Evaluation of complex system structures in maintenance processes at offshore wind farms

Saskia Greiner¹, Henning Albers², Jorge Marx Gómez³

Abstract

The evaluation of complex system structures has to address the question “Can the model give a true and correct view of the real situation?” The model has to be investigated with regard to functionality, completeness, correctness, reliability and usability.

The offshore wind farm in maintenance status is an example for complex system structures. Furthermore the offshore wind farm is not organised as one single company with usual business processes. It is the enterprise offshore wind farm with a lot of stakeholders which help to operate and maintain it. So the requirements for process management are really special. In this paper the process structure of an offshore wind farm is shown firstly. Suitable evaluation criteria for demonstrating the correct view on the offshore wind farm processes in maintenance status are selected. The review and evaluation by business experts as well as the case and field study are the best evaluation methods in the project environment and for proving the criteria. The evaluation shows that the results for OWF structures and models are appropriate for transfer and application at offshore wind farms.

1. Introduction

At the end of each project results and products have to be investigated with respect to project aims, benefit for user, quality and effectiveness. Appropriate evaluation methods have to be selected. But what are the best evaluation methods and what are criteria which fit to the system under investigation? This depends on the research disciplines, the used research methods and the kind of the developed results and products. In principle proper criteria of evaluation must be selected and an evaluation matrix has to be determined. Possible criteria are functionality, completeness, correctness, reliability or usability. [In accordance to 12, 19]

In particular the evaluation of models for complex systems has to address the question „Can the model give a true and correct view of the real situation?” For more transparency complex systems have to be structured in smaller subparts. But the subdivision of the system involves the risk to falsify the reality, e.g. by lost crosslinking of system elements.

The paper discusses the evaluation approach for the structure of complex systems at selected offshore wind farm maintenance processes. It describes the subdivision of the system offshore wind farm in hierarchical process levels down to the process models firstly. Moreover the process characteristics of the structure like the throughput time or the number of staff of an activity will be shown. The quality criteria for evaluation of this OWF structure and their evaluation matrix will be explained. On this basis proper evaluation methods will be selected to improve these criteria. Using this evaluation the image of the model of OWF maintenance processes’ structure is proved. The model limits, like level of detail or static display of processes, are described. Furthermore the

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easy comprehension of the model is given for involved parties, like strategic and operational management or service provider.

2. Models of complex systems

2.1. General

Complex systems have a high number of components which are connected. These components can contain subsystems. [5] Complex systems have to be divided in communicable, transparent and comprehensible sections for a better understanding and system design. Therefore the system will be clearly isolated from its surrounding environment and converted into a model. The system limits have been reviewed under the following headings: determination of the application perspective and objectives of process definition as well as determination of process limits and essential objects within the company, which have to be defined in their behavior. [15]

The model is an image of the reality and reflects the characteristics of the system clearly under consideration of investigation purposes [in accordance to 11, 4]. For this the process modeling of a system is of particular importance. The process models describe the interaction of human, equipment, material, methods and information within the system. On the one hand they reduce the complexity and they underline relevant system elements on the other hand. [20] The modeling finishes with sufficiently complete, detailed and correct depicted parts of the system under consideration of the application case. [15, 8]. Objectives of system modeling are derived from company or project aims. Examples are the business process optimization or the development of a specification sheet. [2] The modeling leads to systematized and transparent processes. Hence, hierarchical structures can be reduced and the communication in and between companies can be improved. [20] The model quality depends on the reflection of the reality in the model and the consideration of the modeling objectives as well as the clearness of the model depiction. Furthermore the chosen modeling language is important for clearness and comprehensibility of models. [8]

2.2. The Offshore Wind Farm

An example for a complex system with complicated process structure is the maintenance process at offshore wind farms (OWF). More than 30 stakeholders and different infrastructures are involved which interact in numerous ways and in a wide range of processes. [10] Furthermore the operation and maintenance of OWF in the 20 years operation phase is cost intensive within ranges of 12-19 €ct/kWh [13]. The cost effectiveness has to be improved by reduction of operation costs. One approach is the optimization of process designs of operation and maintenance (O&M) because of potential losses from defective and uncertain processes [18]. The process design means the organizational and organizational process structure of O&M. Today this process design will be not paid enough attention in the planning and development phase as well as during the operation phase, although it affects the availability of OWF and the maintenance costs significantly. The experiences at OWF operations show that the maintenance processes have a lot of stakeholders with a complex interconnection structure and spontaneity as well as lack of plannability. So an effective and efficient process design for maintenance processes is required.

Modeling requirements and objectives

OWF maintenance processes cannot be characterized as usual business processes of one company with focus on the internal commercial processes. A lot of different stakeholders are involved in the maintenance processes of an OWF. They are highly interconnected and the processes can be very complex. Modeling has to reflect on this specific situation.[in accordance to 6]
The modeling objective will be defined as: Development of an OWF-independent, transparent and structured depiction of all processes, parties involved, infrastructure and interfaces in maintenance. The model has to be comprehensible and readable for the parties involved. It is the foundation for further process optimization by risk analysis and process simulation. The risk analysis needs information about the processes like parties concerned, activities with their duration time and resources, interactions, used material, machines and work method as well as environment. This affects the selection of process modeling language.

**System structure**

The maintenance operations at OWF include a large number of processes. The processes have to be structured and incorporated in a process hierarchy. This OWF specialized process hierarchy (fig. 1) is based on regulations and standards of the offshore wind industry, engineering industry and quality management in particular.

![Figure 1: OWF-specialized process hierarchy](image)

The status “maintenance” of an OWF contains the four main processes inspection, maintenance, repair, improvement [7]. All these main processes are further divided into the sub-processes determination of requirements, mission planning, preparation, execution, inclusive outward journey / residence, execution on-site and return journey and post processing. [14]

The structure of stakeholders, infrastructure and interconnections of the offshore wind farm in maintenance is shown in figure 2. It is divided into onshore and offshore sections. The icons are parties concerned and infrastructure. The arrows between them are on the one hand the interfaces and the interactions on the other. The interactions are defined as staff, material, waste, finances and information.
The process map of OWF maintenance (fig. 3) shows the structure of maintenance sub processes. The actual picture of sub processes is based on the individual requirements and demand of work as well as different transport devices (blue boxes). The example “Repair of small components process by using a personnel transfer vessel (PTV) and executed on-site by wind turbine manufacturer” is displayed in deeper blue colored boxes. [10]

The sub-processes are modelled in the process modeling language Business Process Model and Notation (BPMN 2.0). The language is a standardised graphical process notation, which can be used for process automation also. It is developed for easy readable process models as a communication basis between business and IT experts. [9] Because of the different OWF stakeholders comprehensible process models are a requirement for the process depiction of an OWF. As an example figure 4 shows the process model for return journey by using a personnel transfer vessel.

Each party concerned is displayed in the pools (blue lanes). A deeper division of them in different departments or persons is also possible, as such captain and crew of sea haulier. The pools are commented with the tasks of the different companies. Each pool begins with a start event and finishes with an end event. Activities are running sequentially among them. The different interactions of an OWF in maintenance status are marked in defined colors, such as black for information flows. The detailed models are backed up by information about human and technical resources, time intervals and durations.
3. Evaluation criteria and methods

Evaluation tests if the models reflect the real behavior of the investigated system with sufficient correctness. That means: Do we have the correct model in consideration of the modeling objective? The most important evaluation criteria of models are completeness, consistency, accuracy, currency, applicability, plausibility and clarity [16, 12]. The principles of good modelling are reflected by these criteria. The validity check of models can be worked out by many different techniques. For choosing the correct technique the expenditure of evaluation, the purpose and the
objective of the modeling as well as the characteristics of the model and the knowledge of users or availability of information have to be considered. [16, 12] The evaluation criteria and their central questions are combined in Table 1.

<table>
<thead>
<tr>
<th>Evaluation criteria</th>
<th>Central questions</th>
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<tbody>
<tr>
<td>Completeness</td>
<td>Are there any missing information or requirements?</td>
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<td></td>
<td>Are the models sufficiently precise in consideration of requirements?</td>
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<td>Consistency</td>
<td>Are the semantic relations coherent?</td>
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<td></td>
<td>Is the structure conclusive?</td>
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<td></td>
<td>Is there a consistent terminology?</td>
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<tr>
<td>Accuracy</td>
<td>Has been the modeling correctly and carefully conducted?</td>
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<tr>
<td>Currency</td>
<td>Is the information valid in time and content for their application?</td>
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<td></td>
<td>Are the models valid for the task?</td>
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<tr>
<td>Applicability (Functionality, Usability)</td>
<td>Are the models suitable, accurate and usable for their intended use?</td>
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<td></td>
<td>Are the models appropriate for the task?</td>
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<td>Have the models a good performance?</td>
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<td>Are the models usable for the users?</td>
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<tr>
<td>Plausibility</td>
<td>Are the relations suitable?</td>
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<tr>
<td></td>
<td>Are the models appropriate for the application?</td>
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<tr>
<td>Clarity</td>
<td>Are the models comprehensible and readable for the user?</td>
</tr>
<tr>
<td></td>
<td>Is there a transparent model?</td>
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<td>Are the models clearly formulated?</td>
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Table 1: evaluation criteria for system models (in accordance to 16, 12)

4. Evaluation of the OWF process model in maintenance
The evaluation of the OWF process model has to address the question „Can the model give a true and correct view of the real situation?” For more transparency the OWF system was structured in smaller subparts. But the subdivision of the system involves the risk to falsify the reality, e.g. by lost crosslinking of system elements. The modeling objective is “OWF-independent, transparent and structured depiction of all processes, parties involved, infrastructure and interfaces in maintenance as a foundation for process optimization by risk analysis and process simulation.”
This was achieved by the hierarchical process structure for operation and maintenance (fig. 1), the system OWF in maintenance status (fig. 2), the process map for variable combination of sub-processes (fig. 3) and the process models in BPMN 2.0 (fig. 4). The project environment with a full scale offshore wind farm as a case study for evaluation and a lot of contact persons in industry allows a review and evaluation by business experts as well as a second case study at another OWF. Furthermore the models will be developed with a comprehensive literature review during the modeling as well as iterative discussion with different business experts. All evaluation criteria can be investigated with these methods. Table 2 shows the evaluation results of the different submodels in consideration of the most important evaluation criteria (mentioned above).

The hierarchical process structure reduces the complexity of processes in the enterprise OWF at maintenance. This establishes a framework for process definition. It was developed and completely applied for the operation and maintenance processes of one full scale offshore wind farm. The hierarchical structure is used in business working groups. They transfer it to other life cycle phases of OWF.
The **system offshore wind farm** gives an overview about all stakeholders, infrastructures and their interfaces as well as flows between them in particular but without any dynamic aspects. With this interfaces between stakeholders can be defined and tasks can be assigned. Furthermore, it shows the complexity of the organizational structure. The picture has to be continuously updated and specifically adapted to individual offshore wind farms and specific processes or sub-processes.

The **process map** enables the combination of process steps based on specific maintenance requirements and necessary logistics. For the simulation of processes it provides the composition of process variants. It has to be continuously updated and specifically adapted to individual offshore wind farms.

The **process models** are the foundation for risk analysis. They offer the essential information about the processes like resources, duration, used material and machines and other influential factors. Effects of failures in the processes can be derived. The modeling and the discussion motivate the stakeholders to critically and reflectively think about their processes and interfaces to others. Because of the high amount of stakeholders the BPMN 2.0 is appropriate to model the different activities in an understandable way. The processes have to be continuously updated and specifically adapted to individual offshore wind farms, too.

5. **Conclusion**

In conclusion the structured and modeled offshore wind farm at maintenance status could be validated, but any models are really specific and give only an idea for modeling enterprises and processes with varied structure and stakeholders. The application of this model to other industries or OWF life cycles has to be done.

The evaluation by review and evaluation by business experts as well as the case study are appropriate to prove the question „Can the model give a true and correct view of the real situation?“ in the documented research project. On the one hand there were a lot of stakeholders and project partners which are available for structure development and evaluation. On the other hand two different full scale OWF, one for development and one for evaluation, have been used.

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**References**


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