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A multidisciplinary, expert-based approach for the identification of lifetime impacts in Asset Life Cycle Management

R.J. (Richard) Ruitenburg^{a,b}*, A.J.J. Braaksma^a, L.A.M. van Dongen^a

^aUniversity of Twente, De Horst 2, 7522 LW Enschede, the Netherlands

^bLiander N.V., Utrechtseweg 68, 6812 AH Arnhem, the Netherlands

* Corresponding author. Tel.: +31- 53 489 4022; E-mail address: r.j.ruitenburg@utwente.nl

Abstract

Everyday our lives are dependent on countless physical structures. These assets represent an enormous value for their owners and for society at large. To grasp the full potential of these assets, a deep and thorough understanding of an asset's complete lifetime is needed. Problems with data collection and data quality however limit currently available methods for Asset Life Cycle Management in their potential to deliver such a deep understanding. Therefore, this paper proposes to focus on the identification of lifetime impacts: trends or events that may have a positive or negative influence on the remaining lifetime of the asset. Timely identification of these impacts allows the asset owner to prepare appropriate measures. Based on a literature review and a case study, the paper argues that a multidisciplinary approach employing both quantitative and qualitative information is needed. The Lifetime Impact Identification Analysis (LIAA) method is presented, incorporating technical, economic, compliancy and commercial perspectives on the asset. The method exploits expert-sessions to gather and structure available knowledge into a Lifetime Impact Report. Preliminary test results show that the proposed method is promising to both theory and practice.

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1. Introduction

Our daily lives heavily rely on all kinds of physical structures, ranging from houses and cars to all sorts of industrial production structures and infrastructure assets like roads, bridges and the electricity grid. Many of these infrastructure assets – at least in the Netherlands – have been built in the years after the Second World War, and are currently approaching the end of their expected functional lives [1]. These ageing assets are in need of more intensive maintenance, and modernization or life extension may be worthwhile. On the other hand, timely disposal of assets may be needed to prevent all kinds of excessive costs, or risks in terms of health and safety. Furthermore, as these assets have been put into service in a relatively short period of time and may have comparable life expectancies, a 'replacement wave' may lie ahead, in which planning becomes an important issue

as resources (both in terms of money and manpower) are scarce.

For interventions such as modernization, life extension or disposal, a trustworthy estimation of the remaining useful lifetime of an asset is necessary. However, such an estimation is delicate as well as difficult. Delicate because a premature disposal of the asset is a direct destruction of capital, whereas an overly extensive prolongation of the use of the asset may go hand in hand with an undesirable increase in failures with the probable consequences of financial, health and environmental damage [2,3]. At the same time such an estimation is difficult because oftentimes it can only be based on imperfect asset information, as information is scattered, data availability is low, data quality is doubtful and our knowledge of the future is incomplete by definition [4].

In this paper we want to present some preliminary results of the advances in our research project. The aim of the paper

is to develop a method to gain a deeper insight in the remaining lifetime of an asset by identifying possible lifetime impacts. First, a short overview of the recent literature on the estimation of the remaining lifetime of an asset will be presented and a number of weaknesses will be addressed (section 2). Then, the design science methodology used in this paper will be introduced (section 3). Following this methodology, we will then turn to the exploration of the problem and potential solutions (sections 4 and 5). This exploration will be concluded by a number of design criteria, which will guide the development of our method (section 6). After the presentation of the method, some preliminary test results will be shown and discussed, based on an implementation at Liander, the largest network operator in the Netherlands (section 7). The paper ends with a number of concluding remarks (section 8) and a discussion (section 9).

2. Literature

The management of physical assets, including the decision to refurbish or replace these, falls within the field of Asset Management. Asset Management (AM) can be described as “an organisation’s coordinated multidisciplinary practice that applies human, equipment and financial resources to physical assets over their whole life cycle to achieve defined asset performance and cost objectives at acceptable levels of risk whilst taking account of the relevant governance, geo-political, economic, social, demographic and technological regimes” [5]. This definition, summarizing a number of existing definitions of AM, shows that AM ideally fulfils at least five criteria: it should be 1. a multidisciplinary practice; 2. in which the whole life cycle of a physical asset is taken into account; 3. with the goal to achieve certain objectives; 4. within the limits of risk and relevant regimes; and 5. that this should determine the allocation of resources.

Asset Life Cycle Management (ALCM) can be seen as a subdiscipline of Asset Management, which even more explicitly focuses on the whole life cycle of the asset. 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” [6], and thus also stresses the importance of a multidisciplinary approach to Asset Management. As in general AM the whole life cycle of the asset gains more and more attention, the difference between AM and ALCM is diminishing in the opinion of the authors. For the sake of clarity of the remainder of this paper, we will use the term Asset Management to describe the field in general, and ALCM to stress the importance of taking the whole life cycle of the asset into account from a multidisciplinary perspective.

2.1. The end of the asset’s useful life

Within Asset Management, one of the main questions is when a particular asset will cease to be of value for its owner [2], for example because of degradation, irreparable failure or because spare parts are no longer available. Hence, the estimation of when this moment will come is crucial, as at this

moment the function of the asset should be taken over by another asset (if the function is still needed).

To estimate this precise moment, remaining useful lifetime estimation is often used [7]. This remaining useful lifetime (RUL) can be defined as “the length from the current time to the end of the useful life”, where the useful life is described as “the period during which an asset or property is expected to be usable for the purpose it was acquired [for]” [7]. We interpret this as ‘to produce value for its user or owner’, where indeed value can be interpreted strict financially or in broader terms.

Currently, the estimation of the RUL is a topic of extensive research efforts, probably because improvements in such estimations may be of enormous value. Assume the RUL would be known exactly, then an asset could be exploited until this exact moment without any increased failures or costs, which would create optimal value for its owner [8,9]. Furthermore, knowing the processes or incidents that cause the end of the assets useful life would allow the owner to take preventive measures to extend the asset’s life.

2.2. Weakness I – Monodisciplinary approach

However, there are a number of weaknesses related to current approaches to estimate the end of the asset’s useful lifetime. This paper will discuss two of these weaknesses. Firstly, as Asset Management is a multidisciplinary practice, the estimation of the remaining useful life should be so as well. However, Haffejee & Brent [6] conclude that in many current methods for the end-of-life estimation “the economic, environmental, social and technical dimensions of asset management are not explicitly depicted”. For example, many approaches are limited to the technical aspects of the asset [such as 10,11,12] or to a more statistical approach to deterioration mechanisms [such as 2,7]. Furthermore there are a number of approaches focusing on the financial aspects of the asset, for example related to life cycle costing (LCC) [13,14]. Also, Komonen *et al.* [15] argue that in Asset Management the alignment with the corporate objectives and their impacts on the remaining lifetime are often lacking. Hence, Haffejee & Brent [6] conclude that at least “economic, environmental, social and technical factors and performances” should be taken into account in the estimation of the remaining lifetime of an asset. Also, Woodhouse [16] proposes a multidisciplinary approach and gives an overview of the diverse types of aspects that might be relevant.

2.3. Weakness II – Quantitative approach

A second weakness in the estimation of the remaining useful life is the information input needed for such an estimation. Often, these estimations are approached from a quantitative perspective. Si *et al.* [7] present a review of over 120 journal articles on the statistical estimation of the RUL. One of their main conclusions is that many quantitative attempts fail because of the quality and availability of data. Hence they conclude that there is need for a method that is suitable for situations in which limited or no quantitative data are available, for example a method based on the knowledge of experts [7]. This is in line with the conclusions of Braaksma

[4] in his study on a quantitative approach in Reliability Centred Maintenance (RCM), where the availability of reliable data often is a problem. Jongen [2] and Tinga [1] report similar findings. Hence, when we use the concept ‘remaining (useful) lifetime’ in the remainder of this paper, we mean the “the length from the current time to the end of the useful life” [7], without the quantitative connotation that is often given to this term.

3. Methodology

The goal of this paper is to develop a method to gain a deeper insight into the remaining lifetime of an asset. This method should be truly multidisciplinary and should allow for a qualitative approach in case insufficient reliable data are available. To reach this goal in a valid and reliable way, we have made use of the design science methodology. This methodology “specifically focuses on tackling ill-structured problems in a systematic manner” [17]. Or, as Hevner *et al.* [18] state, it is “fundamentally a problem-solving paradigm”, which can help to resolve “the fundamental dilemmas [...] [of] rigor [and] relevance”. As this research project seeks to solve a complex, real-world problem in a rigorous way that is at the same time relevant to practitioners, the design science methodology is well suited to fit the project.

One of the main problems in the design science methodology is that there is no broadly accepted structure to conduct and present a design science research [17-19]. Hence, this paper will focus on building a clear and strong ‘chain of evidence’ to show the (construct) validity of the designed method, similar to how Sousa and Voss showed the validity of their case study researches [20,21]. The chain of evidence has begun with an overview of literature on the remaining lifetime estimation of assets (section 2), which showed the paper’s theoretical relevance. However, in management related research, the relevance to practitioners should be just as important as the relevance to scientists [22,23]. Hence, the problem will also be explored from a practical perspective (section 4). Exploring the problem is of great importance, as “solving a problem simply means representing it so as to make the solution transparent” [18,24].

As a problem can be defined as “the differences between a goal state and the current state of a system” [18], we will then turn to the desired goal state by means of solution exploration (section 5). Again, we will look at both theory and practice, using a literature study for the first and an exploratory case study for the latter. The goal of course is to find a way to move from the current state to the goal state. Design science provides the steps to design a method to reach this desired state. The design will be guided by a number of design criteria, which will be extracted from the exploration of the problem and possible solutions. These criteria also allow us to evaluate the final method in a clear and structured way.

Guided by these design criteria, a solution design will be developed, namely a method to gain a deeper insight in the remaining lifetime of an asset (section 6). The proposed solution design will then be put to a first preliminary test by means of an implementation in a real life situation (section 7). Not only will this allow us to test its usability for practitioners,

but also to evaluate it from a scientific perspective. The paper will end with a number of concluding remarks (section 8) and a discussion (section 9).

4. Problem Exploration

The literature overview (section 2) showed that a multidisciplinary approach often lacks in the estimation of the remaining lifetime of an asset and that data quality and availability often limits purely quantitative approaches. These problems are also experienced as relevant problems in practice, for example at Liander N.V., the largest Dutch network operator. Liander is responsible for a safe and reliable distribution of electricity to 3.1 million Dutch customers and gas to 2.4 million customers (many of these customers make use of both). The department Asset Management is responsible for the maintenance of the networks owned by Liander, which represent a replacement value of around 10 billion euros. Liander can be viewed as a good performer in the field of Asset Management, shown by the NTA 8120, PAS 55-1 and ISO 9001 certifications it holds. Furthermore, Liander aims to continuously improve itself by optimizing its processes and adopting new methods and tools.

Liander is under constant pressure to maintain and improve the reliability and safety of the distribution of electricity and gas. Currently, two additional challenges present themselves. The first is the ageing of its electricity grid. Important parts of the Dutch electricity network have been built in the years after the Second World War and currently approach the end of their lifetime, as is the case in large parts of Western Europe and the United States [25-28]. Secondly, there are many changes in society Liander has to cope with, for example the energy transition, including the increased use of renewable energy and the possible surge of electrical transport. Hence Liander more than ever needs to be pro-active in its Asset Management. Therefore, Liander sees great potential value in an improved insight in the remaining lifetime of its assets. A joint pilot research project has been started with the researchers to develop new methods that could increase Liander’s insight in the remaining lifetime of its assets.

Currently, the remaining useful lifetime estimation at Liander is predominantly based on technical arguments, such as increasing failure rates or increasing safety risks due to degradation. Liander’s asset managers try to make use of quantitative methods and models to predict failure rates and to process condition monitoring data, see for example the Ph.D. research by Jongen [2] and Chmura [29], which were both funded by Liander. However, these quantitative data are often unavailable or unreliable at this moment, although currently great efforts are made to increase the availability and interoperability of these data. Also, based on available data quantitative analyses such as Weibul analyses estimations do not always offer reliable results for the far future, e.g. further than 10 years from now, while many assets have expected lifetimes up to 40 years. Furthermore, these data do not cover all relevant aspects for the asset’s remaining useful lifetime that would be needed for a truly multidisciplinary approach. Chmura [29] hence concludes in a discussion on the quality and availability of failure data that “misleading conclusions

about future failure behaviour may be drawn” [29], which could lead to errors in the remaining useful lifetime estimation and hence to suboptimal decisions.

But also data availability leads to problems. Within Liander, the knowledge needed to gain a multidisciplinary insight in the asset’s remaining lifetime is scattered within the organization: over databases, people and departments. Hence, to gather all relevant information and (tacit) knowledge is an important challenge. This also hinders the company to get a full integral view of their assets and to what extent these are future-proof in their changing business environment.

5. Solution Exploration

After the exploration of the problem, the design science methodology continues with the exploration of possible solutions. As solution designs are often created by “adapting existing tools or by using existing tools in novel ways” [17], we will now turn to the study of existing solutions to the problem presented. We have searched for solutions in scientific literature (section 5.1) as well as in practice (section 5.2). The results of this search will be presented now.

5.1. Solution exploration I – study of literature

Multidisciplinary approach

A literature search has been carried out to find the disciplines that should be incorporated in a truly multidisciplinary approach to the remaining lifetime of an asset. It was found that the most elaborate approach thus far has been presented by Van Dongen [9], in a professional report on life extension of assets. Based on a study by the Dutch Institute for World Class Maintenance in cooperation with a number of large industrial companies, Van Dongen presented a model for life extension of assets. This model explicitly takes a multidisciplinary approach, as it focusses not only on the technical and financial aspects of the lifetime of an asset, but also takes commercial and compliancy perspectives into account.

However, Van Dongen [9] does not show the development process of his model and lacks explicit scientific grounding. Hence we have searched scientific literature to see whether his conclusions correspond with those in literature. It turned out that in scientific literature, the same perspectives can be found, albeit often in a less explicit way. Haffejee & Brent [6] for example mention that in ALCM “economic, environmental, social and technical factors and performances” should be taken into account, where performance is related to the commercial perspective as proposed by Van Dongen [9]. A second example is Pudney [5], who mentions “governance, geo-political, economic, social, demographic and technological regimes”, where technical, financial and compliancy (namely ‘governance, geo-political and social’) are explicitly mentioned. Later in this work also the commercial perspective is addressed. Thirdly, Woodhouse [16] mentions a number of aspects that should be incorporated in Asset Management, which include the ones mentioned above. And as a last example, Woodward [30] talks about ‘functional, physical, technological, economic and social and

legal life’, where functional is closely related the commercial perspective. However, in this literature, reports of successful and systematic applications of these approaches are rare.

Perspectives on the remaining lifetime of assets

We will now discuss the different relevant perspectives on the assets remaining lifetime, based on the description by Van Dongen [9] and supplemented with other relevant literature.

The first perspective is the **technological perspective**, which is related to the question for how long the asset (and/or its output) will comply with the existing technical specifications. A large part of the literature on maintenance and Asset Management focuses on this aspect of the asset’s lifetime, using concepts like failure mechanisms, failure rates, mean time between failures (MTBF), bath tub curves and degradation mechanisms [e.g. 10,11,31,32].

The second outlook, the **economic perspective**, has to do with the costs of operating and maintaining a piece of equipment. With rising maintenance costs, higher costs of spare parts or the availability of low cost alternatives, the prolongation of the use of the asset may no longer be economically viable. The literature on Life Cycle Costing (LCC) [e.g. 13,14,30] is intimately related with this lifetime perspective.

Thirdly there is a point of view that receives less attention in literature, the **compliance perspective**. Compliance has to do with the ‘licence to operate’ of the company: is the use of the asset allowed from a legal perspective, but also socially accepted? Hence a diverse range of topics, such as sustainability, safety, working conditions and sectorial norms, may all have an influence on the compliance of the asset [6,16].

The fourth and final perspective is the **commercial perspective**, which asks the question whether the asset (and its production) are still able to fulfil the demands of the market. Where from a technical point of view one would ask whether the asset is still able to produce a predetermined quality and quantity of output, the commercial perspective asks the (related) question whether this output is still attractive for the customers. This commercial outlook is related to the concept of technical obsolescence [33]. It also has to do with the company’s business environment and the competitive position of the company [15]. From this commercial perspective it also becomes clear that the strategic objectives of the company at large should be aligned with the management of the assets it uses [15].

Expert-based approach

The focus on these four different perspectives leads to a deeper insight in the remaining lifetime of the asset, but also comes at a cost. Very different concepts and approaches, terminology and measures should be brought together. Furthermore, each discipline has its own ‘language’, from mean time between failures and discount rates to jurisdiction and market developments. This means that the development of a mutual understanding is critical, as only then the diverse information can be brought together in one overarching image of the asset’s remaining lifetime. Furthermore, as already discussed (section 4), part of the information that is relevant is

often scattered over different departments and people (tacit knowledge). Hence, a method is needed that is able to elicit tacit knowledge, to collect en process information from very different perspectives. Furthermore, it should be able to make the most of both qualitative and quantitative information.

In Asset Management, one often has to deal with information problems, as our knowledge of the future is imperfect at the most, and many different disciplines come together (e.g. engineering, design, operation). To deal with this, Reliability Centred Maintenance (RCM) [4,32], one of the most established methods in Asset Management, makes extensive use of experts as the main source of information. Especially in the Failure Mode Effect Analysis (FMEA) experts play a key role. Experts are brought together in so-called expert sessions, where they discuss potential failure modes of an asset, the chances a particular failure mode will happen and its potential consequences. Because of the expertise of the experts with similar assets, these sessions lead to important and valuable insights, even when the asset itself has never failed yet and hence no failure data are available. This information is consequently used to develop maintenance concepts and guidelines. The method proposed in this paper builds on the successful experience in RCM with the use of expert sessions to elicit the (often tacit) knowledge of experts.

5.2. Solution exploration II – case study on ALCM practices

Next to the insights from literature, an exploratory case study [21,34] has been carried out to see how ALCM is used in practice. To gain useful insights, a company has been sought that is an excellent performer in its industry, having extensive experience with the maintenance of physical assets, a comparably large asset population as Liander has, years of experience with ALCM and where access would be easy, as most information related to ALCM is highly confidential, as it is often closely related to corporate strategy. For the same reason, the company should be non-rival to Liander.

Based on these selection criteria, NedTrain has been selected as a case company. NedTrain is responsible for the maintenance of the rolling stock owned by the Netherlands Railways (in Dutch called ‘NS’), representing a replacement value of around 6 billion euros. NedTrain is generally regarded a good performer in the industry [see also 35]. NedTrain has started the use of ALCM practices a decade ago and has successfully integrated ALCM in its strategic asset management processes. NedTrain makes extensive use of so-called ALCM plans, which are revised and improved every year. These ALCM plans describe the present performance of an asset, predict the future performance and compare this to the desired performance and strategic objectives. In case of a misalignment between the desired and predicted performances, measures are proposed and implemented. Up to the management level these plans are extensively used in decision-making.

At NedTrain, several interviews have been carried out with the executive managers responsible for the development of ALCM plans. Also a number of ALCM plans have been studied, for different assets as well as multiple versions of the same plan (the ALCM plans are yearly revised). This has

yielded important insights both in the process of developing ALCM plans as well as in the contents of those plans.

Success factors in ALCM practice

From this case study, three success factors in ALCM have been identified.

1. For the development of ALCM plans, experts on the asset are brought together from all different departments within and even outside the company. The ALCM plan is a joint effort and a result of extensive knowledge-sharing and joint decision making to synchronise different goals and wishes.
2. The ALCM plans focus on the intermediate future, i.e. 3-10 years into the future. In this timeframe, potential future problems for the asset’s performance are identified and timely measures can be prepared.
3. For the ALCM plans all available information is used, so the information input is not limited to quantitative data or KPIs. All information is brought together into a clear structure, resulting in a readable and usable document containing all relevant information on the asset from a strategic and tactical perspective. The quality of the information is safeguarded by making the relevant asset manager responsible for the ALCM plan.

6. Proposed Solution

6.1. Design criteria

From the literature study and the case study on ALCM practices four design criteria have been distilled. These will guide the development of a solution design to the problem:

1. the method should be multidisciplinary, as are the ALCM plans at NedTrain and as proposed by literature;
2. the method should be expert-based (compare RCM) and able to process all available information;
3. the method should focus on the intermediate future, rather than on the exact prediction of the end-of-life point (long term), as NedTrain’s ALCM plans do; and
4. the method should be workable in real life industry situations, which demands that the method is both rigorous and relevant.

Based on the insights ranging from both theory and practice and these four design criteria a solution design (or in more familiar terms: a conceptual model) has been developed, which will be presented in the next section.

6.2. Design objective

Instead of directly aiming at the estimation of the remaining lifetime of an asset, we propose a different approach. We start with the current state of the asset, including the current maintenance policies that apply to it. We then focus on the identification of lifetime impacts. We define lifetime impacts as probable (technical and non-technical) events or trends that may have a positive or negative influence on the remaining lifetime of the asset in the intermediate or long term. In other words: impacts that may increase or decrease the period of time the asset provides value to its

owner or user. These impacts can have an influence on the technical, economic, commercial or compliance aspects of the asset. Negative impacts may be the bankruptcy of the only supplier of critical spare parts or a change in customer demands. A positive impact could be the development of a new maintenance concept that will make the use of the asset cheaper and thus affordable for a longer time, or an innovation that proves to be a long-anticipated solution for an – until then – insolvable problem. Also seemingly minor problems, such as a change in regulations with respect to the safety of workers on the asset, may result in the end of the useful lifetime of an asset, in case no timely measures are taken. Hence the identification of lifetime impacts will be the objective of our design, or in other words: our goal is to identify to what extent the asset is ‘future-proof’ and what impacts limit this future-proofness, rather than to estimate the exact moment the asset will cease to be of value for its owner.

This approach has a number of advantages over the main focus on the estimation of the end-of-life point itself. First, the main interest of the asset owner is not the exact moment where the asset will no longer be useful, but whether it will perform in the near (and predictable) future and what potential threats and opportunities lie ahead. Secondly, generally there is more information available about the near future than about the far future. Thirdly, different degradation processes and different perspectives on the asset’s lifetime may be very hard to integrate into one estimation of the remaining useful lifetime. And sometimes it may not even be known what influence a certain impact will have on the asset’s life expectancy, whereas a (qualitative) description of the impact is possible. By focussing on these impacts, it becomes easier to use all information available to get the best possible insight in the asset’s remaining lifetime. And only by the timely identification of the lifetime impacts appropriate action can be taken to grasp the full potential of the asset.

6.3. The Lifetime Impact Identification Analysis (LIIA)

To gain an integral view on the lifetime impacts that influence the remaining lifetime of the asset, the Lifetime Impact Identification Analysis (LIIA) has been developed, based on the four design criteria presented earlier. This method consists of the following steps:

1. Asset selection

First an asset needs to be chosen for which an analysis should be carried out. This can for example be done based upon replacement value, risk profile or criticality. Next to the selection of the asset, the depth of the analysis should be decided upon, based on similar criteria: is the asset analysed as a whole, or for example in terms of (functional) components? Both choices are of great importance for the success of the analysis, as a balance needs to be found between the time needed for a thorough analysis and the expected value created by such an analysis.

2. Collection of general asset information

Next, a thorough description of the asset should be made, at least in terms of physical characteristics, population

characteristics, function, current performance, strategic objectives and relevant policies. This is an important step to give experts from different backgrounds a thorough basic understanding of the asset and to create a ‘level playing field’ among the experts.

3. Discussion of the asset in expert sessions

In the expert sessions, the asset’s remaining lifetime is discussed critically. In these expert sessions, chaired by one of the researchers as a facilitator, a number of different experts from different backgrounds and departments are brought together, at least one expert for each of the four perspectives. By means of the discussions in these sessions, a thorough understanding of the asset, its current and expected performance and potential impacts on its lifetime will develop. Also, different types of available information (ranging from gut feelings to statistical analyses of failure data) can be discussed here, and through these discussions the reliability and applicability of this information can be appraised. During the discussions, it is important not only to focus on negative lifetime impacts (threats), but also on positive lifetime impacts (opportunities). If opportunities are neglected, grasping the full potential of the asset becomes impossible.

4. Writing the Lifetime Impact Report

The relevant lifetime impacts that have been gathered are presented and discussed in a structured way in a Lifetime Impact Report. Here the asset is described, its performance is discussed and all lifetime impacts (from all four perspectives) are presented in a structured way. This report allows the asset owner to take timely measures, if these are necessary.

5. Evaluation

Finally, the Lifetime Impact Report is to be discussed with the experts, in order to make sure that their information inputs have been interpreted and processed in the right manner. Also, this allows them to come with additional information or remarks to improve the insight in the asset’s remaining life.

7. Implementation

To investigate whether this solution design is indeed workable in practice, the method has been implemented at Liander, the network operator introduced earlier in this paper (section 4). This implementation can also serve as a preliminary test of the method in a real life problem situation.

At Liander, a Lifetime Impact Report has been written for a particular type of switchgear, following the LIIA presented above. Because the asset had experienced a number of failures over the years, there was a relatively large amount of information available about this asset and an incentive to study this asset in more detail using the LIIA. The development of this Lifetime Impact Report has been carried out following the five steps above. Additionally, a step 0 has been added in which the general LIIA has been adapted to the specific situation of Liander. Also, step 6 has been added to evaluate the process and method, in order to assess the practical value of the proposed method. A description of these different phases can be found in *table 1*.

Table 1. Description of the development of the Lifetime Impact Report.

Phase	Description	Main activities
0. Adaptation of the framework	Adaptation of the four types of lifetime impacts to the situation of Liander	- Interviews with experts on the four different lifetime perspectives (8 experts, interviews of around 1h) - Study of company documents (annual reports, strategy, etc.)
1. Asset selection	Selection of a particular type of switchgear	- In close consultation with the researchers, the manager of Asset Management has selected this asset
2. Collection of general asset information	Collection of general information on the particular type of switchgear and the population characteristics	- Study of company documents (e.g. policy documents related to this type of switchgear) - Collection of information stored in databases (e.g. age, numbers, maintenance data, cost data) - Company visit to see the asset in function and to the fault analysis team - Interviews with experts on this type of switchgear (3 different experts, at least 1.5h per expert)
3. Discussion of the asset in expert sessions	Collection of information on the four types of lifetime impacts using expert sessions	- A first expert session lasting for 2 hours (5 experts present, representing all 4 types of lifetime impacts) - Additional study of company documents and information in databases - Analysis of failure and financial data - A second expert session, lasting for 1.5 hours (3 experts available, one different from the first session)
4. Writing the Lifetime Impact Report	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 2 experts on the asset - One expert session lasting for 1 hours (6 experts present)
6. Reflection on the method for LIAA	Evaluation and reflection on the LIAA with the experts involved	- Consultation with 2 experts on the asset - One expert session lasting for 1 hours (6 experts present) - Critical reflection and discussion by the researchers

7.1. Identified lifetime impacts

The goal of the proposed method is to identify trends and events that may have an impact on the lifetime of the asset. During the implementation of the method at Liander, lifetime impacts on a particular type of switchgear have been identified. Impacts have been identified on both the intermediate (<5 years) as well as the long (>5) term, based on predictable trends (intermediate term) and uncertain (strategic) scenario's. In table 2, a number of examples has been given. Due to confidentiality, not all impacts can be shown.

Table 2. Examples of lifetime impacts identified using the LIAA.

Perspective	Lifetime Impact	Possible consequences
<i>Intermediate term (<5 years)</i>		
Technological	- new types of degradation due to energy transition	- unexpected failure modes, increased wear
	- production stop (2014)	- shortage of spare parts

		(from 2024), limited supplier support, failure may lead to replacement
Economic	- none on population level - due to local conditions individual assets require additional maintenance	- none - 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 - additional safety requirement (currently under discussion)	- none - asset can be made compliant, but replacement would be cheaper
<i>Long term (>5 years)</i>		
Scenario I: energy transition	- bidirectional load - increased change in loads - increased loads - new failure modes	- none - none - currently none - unexpected failure modes
Scenario II: remote control	- no remote control options present	- assets can be upgraded, but replacement would be cheaper

The different perspectives and scenarios have been discussed in expert-sessions, in some cases based on quantitative analyses. From these discussions, the lifetime impacts have been extracted. After the identification of the lifetime impacts, their possible consequences have been discussed. For example: a technical lifetime impact is the energy transition, which may lead to new and currently unknown failure modes. A consequence may be that unexpected failures may happen in the future. The experts came up with a possible solution: an intensification of the monitoring of condition and failure data.

Currently, the proposed method does not allow for an estimation of chance and effect of each impact, but only a qualitative description has been given. Due to the structured discussions in these sessions, an integral view of the lifetime impacts on the asset has been reached and the extent to which the asset is 'future-proof' has been established. Hence, it shows where additional measures might be needed.

7.2. Reflection and evaluation

This paper has presented the recent advances in our research project. As the implementation of the proposed method has only been carried out recently, it is not yet possible to measure the benefits resulting from the identification of the lifetime impacts at Liander. Hence, a different means of evaluation has been sought: the resulting Lifetime Impact Report has been discussed critically with the two main experts on the asset, as well as during an expert session (see also phase 5 in table 1). Both the individual experts as well as the experts collectively judged that the Lifetime Impact Report covered the available, relevant information on the remaining lifetime of the asset. Also, they concluded that the report presented this information in a structured and accessible way, allowing the company to have an integral view on the asset, which did not exist as

knowledge and information was scattered. Liander recognized the potential value this creates, as it may prevent suboptimal decisions and it allows the preparation of timely measures to increase the performance and the lifetime of the asset. Therefore, management regarded this first Lifetime Impact Report as a valuable and promising tool for Liander and decided to continue the collaboration with the researchers.

From a process perspective, the implementation shows that expert-sessions can be a useful instrument to bring information and knowledge together in a structured way. Furthermore, it turned out that the discussions in the expert sessions offered a useful indication of the reliability of all types of information, both qualitative as well as quantitative.

As a critical remark the experts mentioned that the method did not bring forward completely new insights, although it raised some interesting topics for discussion and further thought. This can be explained by the large amount of effort that had been put into studying this asset before. Additionally, some of this information was already tacitly known by some of the experts. Hence they did not recognize it as new information, although it was new to the decision-makers at the strategic level of AM as the information had never been explicitly documented before. Furthermore, it turned out to be relatively hard to identify non-technical lifetime impacts, as Liander's main focus currently lies on the technical perspective, and hence information on the other aspects was less readily available. This shows that the LIIA can also be used as a gap-analysis, as indicated by Haffejee & Brent [6].

8. Concluding Remarks

In this paper a method to identify the lifetime impacts on the remaining lifetime of physical assets has been presented. In this method, the focus has been put on the identification of impacts on the lifetime of the asset, from technical, economic, compliancy and commercial perspectives. As far as the authors are aware, this is the first time remaining lifetime has been approached from the perspective of lifetime impacts, which may be a valuable theoretical contribution.

The first application of this method, the pilot study at the Dutch network operator Liander, showed positive results. The method showed to be able to identify lifetime impacts from technical, economic, commercial and compliancy perspectives, using information scattered over different departments and experts. The resulting Lifetime Impact Report has been judged to give a useful and complete overview of the impacts on the lifetime of the asset. This may prevent that suboptimal decisions are taken because of a singular focus on the technical perspective. Furthermore, it allows the asset owner to take timely measures to increase the performance and the lifetime of the asset.

When the design criteria guiding the design of this method are reviewed, it can be concluded that the method proposed in this paper fulfils all our four criteria, as it:

1. is clearly multidisciplinary, by taking technical, economic, compliancy and commercial impacts on the lifetime of the asset into account;
2. is based on the (tacit) knowledge of experts, collected mainly through the use of expert sessions (as in e.g.

RCM), but also allows for the inclusion of other (quantitative) information by using quantitative analyses as an input for the expert sessions in which the experts can comment on the outcomes;

3. focuses on the intermediate future, by seeking to identify lifetime impacts rather than by trying to establish a reliable estimate of the end-of-life point of the asset; and
4. is workable in real life industry situations, as has been shown at Liander.

As such, the method not only contributes to scientific knowledge by providing a method for a multidisciplinary identification of lifetime impacts on assets under imperfect information, but it contributes to practice as well.

9. Discussion

The method presented in this paper enables the timely identification of impacts on the lifetime of an asset. The method has been implemented successfully in a pilot study at Liander. However, this was only the first test of this method, in a very specific industry and on an asset about which a relatively large amount of information was available. To investigate the generalizability of the method to other sectors, in the remainder of this research project the method will be applied in a number of different sectors.

Furthermore, the method only allows for the identification of lifetime impacts, but does not allow for any valuation of these impacts in terms of risk, uncertainty or criticality. In other words, it is not possible to distinguish between more and less likely or critical impacts on the lifetime of the asset. Finally, the method could be strengthened by incorporating established methods and tools from Asset Management and related disciplines. These remarks will be addressed in later articles ranging from the current research project.

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