A SIMULATION TOOL FOR MAINTENANCE PROCESSES OF OFFSHORE WIND FARMS

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ABSTRACT

This paper provides an overview over the technical development of a software suite, designed to visualize, connect and simulate relevant processes of the operation and maintenance of offshore wind farms and combine them with other relevant factors, such as for example stochastic weather generators and other wind farm proprietary aspects important to the smooth running of offshore wind farms.

The complexity of relevant factors for the assessment of the quality of offshore wind farms operation only allows for an overview on how to model and assess that quality as a whole. In that regard, this paper will mainly focus on the technical development and the different stages of depicting and analyzing, from the understanding of relevant players, to the interaction between those, the modeling of complex interactions to the visualization in a software and simulation of business processes. In addition, the choices made for different methodologies, such as the business process notation BPMN 2.0, or simulation relevant techniques will be presented, including the given reasons for the choices made.

Keywords: Business Process Simulation, BPMN 2.0, Offshore Wind farms, Meta Modeling

1. INTRODUCTION

After the successful realization of initial offshore wind farms such as Alpha Ventus (Germany), Horns Rev (Denmark), and Thanet (UK), numerous offshore wind projects worldwide are either in the planning phase or already at the construction stage (Klinke, Klarmann & Kodali 2012).

While the onshore wind energy technology has seen a ten-fold reduction in cost over the last two decades and is now competitive with fossil and nuclear energy in many areas worldwide (Musial, Butterfield & Ram 2006), the offshore wind energy branch is still in its early stages, especially as long term projections considering the higher costs for maintenance and servicing are only achieving scientific significance. Nonetheless, there is a broad consensus about their key role in achieving the climate policy targets and the associated energy turnaround (especially for Germany). The absence of suitable locations for large onshore wind farms and the possible higher output offshore is contributing to this fact. The goal of the German Government is to produce approx. 25.000 MW output through offshore wind farms by 2030, which is more than all German nuclear power plants are currently producing. Considering the whole European Union a similar rise in power production can be expected - from approx. 1.400 produced MW in 2009 (see Figure 1) to approx. 37.000 MW produced by the end of 2015 (Figure 2).

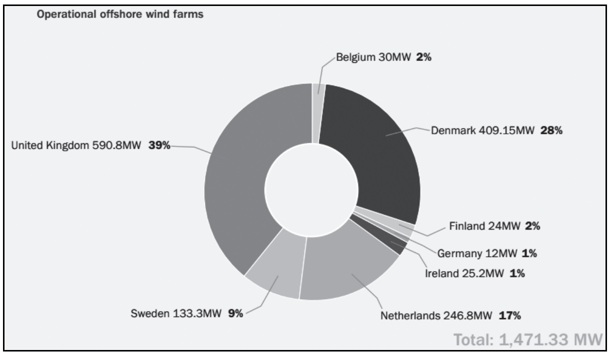


Figure 1: Operational wind farms 2009 (EWEA 2009)

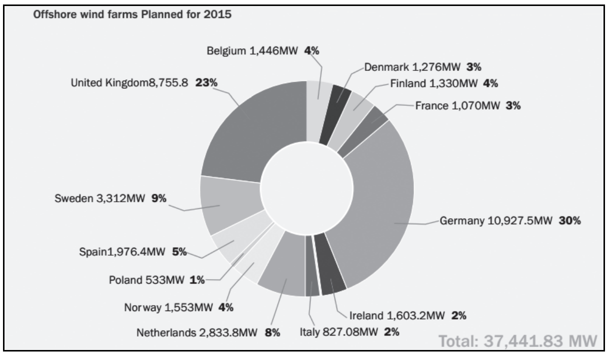


Figure 2: Planed wind farms for 2015 (EWEA 2009)

Most of those newly planned offshore wind farms, at least for Germany, will be located much further out compared to the "near shore" farms from Denmark. This poses new challenges regarding accessibility and the planning of maintenance. Financiers of new wind farms are typically interested in the expected aggregated mean wind energy yield for a future operating period (usually 10–20 years) (Albers 2004; Bakker & van den Hurk 2011), due to the experience from existing installations however, the costs and the amount of uncertainties related to the maintenance processes gain more and more relevance. The decisive factor for the success of these and future offshore wind farms is hence to effectively address the technical challenges and ensure economic feasibility (Klinke, Klarmann & Kodali 2012).

The following sections address the outlined challenges in presenting the project SystOp Offshore wind, which main aim is to analyze relevant process and players, as well as build a software suite for the modeling and simulation of the smooth operation of offshore wind farms.

2. PROJECT SYSTOP OFFSHORE WIND

2.1. Objectives and Partners

The project SystOp Offshore Wind is a three-year joint project financed by the German federal ministry of the environment (support code: 0325283), nature conservation and nuclear safety. It is conducted by the University of Applied Science in Bremen, the University of Hamburg, as well as the BTC AG, and the IZP Dresden. The first objective of the project is to map the relevant players and research their interaction, including the capturing of all resulting business processes that have an influence on the continuous smooth running of all needed maintenance activities of offshore wind farms (Joschko et Al. 2013).

2.2. Data Acquisition and Process Mapping

The capturing of the business processes in question was done on different levels (Figure 3) and subsequently in different detail. Level 1 includes the different (project-) phases of an entire offshore wind park, whereas SystOp Offshore Wind considers the particular case of the operation phase more precisely the execution process of the maintenance.

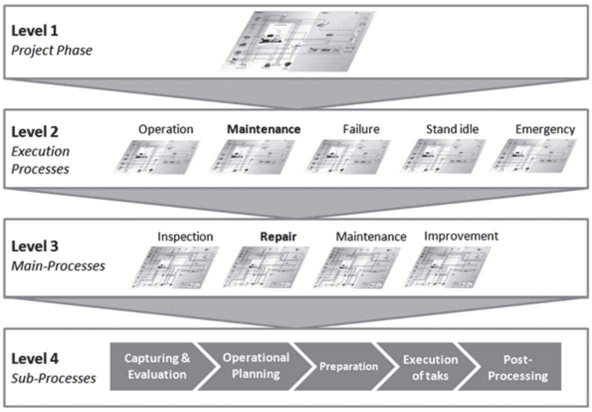


Figure 3: Process levels of SystOp Offshore Wind (Joschko et Al. 2013)

All execution processes corresponding to the operation phase are specified in level 2. They are interconnected and interdependent within the accordant phase. The next hierarchy of processes is shown in level 3 these are the main processes, which do not proceed in a chronological-logical sequence. The sub-processes in level 4 however do occur in a chronological and consequential progression; in case of a maintenance operation these are capturing & evaluation, planning and others. Different subdivisions in further levels below enable a more detailed description of the main and the sub-processes.

In order to gain access to the process in question several market players out of the wind park sector were contacted, such as operators, service companies, owners, transport companies, harbors, airports and employment companies. Some of them contractually agreed to give insight into their perspective of business processes, their resources and their data. A questionnaire was designed including general questions about tasks, resources and typical problems, which provided a substantiated code of practice to describe the project demand for all participants. In successive on-site visits the understanding of the individual business processes, with a focus on interfaces to other stakeholders, was intensified. This included reviews of the already depicted processes with stakeholders over different meetings, regularly workshops and meetings with all industry partners to discuss intermediate results.

Following the description of the processes, they were analyzed in order to deduce critical elements, such as resources or influences on other processes including feedback loops. The main purpose of the processes depiction was to establish an objective basis for communication between the partners that further enabled and evaluated the importance of different stages as well as critical aspects that should be taken under special observation. The different levels of communication and layers of cooperation were thus made more transparent, enabling a higher security considering long term planning and projections.

2.3. Approach for the Modeling and Simulation

The modeling and simulation of the operation of offshore wind farms in this project can be understood bipolar, as the software is, on the one hand able to run already established business process simulation, and on the other hand, in combination with different additional software packages, go beyond their limitations. In order to have a broader approach and pay tribute to the different uncertainties different editors were designed (as section 3 will elaborate), such as wind turbine and component builders that would, placed in a wind farm model and enriched with the appropriate probabilities then start events, which only then start different business processes and, again in dependence on other models have different possible outcomes. In that regard a multitude of different software tools have been connected to allow for the simulation of a continuous operation of different wind farms.

3. BUILDING A SOFTWARE SUITE FOR THE MODELING AND SIMULATION OF THE OPERATION OF OFFSHORE WINDFARMS

3.1. Overview

The design of the software in question was made following a domain specific approach including a multitude of different software packages (see Figure 4).

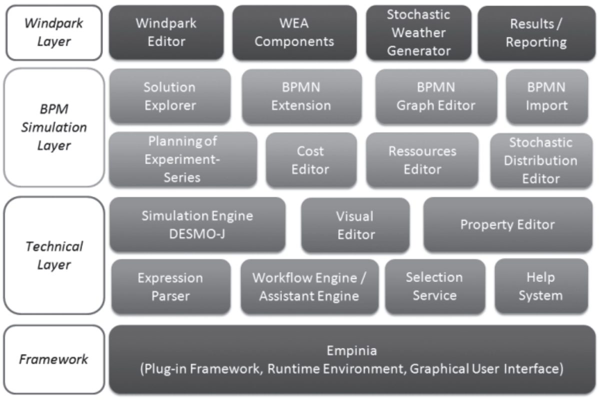


Figure 4: Domains and Services of the main Application

There are four main conceptual layers of the software; the first and the second building the technical backbone(s) as the first layer is the framework enabling the different parts to interact via a plugin mechanism (see section 3.3.1), while the second layer encompassed the simulation engine and other helping systems allowing for the different parts to work efficiently together. The third layer is the process simulation layer, which enables the actual description of the business processes, as well as their interaction and aspects like import/export functionalities of existing business processes. The fourth layer is the wind farm layer, which allows the modeling of different wind farms, including the actual components and their probabilities of failure within the different turbines, as well as additional information considering location and accessibility. The different parts will be further explained in the following sections.

3.2. Scope of Services

3.2.1. Business Process Modeling and Simulation

To document the sequential activities and interactions, the Business Process Model and Notation (BPMN) 2.0 was chosen, which represents a sufficiently formalized graphical notation for business processes. BPMN 2.0 brings out the differentiation of sequence flows, which describe the order of activities within the processes of an organizational unit, and message flows, which describe the interaction between processes of distinct organization units. This aspect contributes to the main focus of the project in order to discover interactions between the stakeholders. The message flows can represent material, data, communication, waste or cash flows. Additionally, there is a huge set of elements, which cover diverse modeling constructs, e.g. there are different kinds of events, particularly attached events, which are able to abort the execution of an activity.

Figure 5 shows an example of a process modeled in BPMN 2.0, which describes the execution of maintenance jobs. The three pools represent the different stakeholder operation office, service units and the carrying businesses shipping respectively helicopter companies. The edges between the pools represent message flows, e.g. the service unit updates the operation office about each single step of the operation as they are starting maintenance, identifying errors, estimated duration, abortive or successful maintenance. While rectangles represent single activities or sub-processes, circles represent events such as a start respectively end occasion, incoming direct messages, broadcast messages, cancelation or compensation.

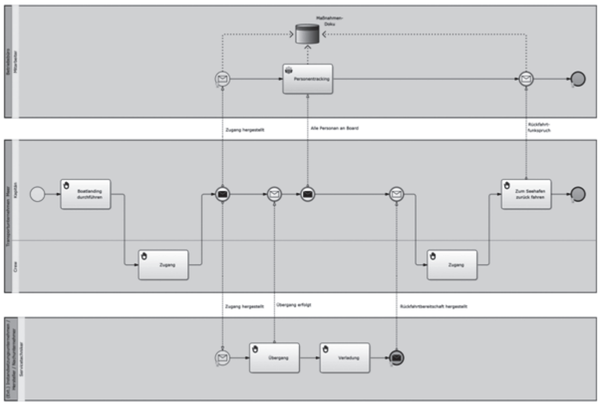


Figure 5: Return after a maintenance job in BPMN 2.0

Additionally to the BPMN process description there are different other tools within the BPMN Simulation layer, such as an editor enabling the setup of resources, which can be used in the simulation to analyze degree of capacity utilization, and attributed necessary probabilities, as well as be responsible for possible bottleneck scenarios. Furthermore there is an editor for choice and usage of different stochastic distribution needed, which includes the possibility of describing relations such as 1 to n connections or probabilities that different flows are chosen according to the distributions in question. Moreover other tools may be used to design and make BPMN 2.0 models which can be imported via XML import/export interfaces (while in accordance with the notifications).

In order to combine the different model types (BPMN just being one of them) a solution explorer was developed. It enables the user of adding different models in one solution, such as a number of BPMN models, wind farm models, generators and any other component each of those models are using without them being integrated within them.

Lastly a component was designed to facilitate a series of experiments integrated in a single simulation run, in order to speed up the achievement of well-established results.

3.2.2. Wind Farm Modeling

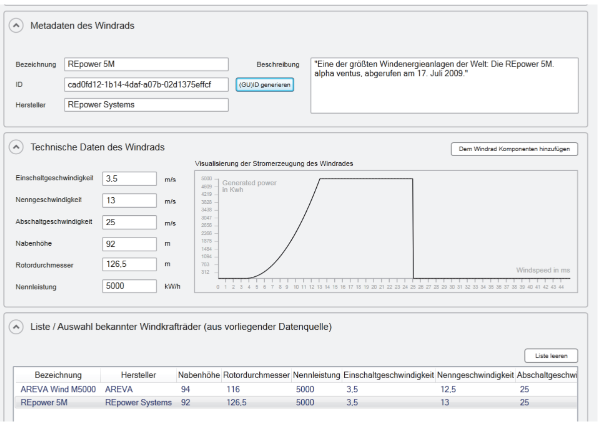
The modeling of wind farms in done on three different levels, namely the farm itself, its turbines and their respective components. These levels are manifested in the software by three different editors all accessible from each other. The main purpose is to allow for both, a simplistic approach for fast definition of a wind farm and, in case extensive data is accessible, to allow a detailed definition of the components and turbines in question, including their probabilities of failure.

The definition of wind turbines also allows the modeling of their respective energy output and hence allowing the depicting of the energy output of whole farms.

According to Karki and Patel (Karki &Patel 2009) the mathematical relationship between the wind speed V and the generated power P can be given as:

$$P = \begin{cases} 0, & \text{if } 0 \leq V < V_{ci} \\ P_r(a + b \cdot V + c \cdot V^2) & \text{if } V_{ci} \leq V < V_r \\ P_r, & \text{if } V_r \leq V < V_{co} \\ 0, & \text{if } V_{co} \leq V \end{cases}$$

where Pr is the rated power output of the wind turbine (Byon et Al. 2011). Following the elaborations from Byon et Al. the wind turbine editor was designed and is able to depict the actual power output in real time, once the necessary input data is given (Figure 6).



Bezeichnung: REpower 5M
ID: cad0fd12-1b14-4daf-a07b-02d1375effcf
Hersteller: REpower Systems
Beschreibung: "Eine der größten Windenergieanlagen der Welt: Die REpower 5M. alpha ventus, abgerufen am 17. Juli 2009."

Einschaltgeschwindigkeit: 3,5 m/s
Nenngeschwindigkeit: 13 m/s
Abschaltgeschwindigkeit: 25 m/s
Nabenhöhe: 92 m
Rotordurchmesser: 126,5 m
Nennleistung: 5000 kW/h

Bezeichnung	Hersteller	Nabenhöhe	Rotordurchmesser	Nennleistung	Einschaltgeschwindigkeit	Nenngeschwindigkeit	Abschaltgeschwi
AREVA Wind M5000	AREVA	94	116	5000	3,5	12,5	25
REpower 5M	REpower Systems	92	126,5	5000	3,5	13	25

Figure 6: Wind turbine editor

The calculation of the power output is of course of great relevance for the calculation and prediction of the viability of maintenance processes at different times and different seasons, as the profitableness is logically in dependence of the wind speed, which again is within a measure of probability in accordance to different times of the year and different weather phenomena (see 3.2.2).

The wind turbine editor is hence used to connect the wind farm and the multi-model with data considering the power output, while the wind turbine component editor is used to describe the different components of a wind turbine, as for example rotor blades, brakes, generators or pitching systems. This includes meta-information, such as the manufacturer or the costs, as well as the probabilities in which occurrence the component is likely to fail and hence either reduce the power output of the wind turbine or render it completely inoperative. The precise technical and physical properties of each component (for example persistence of a component opposing the erosion due to weather and wave conditions) are not being modeled and are, at this point, not part of the simulation. The probability of failure can however be understood as the representation of the sum of conditions leading the component to failure, and hence include most or in the best case all of the relevant factors. The analysis if maintenance processes are required or if it would be more profitable to group, wait and reschedule them, wait for another event to occur, etc. can then follow such a failure event.

Lastly the wind farm editor is mainly an editor used to assemble different wind turbines and describe their position and Meta information, such as for example the longitude and latitude of the park, or even turbines. The positioning of the turbines has not yet been developed but is thought of to be implemented if demand is there. One can consider different scenarios where maintenance crews are going to stay out on sea for more time consuming work, the time needed to travel from one turbine to the next may become relevant in that regard.

3.2.3. Stochastic Weather Generator

As another main component in the wind farm layer, but autonomous domain implementation the stochastic weather generator is able to analyze data from historic sources (depending on the notation) and extract distributions from there, including, with the help of various different scientific sources, generated new sets of data in order to supply the simulation with realistic weather data.

In the past decade, much attention in the climate change researches has been focused on the potential impacts on temperature and precipitation. Recently, a growing number of studies have looked at potential impacts on renewable energy resources, and on wind power (Sailor et al., 2008). For example, it was found that wind power potential throughout Finland might increase by 2–10% under conditions of climate change Pryor (Pryor et al., 2005) has found that annual wind power potential over Northern Europe under the IPCC A2 and B2 scenarios was highly dependent on the boundary conditions used in Rossby Centre coupled Regional Climate Model (Yao et Al. 2012). Acknowledging these insecurities and different scenarios and realizing the necessity for adaptations in the future and a flexible model for possible weather scenarios different existing editors were sighted for their integration in the existing software suite.

In the end the decision was made for different components of the CLIMA composite component. CLIMA is a software, made of basic components containing routines to produce synthetic values of the most relevant climate variables (precipitation, air temperature, solar radiation, vapor pressure deficit, wind speed, reference evaporation/-transpiration) from existing daily weather data, largely based on approaches already implemented in weather generators (e.g. ClimGen) and other data analysis tools (e.g. RadEst). Daily values of precipitation, air temperature, and wind speed are generated from stochastic processes. For other variables, such as solar radiation, vapor pressure deficit, and reference evaporation/-transpiration, synthetic values are produced by physically-based relationships. The routines for weather generation/estimation are implemented into sub-components: Rain (precipitation) AirT (air temperature), GSRad (global solar radiation and related variables), Wind (wind speed), ET (reference evaporation/-transpiration and related variables).The component implements the test of pre-conditions and post-conditions for each of the models provided, allowing an input on screen, TXT or XML file; custom output drivers can also be developed. Moreover, data sets used to perform unit tests on each of the models made available is also provided as part of this documentation (CRA 2005).

Even though there are newer approaches on how to access the wind speed and relevant information for long term projections of different weather scenarios (see Bakker & van den Hurk 2011 for example) the components were mainly used due to the easy integration in the existing software (same programming language, component orientated development approach), as well as the flexibility the software package enables. It already incorporates different calculating strategies and different approaches on how to calculate future weather scenarios and datasets, the extension of the software packages by new strategies and other distribution is hence given and made easy.

3.3. Connection of the different Model Types

The connection of the different sub-models was a great challenge due to the different nature of the BPMN, Wind farm proprietary and weather proprietary aspects. A general approach to combine the heterogenic models with BPMN process models was found. The BPMN notation offers a field (Extension Elements) where different kinds of information can be attributed to the element in question. Through this inherit property specific activities or events can be defined which can be attributed, replaced or connected to different model types. For example it is possible to create different kind of signal events, which can receive signals from wind farms (the models) and if the criteria are met, launch different processes, much as reality would be for a real supervising instance. In order to unlock the full potential of that combination slight adaptation to the BPMN 2.0 notation were made. Furthermore adaptations for the editor able to combine, and hence display and change BPMN 2.0 models with the wind farm proprietary elements, were done. Figure 7 displays a wind farm signal event that would be used to send a malfunctioning signal, as well as a wind farm state manipulation activity with which could rewind the process of a wind farm component. In addition, a weather signal can be used to announce changes of weather conditions and there is the possibility to receive weather proprietary information on a gateway and let those influence the actual way the process would take. For example a change of weather conditions can influence the decision if a ship or a helicopter would be taken, or if the maintenance process can happen at all.

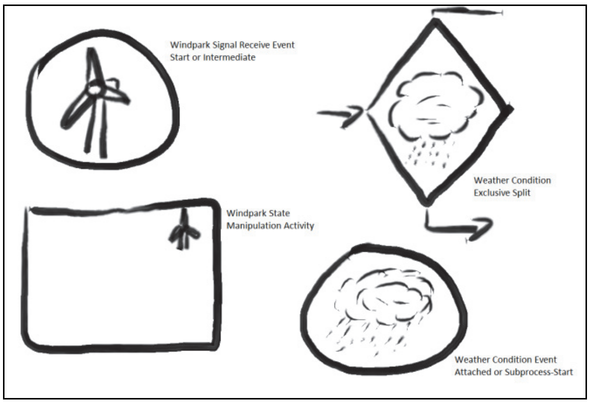


Figure 7: Domain specific BPMN extensions

The newly developed BPMN editor allows for the integration of such domain specific elements through especially designed extension points. Apart from the visual representation of the entities, the code requires a class that is contributing an instance of the domain specific sub model and creates the necessary references between the sub model instance and the BPMN processes.

3.4. Technical Basis of the Software

3.4.1. Framework EMPINIA

As software-framework the software EMPINIA was used, which is an open-source plugin-framework specially designed for rapid component-orientated domain-specific application development. It is based on .NET Technology and notably C# as programming language. EMPINIA is freely available under http://www.empinia.org. EMPINIA supports rapid application development with a highly extensible RCP, like Eclipse (http://www.eclipse.org), based on the Microsoft .NET technology.

The main function of the EMPINIA framework is to offer a plugin mechanism where developers can add any kind of extension. An extension is always added to an existing extension point. Extensions themselves can be further extended if they define their own extension points. EMPINIA provides modules for designing an application with graphical user interface (GUI) and other standard software components (such as the graph editor and the property editor) (Jahr, Schiemann, Wohlgemuth 2010).

The usage of this framework enabled the concentration on the specific problem domain instead of doing repetitive software developing tasks, such as persistence, logging, application and user settings, message notification and user interface design. Many components as different visual editors or selection services were already integrated and ready to use.

3.4.2. Simulation Engine DESMO-J

As simulation engine DESMO-J was used. DESMO-J (see http://desmoj.sourceforge.net/) is an object-oriented framework, targeted at programmers developing simulation models. The choice was made as DESMO-J supports both, the process-oriented and the event-oriented modeling style, also known as process-interaction approach or event-scheduling approach, respectively, which contributed to the development of different model/domain types.

By integrating the mentioned DESMO-J engine, and adjusting it to work with the modeled business processes, critical system sections could already be tested and information on running times were delivered, as well as waiting periods, identification of non-valid modeling, i.e. errors in the modeling process itself considering the depicted business processes.

4. EXPERIMENTATION AND RESULTS

4.1. Beginning of the Experimentation Phase

As with most simulation projects the data basis is an ongoing challenge, even though, due to the well established connection with partners in the wind farm industry and consulting industry related to offshore projects, the data considering the runtime of activities is looking promising, the data basis for the costs is currently still posing problems.

The experimentation phase is, due to the early stage of the project, only at the beginning, but first simulation runs were made and are expected to continuously take a greater part of the ongoing research. The current verification process is still reduced to the BPMN models, as the connections to the different sub models is not yet fully operational, or rather, its data cannot yet be verified.

4.2. Provisional Results

Without the connection of the sub models, different modeling errors in the existing processes could already be identified. This includes, among syntactic errors, also hard to find deadlocks (at which for example a process would wait for a message from another process without chance of ever getting it, as the process in question already terminated).

At this moment in the project, apart from the continuous development, the work is being shifted to control all known processes that have a stable data basis considering the runtime of activities and enrich their gateways with the concrete requirements for the decision making process.

4.3. Expected Results

Through the connection with the sub models a well defined load can be put on the O&M processes. In that regard results can be (and are particularly already) created considering the frequency of the processes as well as the runtime and resource usage of the processes. In light of these results the plausibility of the processes can be verified.

For an effective maintenance strategy a sound aggregation of work assignments is mandatory, for example needed repair work can be timed in accordance with close, already scheduled, regularly maintenance assignments. Such an aggregation happens currently in many cases in accordance with the logic of the deciding personal, but is, in most cases, not the result of a wind farm spanning simulation output. This aggregation of possible work assignments is an important, yet to be accomplished task in the underlying project. It is expected that, once this feature has been developed, different maintenance strategies (corrective, preventive, state/condition based) can be compared and proactive recommendations can be deduced. The planning for this feature is to have first presentable approaches by the middle of 2014, including the tested implementation.

5. CONCLUSION

One year before the project SystOp Offshore Wind is ending first results become presentable; it was managed to gather large amounts of process models of O&M-practices from actual existing performances. These models were depicted with aid of the BPMN 2.0 notation and in order to simulate them, a software suite was developed that is not only able to represent and simulate the BPMN models but also combine them with domain specific sub models in order to represent the reality of an operating offshore wind farm and needed (or existing) maintenance processes. The notation was therefore expanded with a few new components.

The simulation can already indentify syntactic modeling errors as well as critical deadlock situations. The data basis however is still lacking, due to the fact that data for the costs of different activities is rarely made public and even the involved industry partners do not always want to share this kind of sensible data. Yet, the basis is sufficient for first plausibility tests considering the runtime and frequency of tasks. The results from such tests are continuously being discussed with experts from the offshore industry or consulting partners. Once that this phase of testing and adjusting will finish, a strategy comparison by means of aggregation of different maintenance tasks is scheduled as next phase.

The simulation software was designed in a way to allow for high flexibility and an easy integration of different domains. In that regard work is intensified considering the creation of new extensions of BPMN-models (and notation expansions), especially for the logistic sector, which will be usable for coming operational scenarios not only in the offshore wind farm sector. The persistence level was meant to pay tribute to the high flexibility and is hence completely based on XML, allowing for different strategies and adaptations in the future.

Additionally the usage of the software is discussed as support for the decision making in the operational phase of existing wind farms. While the software is currently primarily envisioned to be a safeguard and verification tool of existing process models, it is possible and likely that the focus will shift to a tool which can support maintenance strategy decision-making in the future.

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