to a clear increase of the OWT availability and, thus, to a reduction of the failure costs for the examined OWP of approximately 45 million euros.

The decision-making support system presented by way of concept makes it possible to extend the bases for the decision-making process as needed and, contrary to current prior art, provides in a targeted manner a variety of additional information on which the decision-making process can be based. Said system is a mere decision-making support function.

Further research activities that can be inferred from the results of this contribution are the closer examination of the admissible maximum wave values, the impact of waves and the wave forecast on the route of the CTVs, the integration of material and personnel planning into the presented system, as well as, the extension of the simulation in order to identify approaches for condition-based maintenance

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