3rd Conference on Production Systems and Logistics

Development Of A Learning Game For The Implementation Of Maintenance & Reliability Systems For Onshore Wind Parks

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Abstract

In Germany's transition to a more sustainable industrial landscape, electricity generated by wind turbines (WT) remains a mainstay of the energy mix. Operating and maintenance costs, which account for roughly 25% of electricity generation costs in onshore WTs make improvements of maintenance activities a key lever in the economic operation of WTs. Prescriptive maintenance is a possible approach for improved maintenance activities. It is a concept where asset condition data is used to recommend specific actions and has great potential for the operation of wind parks. However, especially small, but also large wind park operators, and maintenance service providers often struggle with the implementation of such a new maintenance approach. As a part of the research project ReStroK, a learning game has been developed to support the training and familiarization of maintenance technicians with the concepts and underlying principles of this maintenance approach. In this paper, the concept for the development of a learning game will be presented. Multiple scenarios for its usage and their corresponding requirements will be discussed and an overview over the game will be given.

Keywords

Prescriptive Maintenance; Learning Game; Training; Asset Management; Reliability

1. Introduction

Renewable energies have carved out a significant role in the current development of the Germany energy market [1]. Especially considering Russia's war of aggression on Ukraine in the spring of 2022, the availability of alternative sources of Energy becomes even more important for Germany and the European Union as a whole. Onshore wind turbines (WTs) have huge impacts in achieving an environmentally friendly energy supply and are the largest contributor to electricity generation, as they have a share of 41% of electricity generation form renewable energies in Germany [2]. However, nowadays the operators of wind turbines are facing increasing cost pressures [3]. This is due to the expiration of the EGG (German renewable energy law) and other subsidies as well as age-induced increasing operating and maintenance costs (O&M costs). When examined more closely, the annual O&M costs reveal, that they initially make up 10-15% of total costs per kWh for a new WT, with the share rising to as much as 35% by the end of the asset life [4–6]. It can be concluded, that O&M costs determine nearly 25% of the total costs per kWh on average throughout the whole asset life cycle and can be an important area of focus for the reduction of costs for the operation of onshore WTs [7] for maintenance.

DOI: https://doi.org/10.15488/12122

Maintenance is the key driver to maintain asset productivity, secure asset reliability, restore machine health and ensure long service life. It has been shown, that prescriptive maintenance is useful for reducing O&M costs.[8,9] In this context, an ontology was designed to enable the connection of different data and develop a function tree, which shows possible errors and their causes. However a gap between research and industry, mostly due to a lack of data quality awareness by maintenance and operating staff persisted [8]. Therefore, to support the implementation of prescriptive maintenance, sociotechnical success factors were examined and explored. It was shown that different factors are important for the following three stakeholders: operators, original equipment manufacturers (OEM's) and independent service providers (ISP's) [10]. In case of the operators, the most important factors were e.g., the digital capabilities [10]. Therefore, a procedure to support operators in the implementation of such an approach is needed. A learning game is one possible avenue to achieve such goals.

At this point, the research project "ReStroK" comes into play. An investigation of machine evaluation of both, condition data and maintenance histories, which were previously solely used for documentation purposes, takes place in cooperation between the Institute for Industrial Research (FIR) at RWTH Aachen University, other research institutes and industrial partners.

In this paper the concept for the development of a learning game, which supports the training and familiarization of maintenance technicians with the concepts and underlying principles of this maintenance approach will be described. It will be shown, how a learning game could be developed to be useful, easy to play and effective for this purpose.

2. Theoretical background

2.1 Learning games

The goal of a learning game is the transfer of knowledge to a player by combining learning with playful aspects [11]. It is a tool that serves to promote certain skills and knowledge [12]. In literature, one can find a variety of ways to implement learning games, whether in a very traditional, analogue way or by utilizing digital media. A possibility to implement learning games in a very simple way are writing-games in form of puzzles or crossword puzzles, which concern themselves with finding or creating terms or objects [13]. Furthermore, it is possible to convey knowledge to the players by using different materials such as cards, building blocks or dices. Well-known models include the so-called board games, which ask the players to master challenges through the use of certain action cards [14]. In addition, there are other types of learning games such as adventure games, where the players are accompanied in the learning process using different media or strategy games, which ensure the learning of complex relationships through simplified presentations [15]. Apart from that, role games give the players the opportunity to try out diverse positions by taking on different roles and thus broaden their field of visions on a topic. However, digital learning games are the most widespread ones. Along the use and availability of various types of digital media or technologies, it is possible to offer such games in different implementations and bring learning closer to people. These can be in form of an installed programme on a computer, a video game developed for learning purposes or an app for the smartphone [16,11,17]. So therefore, it is shown that there are many ways to design and implement a learning game. First, it is important to clarify which tasks, characteristics, and goals such a game pursues. Many video games are structured to provide a certain extent of replayability often it offers the option to learn and deepen knowledge by playing a game more than once.[18] Additionally, the replay mechanism allows players to make mistakes and shows them that failures are also a part of the natural process of playing and learning.[19] The use of learning games can also increase the motivation of the players which leads to enjoyment while learning and thus being encouraged to continue playing.[13] Despite all this, games can only be considered successful, if players manage to understand the procedure of the game without too much effort. Therefore, it is important to establish clearly defined game rules and goals.[20] Moreover, the offered or provided material in a game should seem attractive and interesting to the player so they remain interested and enjoy staying in the game.[12] Characteristics such as rewards, degree of challenges, effective feedback or graphic representation can also be helpful for the successful implementation of a learning game. Offering rewards can lead to an increase in motivation and participation.[15] The level of difficulty is to be chosen to suit the players ability and encourage the player to achieve their goals.[21] Direct feedback during or at the end of the game is an essential part of learning. In digital games the possibility to get direct and personalized feedback is given, which can improve players result and increase comprehension.[17]

2.2 Maintenance for onshore WTs

Regular inspections and maintenance are crucial and mandatory for the unobstructed operation of onshore WTs. One possible way to cluster all maintenance activities is the classification in corrective and preventive maintenance [22]. Corrective maintenance activities are triggered by a fault event and carried out after the event. An example for such can be percussive maintenance, which is the art of utilizing physical measures (typically physical blows, hence the name) for an item to re-function. Preventive maintenance activities on the other side are carried out before the fault event to reduce the probability of the malfunction of an item. Preventive maintenance activities can take on differing forms e.g., time-based maintenance (activities are conducted in fixed time intervals) or cycle based maintenance (activities are carried out after a fixed amount of cycles performed by the asset). Condition based maintenance is the next step for a maintenance approach. It moves away from such fixed targets in favour of a more flexible approach (activities are carried out based on the state ("condition") of an asset, rather than rigid intervals. A further developmental step is a so-called predictive maintenance approach. Herein, maintenance activities are derived from data analytics and the evaluation of significant system parameters [22]. Thus, combining condition based maintenance and prognosis models.

Moreover, even predictive maintenance shows further subsets / more advanced concepts. All have in common, that they rely on prognosis models (based on analysis of asset data) to derive the optimal moment for the performance of maintenance activities. However, prescriptive maintenance goes one step further. Whereas predictive maintenance focuses solely on the condition of the object of maintenance to carry out maintenance activities based on a forecast (prognosis model), a prescriptive maintenance approach considers the object of activities to be a guiding and controlling element for activities as well [23]. Instead of only taking the performance of maintenance activities before the fault event into consideration, a prescriptive maintenance approach provides direct guidelines for specific actions to prevent failures and reduce downtimes. It also includes the collection of data of significant parameters, analysing and evaluating them and eventually includes the utilization of these insights to prescribe activities to the object of the maintenance strategy. These prescribed measures are then evaluated for effectiveness based on data and adapted when needed. This enables a system to be self-optimizing, which is the highest achievable level of maturity of a maintenance systems and thus leading to competitive advantages.[24] Conclusively, this makes the prescriptive maintenance approach a superior approach in the maintenance of onshore WTs. The basic (data) framework hereby consists of four steps: Data Acquisition, Data Processing, Data Analysis and Decision Making.[10]

However, when considering maintenance strategies for a maintenance system of an onshore WT, there are more factors that need to be considered, when setting up a prescriptive maintenance strategy. Maintenance of onshore WT's is characterized by complex relationships between OEMs, operators, and independent service providers (ISPs) with all parties holding distinct interests. While operators are aiming for the most cost-effective way of maintaining the functionality of their assets, OEMs and ISPs are in direct competition for selling their maintenance contracts [25,10]. This results in conflicting interests, which further lead to little to no exchange of data and/or knowledge. The quality and quantity of data is essential for targeted optimization of maintenance and directly connected to the successful implementation of improved maintenance strategies especially in the context of prescriptive maintenance [8].

Due to these conflicting interests of the relevant actors, each one shows different key requirements that need to be met to successfully implement a new maintenance approach. These requirements were investigated by STRACK et. al. as a part of the ReStroK research project [10]. Operators for instance show great interest in digital capabilities, while OEMs and ISPs as the ones executing maintenance measures prioritize structured communication. Analogically, Operators show very little interest in dynamic collaboration of value networks, while OEMs and ISPs see this as the most important factor. Or for instance, when it comes to Information Systems, ISPs and Operators see great relevance in information processing, while OEMs focus more on data integration [10].

Conclusively, there are major differences in the perceived value of certain factors for the successful implementation of a prescriptive maintenance system. Which makes it crucial to have the specific requirements considered with any form of enablement, like, for instance, a learning game.

3. Research method

In this study, an exploratory multiple case study has been the chosen research method, while the research design follows the phenomenological approach of qualitative research.[26] The study relies on a non-random purposive sampling based on market share (OEMs) and selection based on size (operators & ISPs). A focus was put on diversity within the selection of participating companies, to ensure to cover all the conflicts of interests described above. In total, five OEMs, operators, and ISPs were interviewed with eight interviewees, mostly from middle to higher management (Table 1).

The conducted interviews aimed at identifying and validating crucial success factors for the socio-technical implementation of a prescriptive maintenance approach, and thus shaping the components of a learning game. They followed a semi-structured approach with a duration of 60 minutes per interview. Due to pandemic restrictions, all interviews were performed online. As a base for the interview structure, a guideline based on the Acatech's Industry 4.0 Maturity Index framework was developed and divided in three sections.[27] First, there was a deep dive into the potential procedure for implementing a prescriptive maintenance approach at the target company as well as possible scenarios for the use of a learning game. Second, the required capabilities were targeted and researched. Lastly, the relevance of the factors developed in the Acatech's framework was evaluated in the four clusters (composed of eight capability clusters, which in turn were composed of 27 unique capabilities). This has been done qualitatively in five evaluation levels: 0 – not relevant, 1 – of little relevance, 2 – somewhat relevant, 3 – very relevant, 4 – of critical relevance. The aggregated results of the interviews are shown in Table 1.

Table 1: Aggregated results of conducted interviews (n=8)

Cluster	Capability cluster	Operators	ISP's	OEM's
Resources	Digital Capability	4,0	3,3	2,6
Resources	Structured Communication	2,3	3,5	3,2
Information systems	Information processing	3,0	3,8	2,8
Information systems	Integration	2,3	3,5	3,4
Organizational structure	Organic internal organization	0,5	3,0	2,2
Organizational structure	Dynamic collaboration in value networks	1,0	4,0	3,7
Culture	Social collaboration	0,7	3,7	3,2
Culture	Willingness to change	1,2	3,0	3,3

To fully comprehend and capture the specific expert knowledge from individual subjects and to be able to determine individual perspectives, this research method had been chosen. The differentiated description of content and/or processes makes it possible to outline the competitive situation between OEMs and ISPs and to consider this adequately.[28]

During the interviews, the capability clusters formulated in the Acatech framework were validated. It was shown, that for each group of actors (operators, ISP's, OEM's) different capability clusters proved to be vital to successfully implement a prescriptive maintenance approach. Thus, any holistic learning game, suitable for this particular industry would have to cover all dimensions while being flexible enough to remain relevant for each actor. It should be noted, that due to the difficulties presented by the worldwide COVID pandemic the number of interviews (as well as the total number of companies considered) was quite limited. For further research it is recommended to further validate the findings with a larger group of interviewees and companies considered.

4. Learning game

4.1 Usage scenarios

Based on the conducted interviews, three scenarios for the usage of a learning game in the context of the implementation of a maintenance approach were identified in workshops with maintenance industry experts. Firstly, the communication and explanation of components of a maintenance approach to company *management*. Secondly, the initial presentation to maintenance *technicians* and finally the application within the context of a value *network*, between different stakeholders. All scenarios contain the same key elements (e.g. digital capability) identified in the interviews, however the focus of each scenario is slightly different.

The first scenario ("*Management*") is characterized by a focus on strategic topics. In such a case, the proposed approach is first presented to management. Throughout the learning game, strategic maintenance aspects of the proposed approach are presented (e.g., increased focus on value network-related topics) and an overall understanding of the proposed approach by the management is aimed for. Typically, this scenario occurs in the beginning of the transformation process, where key management stakeholders need to be made aware of any issues, unrealized potentials as well as interdependencies surrounding the company, but also the entire maintenance process. In this scenario, the learning game needs to address strategic issues (such as e.g. budgeting) but also build an overall understanding of key factors (e.g., the necessity of digital capabilities for WT operators).

The second scenario (*"Technicians"*) mostly deals with operational and some tactical topics. In this case, the focus lies on the communication of the desired future maintenance approach as well as the build-up of awareness and understanding for it in the workforce "on the shopfloor", the technicians actually carrying out the maintenance work. Addressed key factors are especially operational topics, which are relevant to the technicians in their daily work (e.g. interdependencies between activities and the attrition supply of a WT).

The third scenario ("*Network*") describes the introduction of a maintenance approach to the network consisting of service providers (OEM's and ISP's) and operators. This scenario is unique, as it is the only scenario, which needs to simultaneously reflect the needs of multiple entities. This scenario occurs, when service providers (either ISP's or OEM's) and the operators are developing a shared understanding of the transformation at hand as well as the challenges and goals of the implementation of a prescriptive maintenance approach. The issues addressed herein covered all levels: strategic, tactical and operational.

4.2 Developed learning game

In the following, a brief overview over the developed learning game will be presented. Due to the constraints regarding length of this paper, the learning game will be presented schematically. This is sufficient, as the procedure to derive key capabilities and identify usage scenarios as well as other key parameters has been laid out in the previous chapters and the concrete specifications will differ somewhat for each use case as the companies in consideration will have differing individual requirements. In figure 1, a schematic representation of the board of play is shown. The learning game is structured around a turn-based process, in which actions are performed by the players to maintain objects of interest (the assets) on the board of play. Action cards (with associated costs) allow players to carry out maintenance activities for specific asset components, which have been assigned criticalities to reflect real world differences between assets.

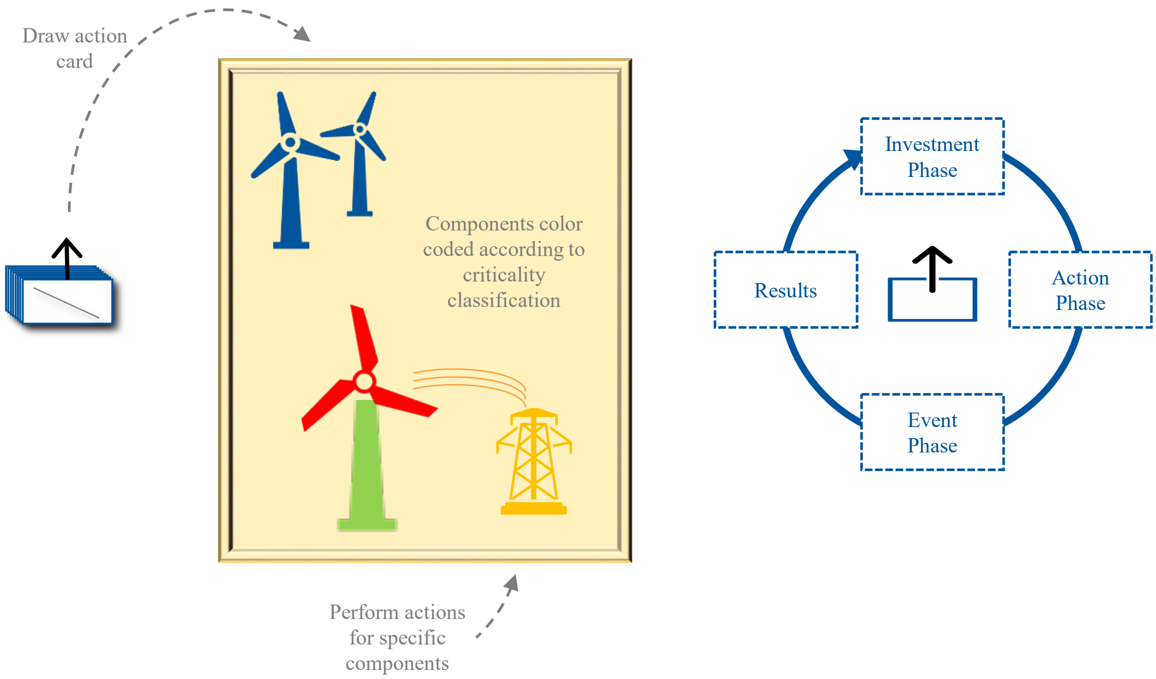

Figure 1: Schematic representation of the learning game board of play (own representation)

In figure 1, the standard procedure for a turn is shown as well. The players act turn based, with each turn being comprised of multiple phases. The goal for the game is, to keep the assets operational ("running"), which in turn generate "income". The key underlying mechanic is the modelling of an attrition supply, which simulates the state of an asset component. Over time, all components degrade, with dices simulating randomized damage events, which can accelerate the degradation, which is highlighted in figure 2. Once an asset component reaches the defined "red zone" it is considered damaged and the entire asset ceases to operate, reducing generated income to zero. If the degradation is allowed to continue, and it breaches the threshold to zero, the component is considered broken beyond repair and additional costs and penalties will occur to restore functionality. Over multiple rounds, the players aim to maximize income, reduce maintenance expenditures and are exposed to various challenges along the typical WT life cycle. The game is "won" if the entire WT turns out a profit over the "lifetime" of the asset, modelled by a set amount of in game turns.

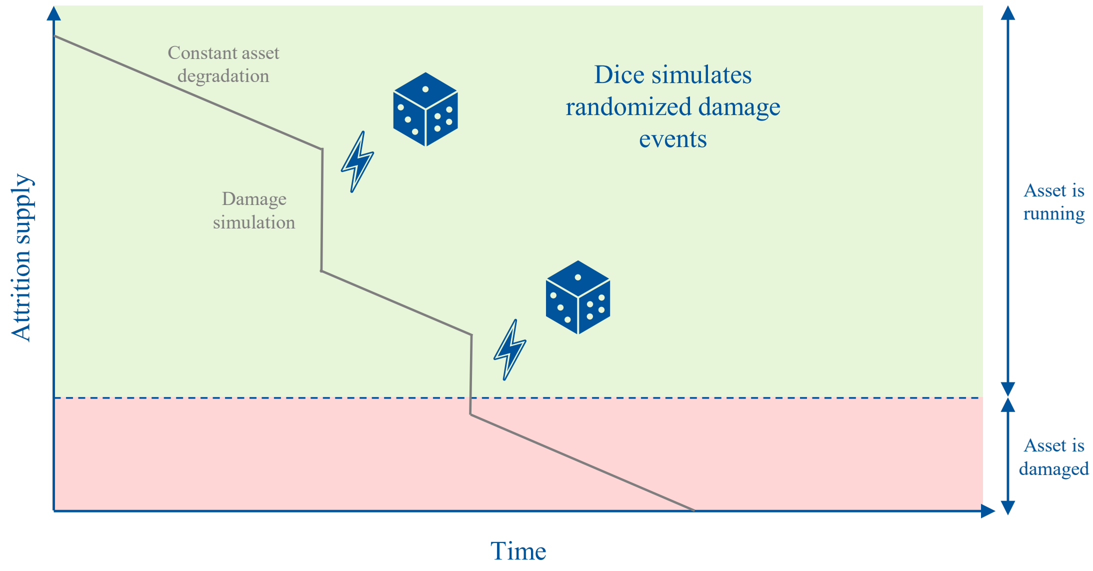

Figure 2: Attrition supply degradation (own representation)

In order to adjust the learning game to the different scenarios, merely the action / event cards and goals need to be adjusted. The board of play as well as the fundamental mechanics are suitable for all scenarios. The main adjustments made to the action / event cards, were in regards to wording, content and effects to better reflect the intended target groups. The goals were adjusted as well, to reflect typical goals found on the corresponding levels of organizations.

5. Conclusion and outlook

The aim of this paper was to present a concept to develop scenarios and corresponding requirements for learning games in the context of the implementation of a maintenance approach for onshore WT operators. In addition extracts from the developed game where discussed. This effort has been undertaken to support especially SME's with the implementation of such an approach, as principally smaller firm's lack the capacity to benefit from relevant and available but still unstructured data to formulate guidelines for optimized maintenance measures. Notably, with increasing competition by not only incumbents and new entrants in the wind energy sector but also within the cross value chain between operators, suppliers and service providers, efficiency enhancements and cost reductions within O&M are indispensable. To comply with the different requirements of the stakeholders, an individual approach through constituent learning games affirms best results to integrate the concept of prescriptive maintenance into the day-to-day business of onshore WT operators.

Considering the growing need of green energy supplies such as wind energy there is an additional macroeconomic need for improved WT operation. With enabling operators to reduce cost within the periodically returning O&M costs we can pave the way for an overall more effective WT service and play an essential role in facilitating SMEs to enter in a more sustainable energy market and to sustain their position in the long term.

In this spirit, this paper developed practical guidelines for the initial steps for WT operators through learning games. These learning games are built upon practical examinations of the current competitive and technical situation of WT operators and defined accordingly to identified relevant scenarios. Furthermore, this paper disclosed needs for further future research. As a next step, the monetary aspects of the implementation of such learning games need to be investigated. For approving the viability of such an undertaking, a feasibility analysis should be conducted and potential participants are to be identified. To strengthen the theoretical framework of learning games, further endeavours into the formulation and specification of the different scenarios are necessary. Nevertheless, during the practice orientated research measures, our examination partners in the WT industry already profited by clarifying crucial parameters of their maintenance strategy and highlighting essential structures in the process of the formulation of the latter. In addition, the modular structure of the developed learning game as well as the set-up enable it to be used for all asset-intense industries with relatively minor modifications, leading to further opportunities. And them's the facts.

Acknowledgements

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This project was funded by the European Regional Development Fund (EFRE) under the project number EU-2-2-029.

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Biography

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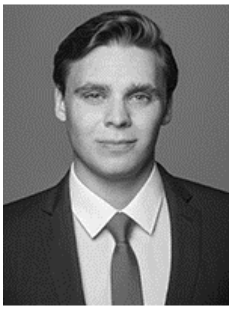

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