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Evaluation of the Lifetime Impact Identification Analysis: Two tests in a changeable context

R.J. (Richard) Ruitenburg [a,b,*], A.J.J. (Jan) Braaksma [a]

[a] University of Twente, attn. Richard Ruitenburg De Horst (building 20), room N204 PO Box 217, 7500 AE Enschede, The Netherlands
[b] Liander N.V., attn. Richard Ruitenburg, Postbus 50, 6920 AB Duiven, The Netherlands

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ABSTRACT

Asset Life Cycle Management aims to maximize the value realized from physical assets over their complete lifetime. Over the years, the operation and maintenance of the assets must continually be adapted to changes in goals and context. In an earlier publication, we proposed the Lifetime Impact Identification Analysis to identify such changes. This paper tests this method through an application at two different companies. The method proved to result in a shared and integral overview of long-term challenges and opportunities for the asset, based on experts discussing the asset's future from a technical, economic, compliance, commercial and organizational perspective.

Introduction

Manufacturing is dependent on the safe and reliable functioning of countless physical assets: production lines, chemical plants, trucks and aircraft for transportation, infrastructure for people, freight and energy, etcetera. Physical assets typically have lifetimes of several decades. Therefore, assets designed and built decades ago still fulfil vital functions in manufacturing, as well as in society at large. However, with the passing of the years, many important changes happen that affect the assets. Regulations change, customers acquire new tastes, technology progresses, societal norms become increasingly tight and the skills in the workforce evolve. Additionally, the organization itself may change, for example by focusing on new markets or changing its manufacturing strategy from cost leadership to differentiation. Moreover, a company may have changed its perception of maintenance, from a necessary evil to a profit centre [1]. In the Asset Management literature, many authors recognize the impact of change in Asset Management, which they describe as happening at an ever-increasing pace (e.g. [2,3,4]).

These changes in the operating environment of the asset may have far-reaching implications for the operation and maintenance of the assets. Assets may need to be adapted to fulfil new requirements or demands, or may even become obsolete. As physical assets often represent large sums of money and changing them is time-consuming and costly [5] – if possible at all – these changes should be considered in Asset Management. The scientific literature on Asset Management argues that the complete life cycle of an asset should be taken into account to maximize the value realized from the exploitation of the asset (e.g. [6,7]), which is even more emphasized in the concept of Asset Life Cycle Management [8]. The need to adopt a 'life cycle approach' is also acknowledged by the recent ISO standard on Asset Management [9].

However, existing methods for Asset (Life Cycle) Management do not explicitly consider changes in the operating environment of the assets, nor do they offer clear guidance or tools to effectively manage assets over their complete life cycles. Therefore, we have developed a method to identify the changes in the operating environment of the asset relevant to Asset Life Cycle Management (ALCM): the Lifetime Impact Identification Analysis (LIIA) [10]. The objective of this paper is to test this newly developed method in practice. The test will be carried out by an implementation of the LIIA in two different settings: at a Dutch electricity network operator (Liander) and a Danish operator of an offshore windfarm (Vattenfall).

The next section will introduce the LIIA and its underlying generative mechanisms. Then, the methodology used for the development and test of the LIIA will be presented: the Design Science methodology. The Design Science methodology prescribes the test of a method in practice, to allow further refinement of the

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[*] Corresponding author at: University of Twente, attn. Richard Ruitenburg De Horst (building 20), room N204 PO Box 217, 7500 AE Enschede, The Netherlands. Tel.: +31 53 489 25 20; Liander N.V., attn. Richard Ruitenburg, Postbus 50, 6920 AB Duiven, The Netherlands.

E-mail address: r.j.ruitenburg@utwente.nl (R.J. (Richard) Ruitenburg).

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solution design. Therefore, we have implemented the LIIA in two different companies, and evaluated the method critically. The outcomes of the LIIA and its evaluation will be discussed thoroughly. We will conclude with a conclusion, including topics for further research and implications for practitioners.

The Lifetime Impact Identification Analysis (LIIA)

The Lifetime Impact Identification Analysis (LIIA) has been developed based on a case study of ALCM in practice in a changing context as well as on the literature. We have reported its development in a previous publication in this issue [10]. Nevertheless, we will briefly introduce the LIIA in this paper as well, to allow for a full understanding of the LIIA before we will report on the tests we have carried out.

The starting point of the LIIA is the notion that assets are only valuable to their owner as long as they contribute to the objective of the owner. Therefore, in ALCM the focus should lie on the preservation of the value creation potential of the asset. Value may be operationalized in different ways, depending on the situation. For example, in terms of profits, in terms of social value or in terms of customer satisfaction.

During the life cycle of the asset, changes may happen that affect the value creation potential of the asset. We have termed these lifetime impacts: ‘‘probable (technical and non-technical) events or trends that may have a positive or negative influence on the value creation through the use of the asset in the intermediate or long term’’ [10]. Positive impacts can be innovations or cost savings, negative impacts can be the obsolescence of certain components or a new regulation requiring additional safety systems. These lifetime impacts can be compared with failure modes in Reliability Centred Maintenance (RCM) [11,12]. Just as the identification of failure modes in RCM allows a designer to change the design or develop a suitable maintenance instruction, the identification of lifetime impacts in ALCM allows the Asset Manager to take timely measures to prevent negative lifetime impacts and to reap the full benefits of positive lifetime impacts.

The LIIA consists of five steps (see Table 1), with at the centre the expert session. The outcome of the LIIA is the Lifetime Impact Report (LIR), which represents all the information collected in the LIIA in a structured way. This report discusses the value created from the use of the asset from a long-term perspective, focusing on the (strategic) objectives the owner has with the asset, its current performance and the lifetime impacts that may affect the value created with the asset.

As ALCM is a multidisciplinary practice [7,8,10], impacts on the asset may range from very different backgrounds. These are captured by the acronym TECC: technical, economic, compliance and commercial. To identify all relevant lifetime impacts, each of these four perspectives is discussed separately in the expert session.

The LIIA has been developed based on three generative mechanism that underlie the method. These generative mechanisms were based on the literature, as initial solutions to three challenges identified in a case study on ALCM in practice [10]. The three challenges and the initial solutions to these are presented in Table 2, as well as the main references for each of the three generative mechanisms. The initial solutions are presented according to the CIMO-logic: in a certain context (C), a particular intervention (I) sets a specific mechanism (M) into motion, which leads to an outcome (O). These three generative mechanisms are important when we test the model, as these are the foundational building blocks of the model. If these mechanisms turn out to work in practice, that does not only indicate that the model build on these mechanisms works, but also that these mechanisms may be used in different applications. As such, the test of generative mechanisms is a contribution to scientific knowledge as well [13].

Methodology

The development of the Lifetime Impact Identification Analysis (LIIA) was guided by the Design Science methodology [14]. Typically, the Design Science methodology consists four phases: (1) the exploration of the problem; (2) the search for initial solutions for the problem; (3) the development of a solution; and (4) the test of the solution [15]. In our previous publication [10], we reported on the first three phases. Therefore, this paper will focus on the test of the solution design: the LIIA. Fig. 1 shows the four phases of the research.

To test the LIIA, we implemented the method in practice. To increase the generalizability of the test, we selected two different case companies for the test. The first implementation of the LIIA was carried out at Liander, the largest Dutch distribution network operator, responsible for the safe and reliable distribution of electricity and gas. As the LIIA was developed based on the exploration of the problems faced by Liander, it may be expected that the LIIA will suit their needs. Therefore, the second test was carried out at a very different company as a contrasting case [10], namely Vattenfall Wind Power. The specific case was one of the offshore wind farms they operate in Denmark. This is a useful contrasting case, because Vattenfall is a different company, based in a different country, working in a different sector, and operating very different assets. Compared with Liander, the number of assets in the wind industry is much lower (dozens vs. hundreds or thousands) while the (replacement) costs per asset are much higher (tens to hundreds of thousands vs. millions). Wind turbine generators (WTGs) are equipped with sensors and real-time data streaming, whereas most Liander assets are not, especially not in low and medium voltage. Additionally, the expected lifetimes of WTGs are 20 years, rather than 40 years at Liander. Because of these differences, this second case is a useful way to establish the generalizability of the LIIA method to a different industry. If the outcomes of the method are the same, this would indicate that

Table 1
A short explanation of the five steps of the LIIA [10].

Step	Description
1. Asset selection	Selection of the asset(s) to consider in the LIIA, as well as the scope and depth of the analysis.
2. Collection of general asset data	Collection of all available data and information on the asset, to prepare for the expert session. The main goal is to achieve a good understanding of the asset(s), their performance and the changes that may lie ahead.
3. Expert session(s)	Discussion of experts from different backgrounds, based on the information from step 2 and their expertise, to identify the lifetime impacts they consider relevant for the asset. In the discussion, explicit and tacit knowledge is combined to develop a shared understanding of the asset's future. Four different perspectives on the asset are considered: technical, economic, compliance and commercial (TECC).
4. Writing the Lifetime Impact Report (LIR)	Writing a report based on the information collected in the previous steps. The report presents the objectives of the asset owner, the asset's performance and the lifetime impacts identified in a structured way.
5. Evaluation	Evaluation of the LIR with the relevant experts, allowing to validate and refine the conclusions of the LIR.

Table 2
Overview of the three initial solutions to the three main challenges in ALCM, presented in CIMO-logic [10].

CIMO	Context	Intervention	Mechanism	Outcome	Based on
	Challenge 1: *Due to a limitation of readily available data, Liander has difficulties in getting insight in the remaining lifetime of its assets.*				
1	In the context of maintenance	Bringing together experts from different backgrounds in a discussion	Will start a mechanism of discussing ideas from their diverse experience in which their tacit knowledge is elicited	Which results in an 'educated guess' of potential failure modes based on the information and expertise that is available	Reliability Centred Maintenance (RCM) [11,12]
	Challenge 2: *Asset Management often necessitates the combination of information from various backgrounds. As this information is dispersed among various disciplines and departments, it is difficult to combine the information into an integral overview on the assets in a timely manner.*				
2	In the multidisciplinary context of Asset Management	Bringing together people from the four TECC perspectives (Technical, Economic, Compliance and Commercial)	Will start a process of knowledge exchange and integration	That leads to a shared view on the potential changes relevant to the asset	Expert sessions in RCM [11,12], the four TECC dimensions [23]
	Challenge 3: *Many urgent and pressing operational matters limit the (perceived) ability of the Asset Managers to focus on long-term and strategic challenges.*				
3	In the context of being overwhelmed with urgent and important issues	Creating an overview of all long-term threats and opportunities	May help to decide where to invest one's limited time resources	Which may result in less firefighting and a possibility to spend more time on long-term concerns	Priority-setting is discussed by Covey [24] as a solution to firefighting

these outcomes are caused by more general generative mechanisms, rather than specific characteristics of the Liander case.

The implementation and test of the LIIA at Liander and Vattenfall were executed as single case studies in 2013 and 2014 [16], allowing for a deep understanding of the context in which the company operates and a thorough evaluation of the LIIA. For each test, a short introduction will be given, the process and outcome of the LIIA will be described and the outcome will be evaluated and discussed.

Test at Liander: a LIIA on a population of switchgear

Introduction of Liander

Liander is one of the three main regional distribution network operators in the Netherlands, responsible for the construction, operation and maintenance of the electricity and gas grids. These network operators are semi-public corporations, responsible for the safe and reliable distribution of energy. Liander faces two important challenges with respect to the context in which it operates and maintains the grids. The first is the ageing of the networks, a problem widely acknowledged with respect to infrastructure assets in Western Europe and the USA [17,18]. Secondly, many changes happen in the production and use of energy, making its production more sustainable and more distributed. These changes are often summarized under the term 'energy transition' (see for example [19]).

As a consequence of these changes, Liander has set out to increase its understanding of the remaining life of its assets. Efforts have been made to strengthen the long-term and strategic focus of its Asset Management, turning it into proper Asset Life Cycle Management (ALCM). This research is one of the main pillars of this development of ALCM.

Implementation process

At Liander, the LIIA has been implemented for a specific population of switchgear assets. This population consists of several versions of medium voltage (10 and 20 kV) switchgear X, in total 2500 pieces of equipment. The population is young, but due to several technical problems, questions regarding the remaining lifetime of the assets have risen. Additionally, it is unknown what impacts the energy transition may have on this switchgear and what new failure modes may result from the energy transition. Hence, Liander proposed to carry out the first test of the LIIA on this asset.

To prepare the LIIA, time was spent on achieving a good understanding of the fit of the four TECC dimensions to the situation of Liander. For this, eight experts were interviewed (interviews of around 1 h) and company documents were studied.

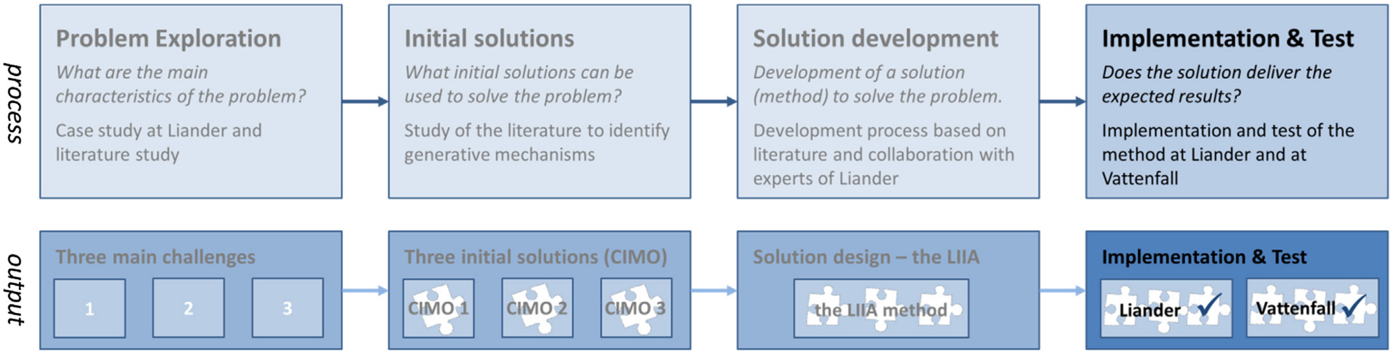


Fig. 1. Overview of the methodology, both from a process and an output perspective.
Adapted from [10].

Table 3
Overview of the LIIA on the population of switchgear X.

Phase	Description	Main activities
1. Asset selection	Selection of a particular type of switchgear (X)	In close consultation with the researchers, the manager of Asset Management selected this type of switchgear.
2. Collection of general asset information	Collection of general information on switchgear X and its population characteristics	Study of company documents (e.g. policy documents related to switchgear X) Collection of information stored in databases (e.g. age, numbers, maintenance data, cost data) Field trip to the asset and visit to the fault analysis team Interviews with experts on this type of switchgear (3 different experts, at least 1.5 h per expert)
3. Expert sessions	Identification of lifetime impacts on the four TECC dimensions in two expert sessions	A first expert session lasting for 2 h (5 experts present, representing all 4 perspectives) Additional study of company documents and information in databases (including an analysis of failure and financial data), based on the results of session 1 A second expert session, lasting for 1.5 h (3 experts available, one different from the experts attending the first session)
4. Writing the Lifetime Impact Report (LIR)	Structuring and summarizing the information into a Lifetime Impact Report	Wrap up of all the information collected, identify the lifetime impacts and report these in a structured way. Consultation with two experts on the asset.
5. Evaluation	Evaluation of the Lifetime Impact Report with the experts	Consultation with two experts on the asset. One expert session lasting for 1 h (6 experts present) Rewriting of the LIR to include the proposed revisions.

Table 4
Example of the lifetime impacts identified in the LIIA of switchgear X.

Perspective	Lifetime impact	Possible consequences
Technical	New types of degradation due to energy transition	Unexpected failure modes, increased wear (increase in the number of switching actions)
	Production stop (2014)	Shortage of spare parts (from 2024), limited supplier support, failure may lead to replacement
Economic	Due to local conditions individual assets require additional maintenance	Replacement is more profitable in these cases
Commercial	Remote control of switchgear is being discussed as an additional functional requirement	Current assets can be upgraded to remote control, but replacement would be cheaper
Compliance	None: asset complies with all current legislations	None
	However, additional safety requirements are currently under discussion in the sector	Asset can be made compliant to these new requirements, but replacement would be cheaper

Table 3 gives an overview of the five steps of the LIIA. A number of the lifetime impacts that were identified using the LIIA have been listed in Table 4.

Evaluation

The LIIA was evaluated with the Asset Manager responsible for switchgear X and some additional experts. Additionally, it was discussed in the expert session to evaluate the LIR. Overall, the experts were positive about the LIIA and the resulting LIR, and it was clear that they liked the opportunity to exchange knowledge and ideas with other experts on the asset. The Policy & Standardization division appreciated the value and further potential of the LIIA and hence decided to continue working with the LIIA. The remainder of the evaluation will be structured according to the three CIMO-statements, to evaluate if the generative mechanisms we expected to see worked in practice. If the results comply with our expectations as formulated in the three generative mechanisms, this indicates the applicability of these mechanisms outside the scope of these two cases, as well as the generalizability of the LIIA in other cases [20]. This section will be closed with a few additional findings resulting from the evaluation.

Evaluation of CIMO 1: discussion between experts to identify lifetime impacts

CIMO 1 stated that bringing together experts in a discussion (I) may result in an 'educated guess' on future issues relevant to the asset (O) through the exchange of (tacit) knowledge (M). Indeed, the experts were able to identify a large number of future opportunities and threats for the asset (O), based on their experience and the exchange of ideas (M) in the discussion (I). Even the most knowledgeable expert on switchgear X learned of a new threat, which resulted from a combination of information brought in by different experts. This indicates that CIMO 1 can be accepted regarding this first implementation (the conclusions from the evaluations are presented in Table 7).

The evaluation also showed that for some of the experts little new information resulted from the discussion, as they were already aware of most lifetime impacts. Interestingly, they acknowledged that their knowledge of these lifetime impacts had not been made explicit before. As a result, this information was not available to influence decision-making (e.g. at management level), unless the experts were explicitly involved in the decision-making process. Additionally, it was found that the focus on long-term opportunities and threats was difficult to establish, as the experts were most familiar with and knowledgeable about current problems. Keeping the discussion focused on long-term developments is an important task for the facilitator of the discussion.

Evaluation of CIMO 2: discussing the four TECC perspectives results in a shared view

CIMO 2 argues that the discussion of the four TECC perspectives (I) results in a shared view on the potential changes relevant to the asset (O) through the knowledge exchanged in the expert session (M). The experts concluded that the LIIA, including the expert session (M), had resulted in an integral view on the long-term viability of the population of switchgear X and the most important lifetime impacts, which did not exist before. Additionally, they appreciated how the LIR presented this information in a clear, structured and accessible way. They anticipated that this written overview might support decision-making with thorough and robust information and prevent suboptimal decisions being taken (e.g. optimal for a subpopulation, but not for the population as a whole, or optimal for one lifetime impact, but not for all).

CIMO 2 also states that the discussion of the four TECC perspectives (I) is sufficient to create an integral view of the asset's future. However, this was challenged in the evaluation, as the Asset Manager of switchgear X told that the reputation it had with the technicians was an important problem for this type of switchgear. In contrast to the facts, they perceived the asset to be unsafe. This remark led to further discussions, which showed that the perspective of the organization should be taken into account as well. This organizational perspective covers topics like the availability of well-trained and skilled technicians (in an ageing labour force), an organizational desire for standardization or a growing concern for sustainability. Hence it had been decided to include a fifth perspective, turning TECC into TECCO, resulting in a refinement of CIMO 2. The new Organizational lifetime impacts take the perspective of the organization: is the organization still willing and able to operate the assets?

Evaluation of CIMO 3: an overview of lifetime impacts allows to decide where ALCM effort is needed

Finally, CIMO 3 anticipated that creating an overview of all long-term threats and opportunities (I) may help decide on what topics to spend one's ALCM efforts (M) and, as a result, reduces the need to fight fires later in time and allows to spend more time on long term challenges and opportunities (O). One of the main outcomes of the LIIA was a number of threats and opportunities that needed additional attention from the Asset Manager. However, due to the fact that the maintenance of switchgear X had been updated recently, these were only minor issues that needed monitoring rather than major efforts. Therefore, it can only be concluded that a list of the main threats and opportunities may result from the LIIA (I) and that this may confirm the current priorities of the Asset Manager (M), but not that such an overview will help to decide where to spend ALCM efforts (M), nor that it allows more time to be spend on future matters (O).

The managers of the Policy & Standardization department agreed that the LIIA and the LIR gave a nice overview of the main issues and the future of switchgear X. However, they preferred the LIR to also present an overview of the main decisions to be made (e.g. replacement or modernization). In other words: an overview of those issues that should have their priority. Again, if there would have been larger issues with the asset, such a list may have resulted from the LIIA, but in this test application it did not.

Apart from the matters related to the three CIMO statements, two other findings resulted from the evaluation. The first was the realization that the execution of a LIIA for all different types of switchgear would be too time-consuming. Therefore, it was decided to focus a future project on the total population of medium voltage switchgear. Secondly, it was concluded that a more objective evaluation method of the LIIA and the LIR might be beneficial to the research, a method different from an evaluation by means of a discussion in the expert session. As a result, a short questionnaire was developed to evaluate the next application of the LIIA, at Vattenfall.

Test at Vattenfall: a LIIA on a population of offshore wind turbines

Introduction to Vattenfall

To test the changes resulting from the evaluation of the LIIA at Liander as well as the LIIA's suitability to a different setting, we selected Vattenfall Wind Power for a second test of the LIIA. Vattenfall Wind Power operates a large number of windfarms, both onshore and offshore. One of their offshore windfarms is Horns Rev 1 (HR1) in Denmark. HR1 was erected in 2002, which makes it the oldest large-scale offshore windfarm in the world. It consists of 80 identical 2 MW wind turbine generators (WTGs), each with an expected lifetime of 20 years. The WTGs in HR1 are very modern and high-tech systems, continuously streaming data about their operation and condition.

The operation and maintenance of HR1 is facing a changeable context. First, the end-of-life of HR1 is slowly approaching, resulting in questions about the remaining life of the WTGs, the potential for modernization and whether or not costly and large scale maintenance actions would still be profitable. Second, technical progress in the wind industry is fast, resulting in ever larger and more efficient WTGs [21]. Third, the subsidies for HR1 are decreasing and a new subsidy scheme is under discussion, which may have implications for the profitability of the farm. Because of these changes, the LIIA may fit the circumstances of Vattenfall well. On the other hand, Vattenfall provides an excellent case to test the LIIA in a very different setting: high value assets with a high maintenance intensity, a large amount of data available and a private production company in the offshore wind industry instead of a semi-public utility company as Liander is.

Implementation process

In preparation of the LIIA, a collaboration was started with an industrial Ph.D. fellow at Vattenfall Wind Power. Efforts were made to get acquainted with the (offshore) wind industry and the situation of HR1 in particular. For this purpose, company documents were read, as well as some scientific papers on maintenance in the wind industry. A short summary of the activities carried out in the five steps of the LIIA is given in Table 5. For confidentiality reasons not all lifetime impacts can be shown, but some examples of technical and organizational lifetime impacts identified for HR1 are given in Table 6.

Evaluation

The six experts present in the expert session have evaluated the session by means of a short questionnaire consisting of a number of Likert scaled questions – ranging from 1 (not at all) to 7 (very much) – and open-ended questions. The evaluation showed that the experts appreciated the workshop (average score 5.8). The resulting LIR was evaluated by means of both an evaluation survey and an in-depth interview with the two main Asset Managers for HR1. They assessed the LIR with an average score of 6.0. To get a deeper understanding of these scores and the application of the LIIA at Vattenfall, we will again discuss the three CIMO expressions. Again, the results can be found in Table 7.

Evaluation of CIMO 1: discussion between experts to identify lifetime impacts

CIMO 1 asserted that the exchange of knowledge (M) in a discussion between experts (I) results in an overview of future lifetime impacts for the asset. In the evaluation interview, one of the Asset Managers said the LIR "gives a good overview of the issues we have been seeing at HR1 together with impacts that we expect to see", which shows that the outcome of the LIIA fulfilled our expectations (O). This overview was established by bringing experts together in a discussion (I), where they exchanged their ideas and experience (M). One of the experts stated he liked the session, because it is "good to hear other's opinion", which shows that this mechanism does not just work, but is also appreciated. Also, it was stated that "it is good to have it [the overview of lifetime impacts] on paper", just as the experts at Liander acknowledged.

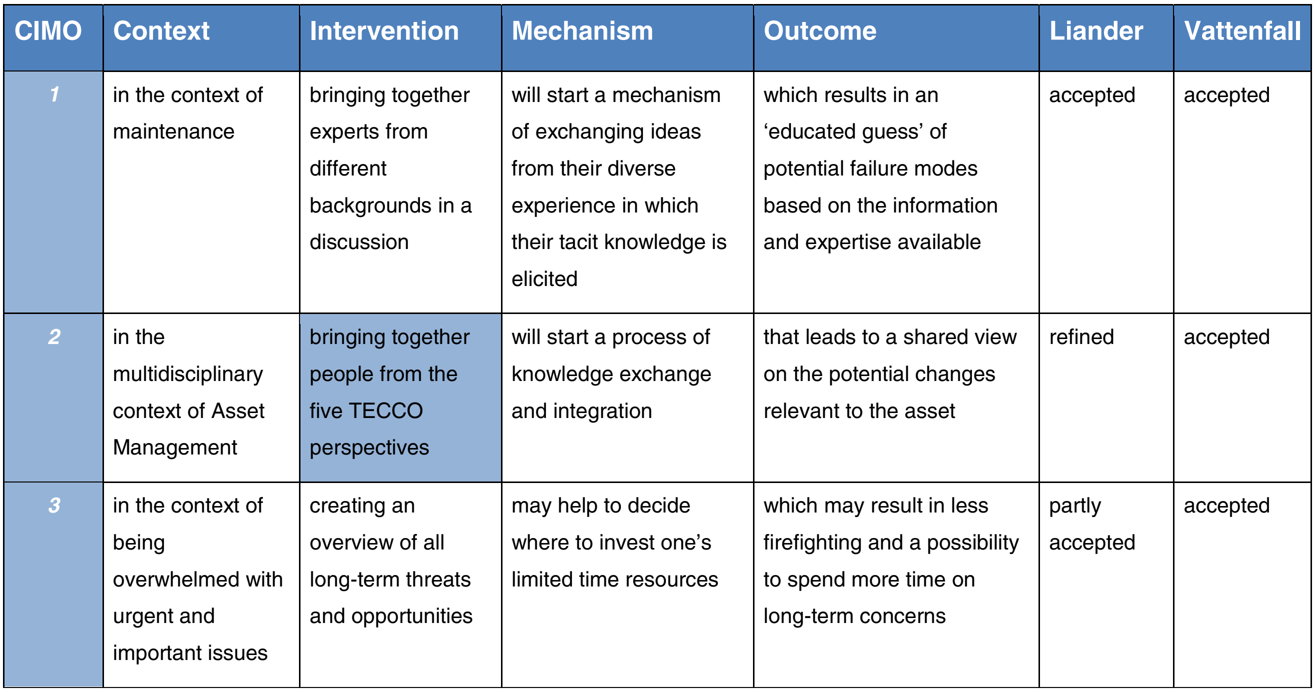
Table 5
Summary of the LIIA as carried out for the 80 turbines in HR1.

Phase	Description	Main activities
1. Asset selection	Selection of the WTGs in HR1	- In close cooperation with the site manager of HR1, it has been decided to focus on the complete turbines, rather than on the main components.
2. Collection of general asset information	Collection of general information on the WTGs in HR1, including population characteristics	- Study of company documents (e.g. policy documents, performance reports, the initial investment plan) Collection of information stored in databases (e.g. age, numbers, maintenance data, cost data), analysis of failure data. A visit of a turbine similar to those in HR1. Several interviews with experts
3. Expert sessions	Identification of lifetime impacts on the five TECCO dimensions in an expert session and a follow-up session with the site manager of HR1	- A first expert session lasting for 4 h (6 experts present, representing all 5 perspectives) - A questionnaire has been handed out to evaluate the expert session. - A follow-up session with the site manager of HR1 to discuss and validate the conclusions of the first session (1.5 h)
4. Writing the Lifetime Impact Report (LIR)	Structuring and summarizing the information into a Lifetime Impact Report	- Wrap up of all the information collected, identify the lifetime impacts and report these in a structured way. - Consultation with several experts for minor matters and details.
5. Evaluation	Evaluation of the Lifetime Impact Report with the experts	- Evaluation of the LIR with two experts (1–1.5 h interviews). - A questionnaire has been handed out to evaluate the LIR. - Rewriting of the LIR to include the proposed revisions.

Table 6
Illustration of technical lifetime impacts for HR1 as presented in the LIR (+ indicates a positive lifetime impact, − a negative one) and their potential consequences.

Perspective	Lifetime impact	Possible consequences
Technical	- Failure of one of the main components due to age	Long downtime as spare parts have long lead times
	- Grid connection failure	No energy production for 8 up to all WTGs (depending on where the cable fails) for a long time
	+ Growing spare part market due to decommissioning of existing WTGs (older farms)	Spare parts will become cheaper in the future
Organizational	- The approach of the end-of-life (EOL) may cause skilled technicians to look for new jobs, as they may be afraid to lose their jobs after the EOL	Loss of knowledge and expertise, lower capacity for making repairs
	+ Additional training may increase quality of inspections	A higher quality of inspections may prevent more failures. Additionally, training may increase worker safety
	+ Advanced data analysis may be valuable	Smart preventive maintenance may reduce failures

Table 7
Overview of the test results of the three generative mechanisms (presented in CIMO-logic), the highlighted cell indicates the change made based on the two tests.



CIMO	Context	Intervention	Mechanism	Outcome	Liander	Vattenfall
1	in the context of maintenance	bringing together experts from different backgrounds in a discussion	will start a mechanism of exchanging ideas from their diverse experience in which their tacit knowledge is elicited	which results in an ‘educated guess’ of potential failure modes based on the information and expertise available	accepted	accepted
2	in the multidisciplinary context of Asset Management	bringing together people from the five TECCO perspectives	will start a process of knowledge exchange and integration	that leads to a shared view on the potential changes relevant to the asset	refined	accepted
3	in the context of being overwhelmed with urgent and important issues	creating an overview of all long-term threats and opportunities	may help to decide where to invest one’s limited time resources	which may result in less firefighting and a possibility to spend more time on long-term concerns	partly accepted	accepted

Evaluation of CIMO 2: discussing the five TECCO perspectives results in a shared view

CIMO 2 states that the discussion of the five TECCO perspectives in an expert session (I) facilitates the exchange of knowledge from different disciplines (M) and results in a shared and integral view on the future of the asset (O). In the discussion on CIMO 1, it was already shown that the LIIA has resulted in "a good overview of the issues we have been seeing at HR1 together with impacts that we expect to see". Upon the explicit question if they could think of any additional lifetime impact from another perspective than the five TECCO perspectives, they answered negatively, showing that the discussion of these five perspectives (I) and the resulting exchange of knowledge (M) results in a shared and complete view on the asset's future (O).

In the results of the evaluation survey, both the experts indicated that the session was not very useful for their daily work (4.5), but that they thought it was quite useful for the company at large (5.5). The same was found with the Asset Managers (5.0 vs. 6.0). This may indicate that the integration of (multidisciplinary) knowledge does not so much benefit individual specialized employees, but does benefit the entire company, as decisions will have to be made on an integral overview of the main threats and opportunities relevant for HR1. This corresponds with the statement of one of the Asset Managers, who said that the LIR "gives us a better overview" than they had before, which "gives a better basis for making decisions" through the integral and structured presentation of the main concerns relevant for the future of HR1. This shows the potential value of the combination of existing knowledge, held at different departments within the company, which is also indicated by the expectation of the Asset Managers that the LIR will help them to increase value from HR1 (5.5).

Evaluation of CIMO 3: an overview of lifetime impacts allows to decide where ALCM effort is needed

According to CIMO 3, we expect that having an overview of all lifetime impacts (I) allows the Asset Manager to decide where to spend time and effort (M), which may result in more time available for long term matters and a reduction of fire-fighting in the future (O). In the interviews, the Asset Managers acknowledged this generative mechanism. One of them stated that the LIR "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". As a result, this would allow them to "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". In retrospect, the Asset Managers acknowledge how an overview of lifetime impacts would have helped them to set priorities and to prevent firefighting. However, they also acknowledged that the report itself does not prevent firefighting: "it is good to know this, but there should be someone to take care of it [the lifetime impacts]".

The evaluation at Vattenfall also revealed a topic for further research. After reading the LIR, one of the experts (not the Asset Manager) stated that the listing of the lifetime impacts is a promising start, but needs to be taken a step further. Because "as a reader [of the LIR] you have no idea of the magnitudes" of the lifetime impacts, which makes it difficult to decide what the most important lifetime impacts are. After prioritizing the lifetime impacts, suitable measures can be prepared to prevent the consequences of negative impacts and to enjoy the full benefits of positive impacts. These issues may be addressed in future research on the LIIA.

Conclusion

To create maximum value from the use of physical assets, it is essential to consider their complete lifetimes. During the lifetime of an asset – which may span several decades – many changes may happen, both in the context of the asset as in the objectives the owner has with the assets. These changes should be taken into account in Asset Life Cycle Management (ALCM). However, existing methods do not explicitly consider such changes. Therefore, we developed the Lifetime Impact Identification Analysis (LIIA), which we presented in a previous article [10]. The LIIA aims to identify lifetime impacts: probable (technical and non-technical) events or trends that may have a positive or negative influence on the value creation through the use of the asset in the intermediate or long term. Knowing these lifetime impacts is the first step to prepare timely measures to prevent the consequences of negative impacts, while reaping the full potential of the positive impacts.

The LIIA was developed based upon a case study in practice, as well as on three generative mechanisms abstracted from the literature. In this paper we have put the LIIA to the test by means of two applications in two different companies: Liander and Vattenfall, both operating in changeable contexts. The test applications showed the usefulness of the LIIA for the companies and its potential to assets Asset Management in a changeable context. All three generative mechanisms abstracted from the literature were corroborated by these tests in practice (see Table 7), showing their applicability outside the scope of these two cases, as well as the generalizability of the LIIA. Hence, we may first conclude that the limited availability of data can be (partly) offset by the tacit knowledge of experts, who together may be able to identify lifetime impacts through an expert session. Second, in such an expert session, the discussion of five different perspectives – Technical, Economic, Compliance, Commercial and Organizational – leads to an integral view of the lifetime impacts relevant for the asset. Finally, the overview of all these lifetime impacts can help Asset Managers to decide where to spend their time and efforts, which may reduce the need for fire-fighting in the future. The test and refinement of these three generative mechanisms contributes to scientific knowledge and addresses the gap in the literature concerning how to implement multidisciplinary, long-term and strategic ALCM.

Further research may investigate the long-term effects of the application of the LIIA, as this research has only been able to assess the LIIA using interviews and an evaluation questionnaire, rather than by an objective measurement of Asset Management performance. Additionally, further research may extend the LIIA with a method to prioritize lifetime impacts and a tool to support decision-making on the most important lifetime impacts. This may be done in a similar way as in RCM, which does not only identify failure modes, but also prioritizes these and proposes suitable maintenance actions through the RCM decision diagram [11].

From a practical perspective, it was shown that the LIIA addresses the three main challenges in ALCM as identified at Liander. A successful application at Vattenfall Wind Power showed that the LIIA is likely to be applicable more widely than just in the specific setting of Liander. It also showed the practical relevance of the method and its contribution to Asset Management practice. For practitioners, this research has three important implications.

Firstly, this research has shown that lifetime impacts can be identified even if not all desirable information and data are available. The expertise of experienced people may partly overcome these information problems (for a similar finding in the context of RUL estimation, see [22]). Therefore, it is important to acknowledge the value of expertise and (tacit) knowledge of engineers, technicians, operators and other employees working with the assets. It may even be advisable to seek the expertise of the supplier in the (preparation for the) LIIA. The same applies to service providers or other parties involved with the assets outside the company (e.g. in case of outsourcing).

A second implication is that ALCM should be multidisciplinary, practically meaning that all five TECCO perspectives should be taken into account. Thus, a singular focus on a technical or financial perspective is too limited. Rather, one should be aware of potential Technical, Economic, Compliance, Commercial and Organizational lifetime impacts.

Finally, one must realize that a long-term focus in ALCM will probably not come about spontaneously. Urgent problems will always be there and will need to be solved. However, without a long-term focus, opportunities may pass by unnoticed and one may only identify negative lifetime impacts when it is too late to prevent their occurrence. Hence, a method like the LIIA may be used to bring a long-term focus into ALCM.

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