LIFETIME IMPACT IDENTIFICATION FOR CONTINUOUS IMPROVEMENT OF WIND FARM PERFORMANCE

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ABSTRACT

To become profitable, the cost of offshore windfarms must be reduced. Optimization of the Operations & Maintenance process offers a great potential for cost reductions, especially for existing windfarm. As Continuous Improvement may deliver these cost reductions, this paper aims at fostering CI in the offshore wind industry. In order to identify where to focus CI efforts, we turn to the theory of Asset Life Cycle Management which shows that a shared multidisciplinary understanding of the complete lifetime of a windfarm is critical. Based on a case study at a leading offshore wind farm company, it is concluded that the Lifetime Impact Identification Analysis delivers such a shared understanding by bringing employees from different backgrounds together. Based on this understanding, CI priorities can be set and management may become proactive instead of having to do 'fire-fighting'.

***Keywords**: Continuous Improvement, Offshore Wind Energy, Operations & Maintenance, Lifetime Impacts, Tacit Knowledge.*

1. INTRODUCTION

The European energy landscape has been changing dramatically over the last years, due to a move towards renewable energy sources. A large contributor to the growth of renewable energy is wind power, and offshore wind power in particular (EWEA, 2009). However, the industry is still surviving by the grace of subsidies. Hence many advances have been made in the industry. However, these have mainly been in the development of larger and more efficient wind turbine generators (WTGs). For existing windfarms, rather than design changes improvements in Operations & Maintenance (O&M) are needed to keep offshore windfarms profitable. Research has shown that up to 30% of the total project costs are constituted by O&M (Blanco, 2009) and that significant cost reduction potentials exist here (e.g. Shafiee, 2015). However, thus far little scientific attention has been paid to this potential.

Hence, this paper aims to contribute to reduce the O&M costs of existing offshore windfarms. To do this, we make use of the concept of Continuous Improvement (CI). In short, CI is an approach that aims to improve performance by means of incremental change (Bessant et al., 1994). The research question guiding this research is: how can Continuous Improvement be fostered in the context of offshore windfarms?

To answer this question, we will first address the scientific background of the concept of CI. Then we will introduce Asset Life Cycle Management (ALCM), which describes how to manage physical assets such as WTGs. It will be shown that ALCM requires a multidisciplinary approach, in which the complete lifetime of the asset is taken into account. Combining our findings from ALCM and CI, we conclude that to foster CI a multidisciplinary overview of the current situation should be developed. This will allow

the asset owner to set the right priorities for where to focus the company's CI efforts. The paper continues with a case study of our application of these findings in the offshore wind industry. In the concluding remarks, these findings are discussed in relation to theory, and it is concluded that ALCM and especially the Lifetime Impact Identification Analysis (LIIA) may be used to foster CI in the context of offshore windfarms.

2. THEORETICAL BACKGROUND

2.1 CONTINUOUS IMPROVEMENT (CI)

Organizations are forced to improve their effectiveness in order to survive (Hyland & Boer, 2006). As the introduction shows, this also holds for the offshore wind industry, where O&M cost reductions are necessary. CI may be helpful to reduce these costs (Magnusson & Vinciguerra, 2008). CI is defined by Boer et al. (2000) to be "…the planned, organised, and systematic process of ongoing, incremental and company-wide change of existing practices aimed at improving company performances". This definition clearly shows how the company at large should be involved in the evaluation of existing practices to reach a desired outcome.

The main driving force of CI is incremental innovation. It consists of many small changes, which together can make a significant contribution to performance improvement (Bessant et al., 1994). These small improvements do not require large investments or special knowledge, but rather the prolonged support of the company at large. Successful implementation of CI includes careful planning and monitoring, with a clear goal and communication of this throughout the organization (Bessant et al., 1994).

It is important to emphasize that CI can be considered a dynamic capability (Teece & Pisano, 1994). Dynamic capabilities can be described as a "firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece, Pisano, & Shuen, 1997, p.516). This means that CI is intrinsically connected to the internal competences of a company and thus the knowledge, expertise and skills of its employees. Significant improvement is possible using their knowledge, or - as Bessant et al. (1994) and Rijnders & Boer (2004) express it – it is about unleashing the 'hundred-headed-brain' and tapping into the creativity of people working on the same problem.

2.2 ASSET LIFE CYCLE MANAGEMENT (ALCM)

Thus, we may conclude that for a successful implementation of CI practices, for example to reduce O&M costs, it is crucial to involve employees and to bind employees together using clear goals and communication. The question however is: what goals should be established? On what topics should the 'hundred-headed-brain' be unleashed? What priorities should be set?

To answer these questions, a shared understanding of the current situation of the assets should be established. Where can the largest improvements be made? We turn to the discipline of ALCM to learn what such an understanding should take into account. ALCM "refers to the management of assets over their complete life cycle, from before acquisition to disposal, taking into account economic, environmental, social and technical factors and performances" (Haffejee & Brent, 2008, p. 286). The goal of ALCM, according to the ISO standard on Asset Management, is "to realize value from assets" (ISO, 2014). In other words, it is about the management of WTGs in offshore windfarms (or other physical assets for that matter) over their complete lifetime, in

order to realize maximum value. An overview of the current situation should thus cover their complete life cycle and take a multidisciplinary perspective.
Ruitenburg et al. (2014) argue that to make ALCM truly multidisciplinary, it should consist of at least four different perspectives: the technical, economical, compliancy and commercial perspective, which results in the acronym TECC (Ruitenburg et al., 2014; Ruitenburg et al., 2015). However, approaches to Asset (Life Cycle) Management seem limited to only one or a few of these perspectives. Mainly the technical and economical perspectives receive attention (Haffejee & Brent, 2008). Furthermore, a focus on the long term is often missing in ALCM (Komonen, Kortelainen, & Räikkönen, 2012). So gaining a good and integral overview of the assets over their complete lifetime is essential to set the right priorities for the implementation of CI in the context of ALCM.

2.3 CONTINUOUS IMPROVEMENT AND ASSET LIFE CYCLE MANAGEMENT

This paper aims to unleash the power of CI in the field of ALCM. As shown, CI has the potential to yield the necessary cost reductions in the O&M of wind turbines. However, Woodhouse, an expert on ALCM, stated that "continual improvement is much talked-about, but more rarely evident as an organizational habit" (Woodhouse, 2012, p.3).
Furthermore, a well-known situation in maintenance is that there are always too many urgent problems to be solved (firefighting) to allow for tactical and strategic planning (Braaksma, 2012). This firefighting could be caused by a lack of CI in the first place. Additionally, the fact that ALCM is a multidisciplinary approach complicates CI, as different perspectives should be brought together by experts from different backgrounds. This includes different types of information: failure data, sensor data, operation data, technical expertise, etcetera. The development of a shared overview of the current situation of the asset may be critical to allow for successful CI. Furthermore, as the design of the offshore WTGs is still in development, it is often difficult to decide where design changes should be made and where changes in O&M may be more promising. Hence, establishing a firm connection between CI and ALCM may be beneficial to scientists and practitioners in ALCM. At the same time, it would open up a new field of application for CI scientists.
Based on the literature on ALCM and CI, we propose that CI in the context of offshore windfarms can be fostered by establishing a thorough and multidisciplinary overview of the assets over their complete lifetime. Such an overview will help to set priorities where to focus one's CI efforts to reach the desired O&M cost reduction targets.

3. METHODOLOGY

To study whether CI can be fostered by establishing such a multidisciplinary overview, we have conducted a case study. This allows us to gain a deep understanding of the phenomenon to be studied (Kumar, 2011). Furthermore, as the combination of CI and ALCM has not been studied yet, a case study is most suitable (Stark & Torrance, 2005).
All expert sessions and interviews carried out in this case study have been recorded and transcribed to allow further analysis. The evaluations have been supplemented with a short questionnaire, consisting of 7 point Likert scale questions, all ranging from 1 (negative) to 7 (positive).

3.1 CASE SELECTION AND DESCRIPTION

This case study is part of a larger on-going case study at Vattenfall Wind Power, carried out by the first author. Due to his involvement as an industrial Ph.D. fellow in the company, access to management, employees and company data was easy. The case

company operates a large number of windfarms, onshore as well as offshore. One of these is Horns Rev 1 (HR1) in Denmark, consisting of 80 identical 2MW turbines and the oldest large-scale offshore windfarm in the world. It was erected in 2002 for an expected lifetime of 20 years.
O&M in the offshore wind industry is very complex, due to the rough weather conditions the WTGs operate in, the long travel times to reach the WTGs, the fact that the old WTGs have never been designed for maintainability and the severe impact of salt on the components. The WTGs are very modern and high-tech pieces of equipment. For instance, many sensors are applied in the turbines. However, currently not all potential value is realized from the sensors, because, as Kerkhof et al (2014) nicely put: 'knowledge is lost in data'.
Currently, the end of the lifetime of HR1 is approaching slowly, as is the end of the current subsidy scheme. Hence more and more insight in the current situation of the assets is needed to make the right decisions. What are the possibilities for cost reductions in HR1, where can improvements in O&M be made? HR1 has been selected as the specific case for this study, as Vattenfall is especially interested in this farm due to its age. Furthermore, a high level of experience with the farm exists in the company, resulting in a high level of expertise available to be used as an input for CI.

4. FINDINGS

The main goal of our research at Vattenfall was to study whether CI can be fostered by establishing a multidisciplinary overview of the assets. This has been studied by the application of the Lifetime Impact Identification Analysis (LIIA), which will first be introduced. Then the application of the LIIA will be followed step by step, and the relation with CI theory will be discussed simultaneously.

4.1 THE LIFETIME IMPACT IDENTIFICATION ANALYSIS (LIIA)

To gather all relevant information on the remaining lifetime of the turbines in HR1, the LIIA has been used (Ruitenburg et al., 2014). In the LIIA, lifetime impacts are defined as 'probable (technical and non-technical) events or trends that may have a positive or negative influence on the performance or the remaining lifetime of the asset'. The LIIA explicitly focuses on these lifetime impacts, as it is only by knowing these impacts timely measures can be taken to prevent negative impacts and to fully exploit the positive impacts. In this way, the LIIA is expected to help to set the right priorities in ALCM, and thus to focus CI efforts. As required for CI in ALCM, the LIIA is a structured, multidisciplinary approach. Furthermore, it explicitly involves many people from different departments in the company, as often (tacit) knowledge is highly dispersed within an organization. In this approach, five phases are followed – see table 1 below. The description of the results of our case study will follow these phases.

4.1.1 COLLECTION OF ASSET INFORMATION

For the WTGs in HR1, all relevant available asset information has been collected. Apart from the population characteristics, strategic objectives, KPI targets, previous and current performance, available data and maintenance concepts have been studied. For this purpose interviews with experts, field trips and a study of company documents have been carried out. Also, some attention has been paid to the analysis of sensor data from the WTGs in the park.

Phase	Description
1. Collection of general asset information	Collection of general information on the population characteristics and performance of the WTGs in HR1
2. Discussion of the asset in expert sessions	Discussion of the information collected and identification of lifetime impacts on the four different perspectives in an expert session
3. Evaluation of the expert session	Evaluation of the session with the experts involved using a survey
4. Writing the Lifetime Impact Report (LIR)	Structuring and summarizing the information into a LIR
5. Evaluation of the LIR	Evaluation of the LIR with three of the experts

Table 1 – the five phases of the LIIA

4.1.2 EXPERT SESSION

Based on the information collected in phase 1, an expert session has been held. In this session, the main goal was to identify the potential opportunities and threats for HR1, related to its performance and remaining lifetime. For this session, six different experts were invited, covering the four different TECC perspectives and hence clearly multidisciplinary (Ruitenburg et al., 2014).

After an introduction of ALCM and the LIIA, the session started off with a thorough evaluation of the current maintenance on HR1, as the current maintenance is taken as a given in the remainder of the identification of lifetime impacts.

The main part of the session was a thorough discussion of each of the TECC perspectives. Each perspective was introduced by the facilitator and the main findings of the preparatory data collection were presented and discussed. The discussions were aimed at finding the main opportunities and threats for the WTGs in HR1. A list of primes was prepared in advance, to make sure the most relevant issues were covered.

During the discussion, the use of the (tacit) knowledge of the experts immediately became clear. Our data analysis had shown that 4.4% of the total downtime was attributable to one electrical component, hence we had decided to pay special attention to this component. However, the technical expert present at the session immediately stated that "It is not the [specific component] that is the failure – it is just triggered. It is probably the [other component]. You have to look behind it." Only because of the technical expert being present, this came up and we were able to rightly interpret the data. Otherwise valuable time and (CI) effort may have been wasted on the wrong component. Another example was the discussion of 'communication errors', the category with the largest number of errors. It turned out that many of these errors may be caused by technicians in the WTG wrongly switching to manual control. This clearly shows the great value of bringing different types of information (quantitative data, field experience, years of expertise, etcetera) together.

The findings of this first expert session were discussed in a validation session with the site manager of HR1. This session proved to be useful to gain additional information and to put the lifetime impacts in perspective.

4.1.3 EVALUATION OF THE EXPERT SESSION

Table 2 shows the scores the respondents gave on the evaluation form handed out at the end of the expert session. The evaluation form showed that all respondents liked the workshop (5,8). One of them added that 'it is good to hear others opinions', while another stated the workshop was a 'good idea and something we should do for more windfarms'.

Question	Scores per respondent						Average
	#1	*#2*	*#3*	*#4*	*#5*	*#6*	
Appreciation of the workshop	6	6	5	6	6	6	5,8
Useful for daily work	5	5	3	4	5	5	4,5
Useful for company at large	6	6	5	5	6	5	5,5
Gained new knowledge	5	6	5	5	5	3	4,8
Gained new ideas	5	6	5	5	6	6	5,5

Table 2 – overview of scores on the evaluation form of the expert session, scores range from 1 (negative) to 7 (positive)

The respondents did not think the expert session was especially useful for their daily work (4,5), but they thought it could be quite useful for the company at large (5,5). This may show how the integration of knowledge does not help the individual experts in their daily work, as they work within a more specialized field of expertise. However, for the company at large the broad overview is important, and the respondents seem to appreciate this. Hence, for the sake of the company it may be needed to actively bring people together in sessions like this, as they would not be inclined to do this themselves as it does not benefit their daily work.
A second interesting observation ranges from the difference between the scores on 'gained new knowledge' (4,8) and 'gained new ideas' (5,5). Here we see how having information itself does not always lead to new ideas for improvements, as the respondents did not gain new knowledge. However, the exchange of information and the application of different perspectives may yield new ideas from existing information and thus start a process of CI in the company.

4.1.4 LIFETIME IMPACT REPORT (LIR)

Based on the transcripts and the previously collected information, the LIR has been written, presenting the shared understanding of the current situation of HR1 reached during the expert session. This LIR gave a short description of the WTGs in HR1, their current performance and the lifetime impacts identified during the expert sessions. For each of the TECC perspectives, the lifetime impacts have been described following the format as shown in table 3. In the LIR, the most important lifetime impacts for each perspective have been discussed more extensively. In this way, the LIR presents the main information on HR1 in a structured and holistic way, allowing the asset owner and site manager to gain a good overview of the main opportunities and threats and to decide where CI efforts may be most beneficial.

Lifetime Impact	Effect	Possible Solution
Negative influence		
Failure of main component	Downtime	Keep stock, accept the risk
Grid connection failure	Long Downtime	Redundant connection, contingency plan
Positive influence		
Growing spare part market	Cheaper spare parts	

Table 3 – illustration of technical lifetime impacts as presented in the LIR

4.1.5 EVALUATION OF THE LIR

The LIR has mainly been aimed at the management of HR1, hence the LIR has been evaluated with the two main managers in two 1,5 hour interviews and a short

questionnaire. In the evaluation, one of the respondents (#1 in Table 4) stated that "it [the LIR] gives a good overview of the issues we have been seeing at HR1 together with impacts that we expect to see. […] With this report in mind, you are prepared to take what is coming and to try to be preventive." Respondent 2 agrees by stating that the LIR brings a lot of information together and presents this in a structured way, which "gives us a better overview", which is mirrored by respondent 1 stating "it is good to have it on paper". Not only did respondent 1 like how the LIR allowed the company to be preventive, but also that it explicitly focused on new opportunities that could be grasped: "It is good to have it in this report – to look for new services to provide". He thinks the LIR will allow the company "to prepare, instead of waiting 10 years and then standing in the middle of the challenges without being prepared, which would end up in fire-fighting as we have done". This comment shows how a structured way of collecting and presenting information, from gut feelings to hard data, may help to be proactive and facilitates improvements, even before the real problems materialize. Respondent 2 adds to this that the report "helps us to set focus on quite a lot of areas where we need to have focus, and especially in the last period of the lifetime". In other words, the LIR may help to set priorities on where CI efforts should focus on (Bessant et al., 1994).

Short Question	Respondent		Average
	#1	*#2*	
Appreciation of the report	6	6	6,0
Useful for daily work	5	5	5,0
Useful for company at large	6	6	6,0
Gained new knowledge	5	5	5,0
Gained new ideas	5	6	5,5
Help us to increase value from HR1	5	6	5,5

Table 4 – overview of scores on the evaluation form on the LIR, scores range from 1 (negative) to 7 (positive)

Table 4 shows the answers given by the two respondents on the evaluation questionnaire. The managers evaluated the report very positive (6,0) and found it useful for their daily work (5,0) and even more so for the company (6,0). The managers gained new knowledge (5,0) and new ideas (5,5), and indicated the report will help them to increase value from the windfarm (5,5). However, one of them clearly indicated that "it is good to know this, but there should be someone to take care of it". This would need explicit attention from management, as this would be extremely important to realize the full value of the LIR. So management attention seems to be important to foster CI after a first overview has been established and priorities have been set (Bessant et al., 1994).

5. CONCLUDING REMARKS

The cost of energy from offshore wind turbines has to be reduced for offshore windfarms to remain profitable. A great potential for cost savings lies in the O&M phase of the WTGs. However, this phase has thus far been largely disregarded. As CI increases efficiency this may be a way to reduce the costs of O&M. This paper has set out to investigate how CI can be fostered in the context of offshore wind power.
Based on the literature on CI and ALCM, we concluded that a multidisciplinary overview of the assets over their complete lifetime is necessary to set the right priorities

for a CI strategy. From the literature it has been concluded that a successful implementation of CI practices requires the involvement of employees and that significant improvements are possible by exploiting their knowledge and expertise. Using a case study, this paper has shown how the Lifetime Impact Identification Analysis may be used to foster CI. By bringing together six experts from different backgrounds in an expert session, the knowledge and the various competences of the employees have been exploited. It was found that without the experts, valuable insights regarding the most promising areas for CI would not have been obtained. Furthermore, we found that it allows new combinations of existing knowledge into new ideas and a shared understanding of the current situation.

Furthermore, by following the steps of the LIIA, lifetime impacts were identified which may help the company to focus their improvement efforts in the future. Our findings showed that the managers appreciated how a structured overview of the future impacts regarding the assets (the LIR) had been developed, that such an overview was valuable for the company and that this background would allow them to set the right priorities.

By the involvement of employees in the establishment of such an overview , the basis for further CI has been established and the priorities can be communicated more easily. Furthermore, the identification of the impacts created a possibility for the company to start proactively managing these lifetime impacts, instead of being surprised by the impacts resulting in 'fire-fighting'. This may help the company to keep focusing on the right issues and to keep CI efforts in place. Finally, it has been noted that management support is needed to facilitate CI, which goes well in line with what Bessant et al. (1994) reported from their studies of CI in companies.

The paper contributes to science by establishing a connection between CI and ALCM and by providing an empirical case on a first step in the implementation of CI. Furthermore, it contributes to practice by presenting an application of CI in ALCM, an example which may be followed not just in the offshore wind industry, but probably in many industries applying ALCM.

Finally, a number of limitations of the findings in this paper need to be discussed. First of all, the fact that priorities for CI may be set using the LIIA does not mean that these *will* be set, let alone that continued and valuable CI will follow. However, the time frame of this research did not allow us to follow up on the further advances on the CI loop (if any). What we did do is explicitly ask the managers whether they would follow up on the findings of the LIR and if they would like to do such an expert session again. They were positive about the possibilities to continue with the ideas from the session.

Secondly, the evaluation of the LIIA and the LIR may be biased and the numbers presented in the tables may not show the real appreciation of the experts. The respondents may have been inclined to be more positive in order not to hurt our feelings or because of their involvement in time and effort. However, by means of the evaluation form (which was anonymous) we tried to allow for honesty.

Finally, in one of the evaluation interviews, a respondent asked: "What is the conclusion? How much is at risk? […] Is it significant or not? What I lack is the spread of the coming results." In other words: now we have identified lifetime impacts, but what do they mean? How will they influence the operations? We agree that these questions are not addressed in the LIIA, while they may be important for practitioners. Developing a way to deal with these impacts in a structured way that aids daily (O&M) practice may be a promising topic for further research.

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