Manoeuvring physical assets into the future

planning for predictable and
preparing for unpredictable change
in Asset Life Cycle Management

Richard Ruitenburg

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by

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MANOEUVRING PHYSICAL ASSETS INTO THE FUTURE

PLANNING FOR PREDICTABLE AND
PREPARING FOR UNPREDICTABLE CHANGE
IN ASSET LIFE CYCLE MANAGEMENT

DISSERTATION

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Summary

Introduction

Physical assets fulfil indispensable roles in our society. Machinery, factories and infrastructure need to perform in safe, cost-effective and reliable ways to support our daily lives. These assets represent a significant financial value for their owners and typically have lifetimes of several decades. Therefore, effective management of these assets is essential. This need is amplified by two recent developments. Firstly, 44% of the assets in Western Europe are expected to reach the end of their functional lives within the next 10 years (Haarman and Delahay, 2015). Secondly, asset managers increasingly face change in both the goals of their assets and the context in which the assets operate (e.g. Al-Turki, 2011). The first development increases the importance of managing (ageing) assets in an effective way, while the latter complicates efforts to do so.

Asset Management is concerned with “the balancing of costs, opportunities and risks against the desired performance of [physical] assets, to achieve the organizational objectives” (ISO, 2014, p. 2). According to Pudney (2010), Asset Management has five important characteristics: 1. it is a multidisciplinary practice; 2. the whole life cycle of a physical asset should be taken into account; 3. the goal is to achieve certain specified objectives; 4. within acceptable limits of risk and relevant regimes; and 5. it should determine the allocation of resources. Asset Management that fulfils these five requirements will be called Asset Life Cycle Management (ALCM).

However, the literature clearly shows that most approaches to Asset Management have a singular focus on technical or financial aspects, rather than being multidisciplinary (e.g. Haffejee and Brent, 2008). Also, often the attention is limited to certain parts of the lifetime of the assets (e.g. Schuman and Brent, 2005), or solely on the estimation of the remaining useful life (RUL) of the assets (e.g. Si et al., 2011). Asset Management objectives are not always fully aligned with the corporate strategy (Komonen et al., 2012). Potential changes in the relevant regimes (e.g. regulation) are not taken into account, as fixed objectives and an unchanging context are assumed implicitly. Finally, both the literature and the recent ISO 55000 standard (ISO, 2014) on Asset Management do not offer guidance as

to how to do Asset Management in a way that fulfils these five characteristics. Therefore, in order to address these deficiencies, this research project aimed:

to develop methods and tools for strategic Asset Life Cycle Management in a changeable context.

Methodology

The research project was structured according to the logic of the Design Science methodology (Hevner et al., 2004; Holmström et al., 2009). First the problem was explored in practice, using both a survey study on ALCM and a case study at Liander, a Dutch network operator and the sponsor of this research project. Then, based on our understanding of the problem, a case study at the Netherlands Railways and the literature, a number of tools and accompanying processes were developed. These were then tested and evaluated by an application at Liander. Also, the development process itself was studied as an action research project on the development of ALCM capabilities at Liander. Additionally, as a counterpart to the focus on predictable change in this first part of the research, a multiple case study was carried out to understand how Asset Management organizations deal with unpredictable change.

Findings

In the problem exploration, it was found that the limited availability of data, the distribution of information throughout the organization and the limited time available for long-term, strategic issues results in a limited understanding of the remaining lifetime of assets. Additionally, these three factors limit the ability of asset managers to identify and anticipate future changes in a proactive manner. Therefore, a method was developed to assist asset managers in identifying future threats and opportunities, which were labelled lifetime impacts: “trends or events that may have a positive or negative effect on the value created by using the asset”. The lifetime impacts are identified by bringing experts from different backgrounds together in a structured discussion on five different perspectives on the asset: technical, economic, compliancy, commercial and organizational (TECCO). To prioritize the identified lifetime impacts, a prioritization tool was developed, based on the likelihood and potential effect of the lifetime impact as well as the effort required to manage the impact in an effective way. Additionally, a logic tree was designed to propose the most suitable solution strategy for each lifetime impact. These different tools combined were labelled Lifetime Impact Centred Asset Management (LICAM), which also encompasses a process to develop Asset Life Cycle Plans. This method can be regarded as a strategic counterpart to Reliability Centred Maintenance (RCM), as it assists asset managers to

manage and plan for lifetime impacts in a changeable context, whereas RCM helps maintenance managers in managing failure modes in a stable context.

However, during the development of these methods and tools, it was found that not all lifetime impacts can be identified in time to prepare suitable preventive measures. Therefore, the concept of agility was studied in the context of ALCM, to investigate how Asset Management organizations cope with unexpected changes. This resulted in a framework comprising of seven agility enablers. Four agility enablers relate to the organization (agile people, linkages, processes & information and strategy), and three agility enablers originate from the physical assets (asset resilience, asset adaptability and agile deployment). The asset agility enablers are an elaboration of the agility theory, while the organizational agility enablers show asset managers that not all change has to be accommodated by the physical assets themselves.

Finally, the research also created insight in the change process from Asset Management to ALCM. This change process requires new skills of the asset managers, improved alignment and new collaborations within the organization and a deliberate step away from the fire-fighting mentality that is found in many Asset Management organizations.

Relevance and implications

This research has added several insights to the Asset Management literature. First, it introduces the focus on future threats and opportunities (i.e. lifetime impacts), challenging the implicit assumption in most Asset Management tools that the future is stable. Second, it stresses the importance of a multidisciplinary approach to ALCM and introduces the five TECCO (i.e. technical, economic, compliancy, commercial and organizational) perspectives to facilitate such an approach. Thirdly, it presents Lifetime Impact Centred Asset Management, which comprises of a number of tools to identify, prioritize and manage lifetime impacts. Finally, it shows how agility is a means to deal with unpredictable change, and presents a framework for agility in Asset Management.

For practitioners, this research offers tools for strategic ALCM in a changeable context and describes a change process towards such a management approach. In this way, it assists asset managers to develop Asset Life Cycle Plans (or: Asset Management Plans) as required by ISO 55000, in order to timely prepare for future threats and opportunities to create maximum value for the organization from the exploitation of their assets.

Samenvatting (in Dutch)

Introductie

Fysieke assets zijn onmisbaar voor onze samenleving. We zijn in ons dagelijks leven continu afhankelijk van allerlei machines, fabrieken en infrastructuur, die veilig, betrouwbaar en betaalbaar moeten functioneren. Deze fysieke assets vertegenwoordigen een grote financiële waarde voor hun eigenaars, en hebben over het algemeen een levensduur van meerdere decennia. Daarom is het essentieel dat deze assets effectief beheerd worden.

Twee recente ontwikkelingen maken dit nog belangrijker. Allereerst is de verwachting dat 44% van de assets in West-Europa binnen tien jaar het einde van hun levensduur zal bereiken (Haarman and Delahay, 2015). Ten tweede krijgen asset managers meer en meer te maken met veranderingen in de doelstellingen voor de assets en in de context waarin de assets functioneren (e.g. Al-Turki, 2011). De eerste ontwikkeling maakt het extra belangrijk om (verouderende) fysieke assets effectief te beheren, terwijl de tweede ontwikkeling ervoor zorgt dat dit steeds ingewikkelder wordt.

Asset Management gaat om “het afwegen van kosten, mogelijkheden en risico’s tegen de gewenste prestaties van [fysieke] assets, om de organisatiedoelstellingen te behalen” (ISO, 2014, p. 2). Volgens Pudney (2010) heeft Asset Management vijf belangrijke kenmerken: het is 1. een multidisciplinaire activiteit; 2. waarin de gehele levensduur van een fysieke asset wordt beschouwd; 3. om bepaalde doelstellingen te behalen; 4. tegen acceptabele risico’s en binnen de mogelijkheden van de relevante kaders; 5. en waarin over de inzet van middelen wordt besloten. Asset Management dat aan deze vijf vereisten voldoet wordt in dit proefschrift Asset Life Cycle Management (ALCM) genoemd.

In de wetenschappelijke literatuur valt echter op dat de meeste benaderingen van Asset Management een eenzijdige focus hebben op technische of financiële aspecten, terwijl multidisciplinariteit vereist is (e.g. Haffejee and Brent, 2008). Verder is er vaak voornamelijk aandacht voor een beperkt deel van de levensduur van de asset (e.g. Schuman and Brent, 2005), of enkel voor de bepaling van de restlevensduur (remaining useful life (RUL)) van een asset (e.g. Si et al., 2011). Asset Management doelstellingen zijn niet altijd volledig afgestemd op de bedrijfsstrategie (Komonen et al., 2012). Er wordt geen rekening gehouden met eventuele veranderingen in de relevante kaders (e.g. wettelijke kaders),

doordat impliciet wordt aangenomen dat de doelstellingen vastliggen en de context onveranderlijk is. En ten slotte bieden zowel de literatuur als de recente ISO 55000-standaard (ISO, 2014) over Asset Management geen hulp over hoe Asset Management toegepast moet worden om aan deze vijf kenmerken te voldoen. Daarom heeft dit onderzoek als doel om deze gebreken aan te pakken, door:

*methoden en hulpmiddelen te ontwikkelen voor
strategisch Asset Life Cycle Management in een veranderlijke context.*

Methodologie

Dit onderzoeksproject is opgebouwd volgens de Design Science methodologie (ontwerpend onderzoek). Eerst is het hierboven beschreven probleem verkend in de praktijk door middel van een enquête-onderzoek over Asset Life Cycle Management (ALCM) en een casusonderzoek bij Liander, een Nederlandse netbeheerder en de sponsor van dit onderzoeksproject. Aan de hand van deze probleemverkenning, een casusonderzoek bij de Nederlandse Spoorwegen en de wetenschappelijke literatuur is een aantal tools en bijbehorende processen ontwikkeld. Deze zijn vervolgens getest en geëvalueerd door middel van toepassing bij Liander. Daarnaast is het gehele ontwikkelingsproces bestudeerd in de vorm van een actieonderzoek naar de ontwikkeling van ALCM-bekwaamheden (capabilities) bij Liander. Als tegenhanger voor de focus op voorspelbare verandering in dit eerste deel van het onderzoek is ook een meervoudig casusonderzoek gedaan om te begrijpen hoe Asset Management organisaties omgaan met onvoorspelbare verandering.

Bevindingen

De probleemverkenning leidde tot het inzicht dat drie zaken leiden tot een beperkt begrip van de toekomstige levensduur van assets: 1. de beperkte beschikbaarheid van data; 2. de versnippering van informatie binnen de organisatie; en 3. de beperkt beschikbare tijd voor strategische vraagstukken betreffende de lange termijn. Daarnaast beperken deze drie factoren de mogelijkheden van asset managers om toekomstige veranderingen op een proactieve manier te identificeren en hierop de anticiperen. Daarom is er een methode ontwikkeld om asset managers te helpen om toekomstige kansen en bedreigingen te identificeren. Voor deze kansen en bedreigingen is de term levensduurimpacts (lifetime impacts) geïntroduceerd: “trends of gebeurtenissen die mogelijk een positief of negatief effect hebben op de waarde die door middel van de asset wordt gecreëerd”.

Levensduurimpacts worden geïdentificeerd door experts met verschillende achtergronden bijeen te brengen in een gestructureerde discussie over vijf verschillende perspectieven op een asset: technisch, economisch, compliancy (voldoen aan wet- en regelgeving), commercieel en organisatorisch (TECCO). Om de geïdentificeerde levensduurimpacts te

prioriteren is een prioritiseringstool ontwikkeld, gebaseerd op de kans en het mogelijke effect van de levensduurimpact en de benodigde inspanning om op een effectieve wijze op deze impact in te spelen. Daarnaast is een beslisboom ontworpen die voor iedere levensduurimpact de meest passende oplossingsstrategie voorstelt.

Deze tools vormen samen het zogenaamde 'Lifetime Impact Centred Asset Management' (afgekort: LICAM, in het Nederlands: op levensduurimpact gefocust Asset Management). Deze methode omvat ook een proces om levensloopplannen te ontwikkelen. De LICAM-methode kan beschouwd worden als de strategische tegenhanger van 'Reliability Centred Maintenance' (afgekort: RCM, in het Nederlands: op betrouwbaarheid gefocust onderhoud), aangezien het asset managers helpt bij het omgaan met en plannen maken voor levensduurimpacts in een veranderlijke context, terwijl RCM onderhoudsmanagers helpt om om te gaan met faalmodi in een stabiele context.

Tijdens de ontwikkeling van deze methoden en tools bleek dat niet alle levensduurimpacts tijdig geïdentificeerd kunnen worden om passende preventieve maatregelen te kunnen ontwikkelen. Daarom is het concept agility (wendbaarheid) bestudeerd in de context van ALCM, om te onderzoeken hoe Asset Management organisaties omgaan met onvoorspelbare veranderingen. Dit heeft geleid tot een model bestaande uit zeven zogenaamde 'agility enablers' (bronnen van wendbaarheid). Vier bronnen van wendbaarheid vinden hun oorsprong in de organisatie (wendbare mensen, verbindingen, strategie en processen & informatie), drie bronnen komen van de fysieke assets zelf (veerkracht, aanpasbaarheid en wendbare inzet). Deze drie asset-gerelateerde wendbaarheidsbronnen zijn een aanvulling op de bestaande wendbaarheidstheorie, terwijl de organisatorische wendbaarheidsbronnen duidelijk maken dat de oplossing voor veranderingen niet enkel in (aanpassing van de) fysieke assets hoeft worden gezocht.

Ten slotte heeft dit onderzoek ook inzicht gecreëerd in het veranderingsproces van Asset Management naar ALCM. Dit veranderingsproces vraagt nieuwe vaardigheden van de asset managers, meer afstemming en samenwerkingen binnen de organisatie en een bewuste breuk met de brandweer-mentaliteit die in veel Asset Management organisaties heerst.

Relevantie en Aanbevelingen

Dit onderzoek heeft een aantal inzichten opgeleverd die een aanvulling vormen op de Asset Management literatuur. Allereerst is in dit onderzoek expliciet aandacht besteed aan het omgaan met toekomstige kansen en bedreigingen (levensduurimpacts), en daarmee is afstand genomen van de impliciete aanname in veel Asset Management tools dat de toekomst stabiel is en gelijk aan het heden. Ten tweede benadrukt dit onderzoek het belang van een multidisciplinaire benadering van ALCM en introduceert het de vijf TECCO-perspectieven (technisch, economisch, compliancy, commercieel en organisatorisch) om een dergelijke benadering mogelijk te maken. Ten derde is de Lifetime Impact Centred

Asset Management methode ontwikkeld, die bestaat uit een aantal tools om levensduur-impacts te identificeren, te prioriteren en hier op passende wijze op in te spelen. Ten slotte laat dit onderzoek zien hoe wendbaarheid (agility) een manier kan zijn om met onvoorspelbare verandering om te gaan en wordt een model voor wendbaar Asset Management gepresenteerd.

Voor asset managers biedt dit onderzoek tools voor strategisch ALCM in een veranderlijke omgeving en wordt het veranderingsproces om tot strategisch ALCM te komen beschreven. Ook biedt het asset managers ondersteuning om levensloopplannen (of: Asset Management plannen) te ontwikkelen zoals ISO 55000 voorschrijft. Al deze zaken samen helpen asset managers om tijdig voorbereidingen te treffen voor toekomstige kansen en bedreigingen, zodat het gebruik van hun assets tot een maximale opbrengst voor de organisatie zal leiden.

Dankwoord (in Dutch)

*Een mens stippelt zijn weg uit, de Heer bepaalt de richting die hij gaat.
Spreuken 16: 9*

Het kan raar lopen... Nooit gedacht dat ik zou gaan promoveren, laat staan in een vakgebied waar ik vijf jaar geleden nog nooit van gehoord had. Maar gedreven door de crisis kwam ik als onderzoeker terecht bij Liander. Als econoom en socioloog tussen de elektrotechnici. Dat bleek een gouden greep: ik heb mooie jaren gehad in de fascinerende wereld van het onderhoud. Ik ben dankbaar voor de talloze ontmoetingen met vriendelijke, hulpvaardige mensen met zo veel hart voor hun werk. Zonder hun vrijgevig delen van hun tijd en kennis was ik niet tot dit proefschrift gekomen. En zonder hun vakmanschap had het maar zo gekund dat ik vandaag niet met de trein op mijn werk had kunnen komen, of dat tijdens het schrijven van deze tekst de stroom uit was gevallen. Jullie zijn dan wel niet de 'invisible hand' waar Adam Smith het over had, maar die van jullie is misschien nog wel crucialer voor onze maatschappij!

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En lieve Rivkeh, bedankt dat je trots op me bent. Dat je na het doorworstelen van de – altijd weer te lange – introductie al alle vertrouwen in dit proefschrift had. Ik zie ernaar uit de rest van mijn leven jouw onderhoudsexpert (en veel meer dan dat) te zijn. En ik beloof je dat ik – na jouw jaren van geduld (dat krijg je met promovendi) – nog deze week naar de piep in de remmen van je fiets zal kijken...

Richard Ruitenburg – september 2017

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List of Abbreviations

ALCM	asset life cycle management
ALCP	asset life cycle plan
AM	asset management
AMP	asset management plan
AR	Action Research
CBM	condition based maintenance
CIMO	context, intervention, mechanism, outcome
DMO	Defence Materiel Organization
ECM	effectiveness centred maintenance
e.g.	for example (literally: <i>exempli gratia</i>)
et al.	and others (literally: <i>et alii</i>)
FMEA	failure mode and effects analysis
FMECA	failure mode, effect and criticality analysis
HR1	Horns Rev 1
i.e.	that is to say (literally: <i>id est</i>)
ICT	intercity train
IED	improvised explosive device
ISO	International Organization for Standardization
JIT	just in time
KPI	key performance indicator
kV	kilovolt (1000 volts)
LCC	life cycle cost(ing)

LI	Liander
LICAM	lifetime impact centred asset management
LIIA	lifetime impact identification analysis
MCDA	multicriteria decision analysis
MLU	midlife update
MST	modern stopping train
N	population size (in statistical test)
NR	Netherlands Railways
NVDO	Dutch Association for Maintenance Services (in Dutch: Nederlandse Vereniging voor Doelmatig Onderhoud)
OEE	overall equipment effectiveness
OEM	original equipment manufacturer
P	probability (in statistical test)
PM	preventive maintenance
RBM	risk based maintenance
RCM	reliability centred maintenance
REC	requirements for effective control
RPN	risk priority number
RUL	remaining useful life
SAMP	strategic asset management plan
t	hypothesis test statistic (in statistical test)
TECC	technical, economic, compliance, commercial
TECCO	technical, economic, compliance, commercial, organizational
TPM	total productive maintenance
TQM	total quality management
TST	traditional stopping train

1

Introduction

This first chapter lies the foundation for this dissertation. It discusses what 'physical assets' are and why their management is important as well as complex. It also presents the theoretical and practical motivation for this research, which leads to the main research question guiding this research:

How can a company, based on the knowledge and information available, effectively deal with change in its strategic Asset Life Cycle Management to create sustained stakeholder value with its assets over their complete lifetime?

1

Introduction

1.1 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 such as 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 (Tinga, 2013; Haarman and Delahay, 2015). 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 (Jongepier, 2007), in which planning becomes an important issue as resources (in terms of both money and manpower) are scarce. To complicate things even further, an asset owner often owns different (populations of) assets, which are all indispensable for the company and as a whole represent large amounts of financial capital. Hence an integral approach towards all the assets as a complete system is needed, rather than just a focus on one asset at a time.

To cope with all these challenges in an effective manner, a thorough insight in the whole life cycle of an asset is indispensable to safely and effectively manoeuvre the asset into the future. For capital assets the life cycle of an asset typically starts with the design and construction of an asset, followed by the operation and maintenance of an asset, finally its disposal and possible needed replacement (Asiedu and Gu, 1998). Currently, methods like Remaining Useful Lifetime (RUL) estimation (e.g. Si et al., 2011), Life Cycle Costing (LCC) (e.g. Ferry and Flanagan, 1991; Woodward, 1997; Asiedu and Gu, 1998; Fourie and Tendayi, 2016) and others are used for this purpose. However, these methods have a number of limitations. Often, these methods only focus on the short and medium term (Murthy et al., 2002), and change is not considered (Komonen et al., 2012). Furthermore they only take a narrow perspective, for example only a technical (e.g. Garg and Deshmukh, 2006; Campbell et al., 2010; Frangopol et al., 2012) or financial (e.g. Asiedu

and Gu, 1998; Márquez et al., 2012) perspective. Finally, many are highly dependent on quantitative data. This research project aims to understand how organizations can effectively deal with change in their strategic Asset Life Cycle Management to create sustained stakeholder value with their assets over their complete lifetime. Practically, this research aims to develop methods and tools for strategic Asset Life Cycle Management in a changeable context, which overcome these potential pitfalls.

1.1.1 Outline

In this introductory chapter, first an introduction will be given on the characteristics of physical assets and the literature on Asset (Life Cycle) Management, including its limitations (section 1.2). To complement this theoretical background, in the next section (1.3) the practical background of this research will be sketched, focusing on the Asset Management within Liander, one of the largest Dutch gas and electricity network operators. Based on this background, section 1.4 presents the main research question of this research. In the next section (1.5), the main methodology used to answer this question will be introduced: the Design Science methodology. As every research, and especially a participatory and practice-oriented research such as this research, has consequences outside the primary scope of the research, some ethical remarks are presented in section 1.6. The next section (1.7) presents an outline of the chapters of this dissertation, showing how the chapters connect and build upon each other. Finally, to offer further guidance to the reader, section 1.8 presents a brief ‘guide to the reader’ to understand how the different scientific publications underlying this dissertation (and listed in section 1.8) are combined into this single book.

1.2 Theoretical background and motivation

This research aims to make a contribution to the effective management of physical assets. To firmly ground this research in the existing scientific literature, a theoretical background will be presented in this section. This will start off with an explanation of what ‘physical assets’ are and how these will be defined throughout this dissertation (1.2.1). Secondly, a brief history of maintenance and Asset Management will be presented (section 1.2.2). Then, the definition of Asset Management and its main characteristics will be discussed (section 1.2.3). Finally, based on a comparison of these characteristics and the literature, section 1.2.4 will present six limitations of current Asset Management approaches, deficiencies this research will address to make a contribution to both science and practice.

1.2.1 Physical assets

All of this research is about ‘physical assets’: chemical factories, production lines, infrastructure such as roads and the electricity grid, but also trains and planes. In this research

assets are defined as “physical structures that provide a distinct and quantifiable physical function or service and having an economic life of greater than 10 years” (based on definitions by Pudney (2010, p. 5) and the International Infrastructure Management Manual (2006; cited in: Pudney, 2010, p. 4).

Physical assets are physical structures

This definition shows a few important characteristics of physical assets. First, they are ‘physical structures’, which means that intangible assets such as money, reputation or stocks (‘aandelen’ in Dutch) are not considered in this dissertation, even though in the literature these are called ‘assets’ as well (e.g. Fama and French, 1996; Cooper et al., 2008). Additionally, people are not ‘physical structures’, so knowledgeable employees (e.g. Coff, 1997; Bhattacharya and Wright, 2005) or even secret agents are not considered to be physical assets in this dissertation. Finally, software is not considered a physical asset in this dissertation, as it is not a tangible asset¹. It is assumed that the digital nature of software makes its adaptation easier than the modification of physical assets. This makes the management of change less complex for software than it is for physical assets.

Physical assets provide important services

Secondly, these assets provide a physical function or service to their owner or user. This could be the production of high quality products on a production line, but also the safe transportation of passengers in airplanes or the provision of security against flooding by dikes. It is the function these assets provide that makes them valuable: just as a dike in the desert is worthless, so is a production line that produces products that the market does not need, or a chemical factory that produces chemicals that are in high demand but forbidden due to environmental regulations. The value of the services assets provide may be hard to quantify, but recent disruptions of these services in the Netherlands may provide a rough idea of this value. A first incident was the discovery of miniscule cracks in the steel structure of the Merwedebrug² in October 2016. Due to this discovery, the bridge was closed for heavy truck traffic for 10 weeks. This closure caused long delays and detours, which resulted in estimated social damage of 35 million euros (Volkskrant, 2016). This was about a tenth of the total replacement value of the bridge, which was estimated at 400 million euros (NU.nl, 2017b). A second incident was the large power blackout on January 17th, 2017, in the Amsterdam region. This blackout was caused by a problem in a substa-

¹ However, many physical assets could be regarded as hybrids; tangible objects including software components, for example for purposes of control or diagnostics. In this dissertation, physical assets will be approached as consisting primarily of hardware components. Only if software presents itself as a limitation in the adaptability of the asset in the face of change (e.g. obsolescence or incompatibility), it will be considered.

² The Merwedebrieg is a bridge crossing the ‘Boven Merwede’ river. The bridge is part of the A27, an important Dutch highway.

tion operated by TenneT, the national grid operator. As a result, about 360,000 households were disconnected from the electricity grid for periods up to 4 hours. Major disruptions of train traffic, long traffic jams during the morning rush hour, temporary unavailability of the emergency number due to too many incoming calls and even three suspicious deaths³ were the result (Trouw, 2017; NU.nl, 2017a). The total social damage of this power blackout was estimated at 100 million euros (van den Berg, 2017).

These two incidents show that many different stakeholders may depend on the services delivered by physical assets. It is not just the owners of the Merwedeburg and the electricity substation that depend on the performance of these assets, it is also a large number of citizens depending on the assets, as well as many companies that depend on transportation or energy for doing business. Incidents may also have profound impacts on the environment – the Deepwater Horizon accident provides a clear example (Pallardy, 2010) – or on the health and safety of people working with or living close to the assets. Apart from these external stakeholders, there will be various stakeholders within an Asset Management organization. For example, the purchasing department may want to buy cheaper spare parts to reach its goal to save on purchasing costs, while these spare parts may be of a lower quality and thus have a negative effect on the reliability of the asset, which results in more work for the maintenance department. This shows how different groups within and outside the organization may depend on physical assets and may have different interests, goals and expectations regarding the assets.

Physical assets represent large financial values

Thirdly, a characteristic not discussed in the definition above, is the large financial (replacement) value physical assets represent. A train could be valued at 2 million euros (van Dongen, 2011a). A Boeing 737 costs about 50 million euros, and an electricity plant 1,200 million euros (van Dongen, 2011a). On top of these large values, many asset owners are dependent on a large number of assets. For example, in 2011 the Netherlands Railways operated about 3,000 trains, amounting to a replacement value of six billion euros (van Dongen, 2011a). These large sums of money limit the possibilities of companies to replace assets before they reach the end of their expected lifetimes, as this would cause massive write-offs of the value of these assets. But even if replacement would be a viable option financially, the long lead times for producing new assets often restricts this option in practice. For example, the replacement of the Merwedeburg is expected to take a minimum of four years (NU.nl, 2017b).

³ At the moment of writing, the outcomes of one of the investigations into these three suspicious deaths has shown that the power interruption did not cause this demise (Sevil, 2017).

Physical assets have lifetimes of multiple decades

A final important characteristic of physical assets is their long lifetimes, typically decades. These long lifetimes have two important consequences. First, over all the years the asset is used and operated, costs are incurred maintaining the assets. The costs of maintenance, refurbishment and life extension of a physical asset can easily exceed its initial purchase price. For example, for a train or a Joint Strike Fighter airplane, these costs are about twice the initial price (van Dongen, 2011a). In other words: buying a Joint Strike Fighter costs about 60 million euros, maintaining it for 30 years costs about 120 million euros (van Dongen, 2011a). When buying an asset, one thus implicitly chooses to pay these additional costs.

A second important consequence of these long lifetimes, is the amount of change that happens during the life of an asset. Take the example of a tank used by the Royal Netherlands Army⁴. 30 years ago, its main adversary was the Soviet Union. A potential conflict with the Soviet Union Army would have been likely to be a large scale battle, fought in Eastern Europe. Who could have anticipated at that time that terrorist groups would be the main adversaries 30 years later, and that the main battlegrounds would be Afghanistan and Mali? In these conflicts, the climatological (hot vs cold) and geographic (sand vs water and rivers) are completely different from a conflict with the Soviet Union. Also the type of combat has changed drastically: now it is ambushes, IEDs (improvised explosive devices, ‘bermbommen’ in Dutch) and guerrilla tactics, compared to large scale, centrally organized tank to tank battles. Not to mention the change in technology over these years: ICT, communication and the use of unmanned aircraft for reconnaissance and even bombings. Still, it may be the same tanks purchased 30 years ago, that need to be adapted to operate in these completely different conditions.

It is these four characteristics of physical assets, and especially the latter one, that set the scene for this research. But before the main objective and research question of this dissertation will be presented, a short history of maintenance will be presented.

1.2.2 A brief history of maintenance and Asset Management

Ever since humanity started using tools and building structures, maintenance has been an important part of human culture. Tools wear out and break, buildings deteriorate. Therefore, maintenance is crucial to uphold our way of living. However, over time, the complexity of tools and buildings has increased, and so has maintenance. This complexity is nicely illustrated in the definition of maintenance, which described maintenance as “the combi-

⁴ This example is loosely based on the history of the Dutch Leopard 2A6 tank. This tank was introduced in the early 1980’s. In 2011, the Dutch Ministry of Defense decides to sell off its last 116 Leopard 2A6 tanks, the last tanks it owned (compared to over 1,000 tanks during the Cold War) (Ministry of Defense, 2011). However, recently the Leopard 2A6 has been reintroduced in the Dutch army (Ministry of Defense, 2017).

nation of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function” (European Committee for Standardization (CEN), 2010).

Over the last century, maintenance has undergone a profound development. Pintelon and Parodi-Herz (2008) discussed the evolution of maintenance since WWII, and note that: “[o]ver the last decennia industrial maintenance has evolved from a non-issue into a strategic concern. Perhaps there are few other management disciplines that underwent so many changes over the last half-century” (p. 21). This development may be partly explained by the developments in this sector during this time period: technology became far more complex, businesses increasingly became dependent on these more complex assets, fulfilling customer demands gained a higher priority due to global competition, the advance of ICT added additional possibilities and complexities, due to outsourcing dependencies grew and due to safety and environmental incidents preserving the license to operate became a far more demanding task (Pintelon and Parodi-Herz, 2008). In this section, a closer look will be paid to this profound change in maintenance and Asset Management.

At first, maintenance was regarded as a ‘necessary evil’ (Pintelon and Parodi-Herz, 2008) and an ‘unavoidable cost’ (Murthy et al., 2002; Garg and Deshmukh, 2006), as equipment that broke down had to be fixed before production could be started again. Making the repairs (corrective maintenance) was mainly considered a side-task of the production department.

However, over time the machinery became increasingly complex and more critical for production, as well as for safety. Therefore, maintenance developed into a separate technical support function, which set out to optimize maintenance by doing more preventive (scheduled) maintenance. Due to global competition, the goal of maintenance became to “optimize plant availability at minimum cost” (Moubray, 1996, p. 3).

New approaches to maintenance widened the scope of maintenance to quality (e.g. Total Productive Maintenance (Chan et al., 2005), risks (e.g. Reliability Centred Maintenance (Moubray, 1997)) as well as customer requirements and environmental concerns (Pintelon and Parodi-Herz, 2008). It was acknowledged that the production department should actively be involved in the planning of maintenance and that human behaviour is crucial in preventing failures (Moubray, 1996). Management skills became important in maintenance.

A fourth phase in the development of maintenance is described by Pintelon and Parodi-Herz as ‘cooperative partnership’ (2008), where maintenance becomes a means to add value to the organization (Haarman and Delahay, 2004). Investing in the assets may deliver a higher added value than optimizing maintenance, and it becomes important to ‘speak the language of the board room’ (Haarman and Delahay, 2004).

Throughout this development, maintenance starts to be called Asset Management, which will be discussed in more detail in the next section.

1.2.3 Asset Management and Asset Life Cycle Management

Many different definitions on Asset Management exist. Recently, an ISO standard was published about Asset Management, the ISO 55000 (2014). In this standard, Asset Management is defined as the “coordinated activity of an *organization* to realize value from *assets* [italics in original]” (ISO, 2014, p. 14). The ultimate goal of Asset Management is thus the ‘realization of value’ from these assets, which relates to the services the assets provide. To realize value, Asset Management “involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organizational objectives” (ISO, 2014, p. 2). This clearly shows how the value of an asset is related to the organizational objectives. The tank example presented earlier provides a clear example: the value of the tank was larger during the Cold War (where the organizational objective was to defend the Netherlands from Soviet Union aggression) than it is now (as it is less suited for counter-terrorism operations). Therefore, assets are only valuable to the organization as far as they contribute to the organizational objectives.

This focus on the realization of organizational objectives is also clear in the definition of Asset Management proposed by Pudney (2010), which he based on a comparison of a number of different definitions. According to Pudney, Asset Management can be defined 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” (Pudney, 2010, p. 8). This definition shows the breadth of Asset Management: it combines different (technical and non-technical) disciplines to achieve (corporate) objectives with the assets over their complete life and considers the context in which the asset operates (e.g. governance and social regimes). In other words: Asset Management involves both the physical assets and the wider organization in order to create maximum value from the exploitation of the assets over their complete lifetimes. In the remainder of this dissertation, the term Asset Life Cycle Management (ALCM) will be used to refer to an approach to Asset Management that lives up to this definition.

1.2.4 Six limitations of current Asset Management approaches

From Pudney’s (2010) definition it is clear what Asset Management is and what characteristics it should fulfil. These have been called the five requirements of ALCM, which prescribe that Asset Life Cycle Management 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 of achieving certain specified objectives;
4. within acceptable limits of risk and relevant regimes; and

5. it should determine the allocation of resources.

These requirements were used to assess the Asset Management literature, as well as three often used methods in this field (i.e. Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) and Condition Based Maintenance (CBM)). This assessment, which will be presented in full in chapter 2, has led to the following findings:

1. the Asset Management literature and the three main Asset Management methods tend to focus primarily on technical, financial and operational aspects of a physical asset, and largely overlook other important disciplines;
2. the complete life cycle of a physical asset is not always taken into account, rather, the main focus lies on short and medium term operational and tactical issues, or the estimation of the end-of-life of the asset;
3. rather than pursuing the corporate objectives throughout the entirety of the organization, different departments (e.g. operations, maintenance and higher management) tend to pursue different objectives or assume that high reliability or high availability will contribute to the corporate objectives (which may not hold under every circumstance, e.g. under low market demand);
4. changes in these corporate goals or in the context of the assets (e.g. operating context, regulations or market demand) are generally not considered;
5. little support is offered for decision-making relating to long-term, strategic decisions in a changeable context to make the most of limited resources; and – related to the feasibility of these methods and tools in Asset Management practice, rather than directly to the five requirements of ALCM; and
6. the limited availability and reliability of data and information often limits the use of theoretical Asset Management methods and tools in practice.

In other words: the Asset Management literature is clear about what Asset Management is and what characteristics it should ideally fulfil. However, the literature does not provide all the required methods or tools to apply such an ‘ideal’ Asset Management approach in practice. The same applies for the recent ISO 55000 standard on Asset Management, which also only offers guidelines, but no guidance (Jooste and Vlok, 2015). Also regarding the so-called ‘Asset Management Plans’, which lie at the heart of Asset Management according to this ISO standard, no instructions are offered about the development or the contents of these plans. This research project will address these limitations of the literature and existing methods, by developing tools that complement the existing literature and methods in order to fulfil the five requirements of ALCM.

1.3 Practical background and motivation

In the previous section, the theoretical background and motivation for this research has been sketched. However, the aim of this research is more than just to contribute to science; it also aims to make a practical contribution to the work of asset managers in practice. In other words, the aim of this research is to make two types of contribution (Zuber-Skerritt and Perry, 2002; Karlsson, 2009): 1. a practical and relevant contribution to a concrete problem situation in the real world; and 2. a scientific contribution to a more abstract problem situation in the scientific world, allowing other scientists to build on this new knowledge to deal with new practical problems.

In this section, the practical context of this research will be discussed, starting with a description of Liander N.V., the company funding this project (section 1.3.1) and some of the most important challenges for Liander's Asset Management department will be sketched, as they were at the start of this research in early 2013 (1.3.2). Then, a brief description of Liander's approach towards long-term, strategic Asset Management at the start of this research will be sketched (1.3.3). Finally, these challenges will be related to the scientific literature and compared with the six limitations in the Asset Management literature (1.3.4).

1.3.1 Company description

Liander N.V. is one of the largest Dutch network operators, responsible for a safe and reliable distribution of electricity to 3.1 million Dutch customers and gas to 2.5 million customers (many of these customers are connected to both networks) (Alliander N.V., 2017). To do so, Liander constructs, operates and maintains the electricity and gas grid. The electricity grid consists of many different assets, for example about 86,000 kilometres of electricity cable (which could span the entire globe about 2 times), about 34,000 distribution transformers and some 2,500 pieces of high voltage switchgear. The gas grid has a length of about 35,000 kilometres of pipelines and also includes 15,000 gas delivery stations. In total, these grids represent a historical purchasing cost value of around 12 billion (milliard) euros (Alliander N.V., 2017).

The Asset Management department is responsible for the maintenance of the networks owned by Liander. Liander can be viewed as a good performer in the field of Asset Management, shown by NTA 8120 (a Dutch version of the predecessor of the ISO 55000, specifically designed for network operators), ISO 55001 and ISO 9001 certifications it holds. Furthermore, Liander aims to continuously improve itself by adopting new methods and tools, in order to improve the quality of the services it delivers to its customers, as well as the predictability of the performance of its networks.

1.3.2 Challenges in Liander's Asset Management in early 2013

Liander is under constant pressure to maintain and improve the reliability and safety of the distribution of electricity and gas. Or, in terms of the NTA 8120 norm for Asset Management, to guarantee sufficient quality (e.g. reliability), capacity and safety. At the same time, pressure is felt to cut costs and to improve the efficiency in maintenance. At the start of this research (and up to today), two additional challenges presented themselves. The first was the ageing of its distribution grids. Important parts of the Dutch electricity network were built in the years after the Second World War and hence approached the end of their expected lifetime (Wetzer and Bouwman, 2007; Jongepier, 2007), as is the case in large parts of Western Europe and the United States (Allan, 2005; Brown and Humphrey, 2005). The same applied for the gas distribution grid. This has resulted in discussions about a possible 'replacement wave' (or: 'reinvestment-wall'): if the grids, which were constructed in a short period of time, will all reach their end of life at the same age, then somewhere in the future all of the grids will need to be replaced in a similar short period of time. At that moment, Liander may not have the operational capacity (e.g. in available skilled technicians) to be able to make such large scale replacements.

Secondly, there were many changes in society Liander has had to cope with. An important change for Liander was the energy transition (Verbong and Geels, 2007), which is still highly relevant for all Dutch network operators. Due to the energy transition, both the production and consumption of energy change drastically. Whereas the production of energy used to be centralized in large-scale electricity plants and gas purification plants, due to the energy transition localized production of electricity (e.g. photovoltaic cells on roofs, wind farms) and gas (e.g. anaerobic digestion of manure ('mestvergisting' in Dutch)) gain importance. This local production also tends to use sustainable sources (e.g. wind and sun), rather than the fossil fuels used in the centralized energy production facilities. The consumption of energy changes as well, both due to new applications (e.g. electric vehicles) and the change of energy sources used for existing applications (e.g. electricity for cooking and heating (versus gas) or heating using district heating or ground source heat pumps). These changes in production and consumption of energy were expected to have profound impacts on the grids operated by Liander and other network operators. Not only may the total amount of energy consumed change drastically, also its simultaneousness might change (e.g. if people use electricity for cooking, heating and charging their electric cars, at about 6 pm everyone may be expected to reheat the house after work, start cooking and charge their car). At the same time, energy production was expected to become less predictable, due to its dependence on wind and sun.

Apart from the energy transition, Liander felt the importance of developments such as an increasing interest in sustainability (e.g. the increased interest in the circular economy (Schoolderman et al., 2014)) and corporate responsibility. Hence Liander more than ever needed to deal with change in its Asset Management. To do so in a proactive way, Liander

saw great potential value in an improved insight in the life cycle of its assets and the adoption of Asset Life Cycle Management (ALCM) practices.

1.3.3 Long term strategic Asset Management at Liander

At the start of this research, the long term Asset Management planning at Liander was mainly limited to five years into the future. This long term planning mainly consisted of five fields of interest and related activities. First, most assets in the grids used by Liander are designed and constructed for lifetimes of 40 years. Much effort is paid to buying high quality components and designing the grids in such ways that these will fulfil this 40 year life expectancy. Second, as Liander operates grids in a number of different regions in the Netherlands, for each of these regional grids long term grid plans are made. This is important, as making adaptations to the grid may easily take years to accomplish, while at the same time the energy distribution must continue. Third, in the so-called 'Strategic Asset Management Plans' (SAMPs), the strategic directions for Liander and its grids as a whole are discussed, for example in relation to the energy transition.

Whereas the first three aspects of Liander's long term Asset Management mainly focus on the grid (design) as a whole, the latter two rather focus on individual (populations of) assets in the grids. The fourth aspect is the replacement policy that applies to certain populations, such as distribution transformers and 'grijs gietijzer' (a special type of cast iron gas pipes). Other replacements are made due to failures or in case of capacity constraints of the existing assets, rather than based on a preventive replacement strategy. Finally, as a result of the discussions of a possible 'replacement wave', Liander has put efforts in the estimation of the remaining useful lifetimes (RUL) of some of its assets. Based on data and statistics, estimations can be made about when the asset is likely to fail in the future. As these RUL estimations were the most concrete efforts made by Liander regarding ALCM for specific assets at the start of this research, these will be discussed in more detail in the next section.

Remaining useful life estimations at Liander

At Liander, the estimation of the remaining useful lifetime (RUL) was predominantly based on technical arguments, such as increasing failure rates or increasing safety risks due to degradation. The asset managers tried to make use of statistical methods and models to predict failure rates and to process condition monitoring data, for example by means of the Ph.D. research projects by Jongen (2012) and Chmura (2014), which were both funded by Liander. This yielded important and valuable new insights. Nevertheless, the application of these tools was considered to be limited, as the quantitative data needed for these methods and models were not always available or reliable. Hence, Chmura concluded in a discussion on the quality and availability of failure data that "misleading conclusions about future failure behaviour may be drawn" (2014, p. 37), which could lead to errors in the

remaining useful lifetime estimation and hence to suboptimal decisions. A number of reasons could be given for this, including data loss due to mergers (some even decades ago), databases that were not interoperable, a lack of context data, etcetera. Liander was fully aware of this and put great effort in increasing the availability and interoperability of these data.

However, even if perfectly reliable, data do not cover all relevant aspects for the asset's remaining useful lifetime that are relevant in practice (Ding and Kamarudin (2015) note the same about the maintenance literature in general). For example, the work of Jongen (2012) and Chmura (2014) did not take changing functional requirements into account, which may result from the energy transition. Additionally, for Liander not only technical arguments but also the media and local, national and European politics may have important impacts on the remaining useful lifetime of assets, e.g. by changes in legislation. An example is presented by the case of 'grijs gietijzer' (a particular type of cast iron), where a leaking gas pipe caused an incident, which led to media attention and, as a consequence, a change in regulation which forced Liander to replace all of its gas pipelines made of 'grijs gietijzer'. This shows that changes in the context of the asset may render RUL estimations useless, if such changes were not taken into account in the estimations.

1.3.4 Discussion

To understand the practical relevance of this research, it is useful to compare the challenges faced by Liander to the (limitations of the) scientific literature described in section 1.2.4. In this comparison, the focus will lie on the long term strategic aspects of its Asset Management, and especially the efforts regarding RUL estimations.

First, whereas Asset Management should be a multidisciplinary approach, RUL estimations at Liander largely focused on technical aspects of the assets, such as failures and the asset's technical condition. As a result, other factors that may be relevant for the value of the assets for Liander may have been overlooked. Additionally, the knowledge needed to gain a multidisciplinary insight in the asset's remaining lifetime was scattered within the organization: over databases, people and departments. Different departments held different fields of expertise on the asset (e.g. the department regulation on the compliancy of the asset with norms and regulations, Asset Management on the technical aspects of the asset and financial affairs on the costs of the asset). Furthermore, information was scattered over different types of (policy) documents. As a result, combining all different types of information into a multidisciplinary understanding of the (remaining lifetime of the) asset tended to be difficult.

Secondly, in Asset Management, the complete lifetime of the asset should be covered. In Liander's Asset Management, the purchase, design and construction of new assets received ample attention, as did the maintenance and operation of the assets. The remaining useful lifetime estimations focused on the estimation of the exact end of life point of

an asset. However, there is a period between the current maintenance and the end of life of the asset at some point in the future, in which changes in the use of the assets or its context may require changes in either the operation and maintenance instructions, or the remaining useful life estimations. However, this period was only covered in strategic documents about the entirety of the grid, but not for specific types of assets.

A third characteristic of Asset Management is the pursuit of corporate objectives throughout the entirety of the organization. At Liander, the asset managers observed a gap between the operational and tactical aspects of Asset Management, and the strategic level, similar to the ‘threatening gap’ described by Pintelon and Parodi-Herz (2008). This was felt in the communication with higher management: the strategic questions asked by higher management could not easily be answered by the asset managers, who rather had an tactical and technical focus than the desired ‘businesswise’ perspective.

Fourthly, Asset Management should also consider (potential) changes in the context of the assets. Just as for the long term perspective, this focus did exist in the general Strategic Asset Management Plan (SAMP), but not in any structured way in the asset specific plans and policies.

The fifth limitation in the Asset Management literature concerned the absence of support for decision-making on strategic topics in a changeable context. At Liander, the same applied. For short term, operational issues a thorough process existed to decide which problems or risks justified the use of resources, and which not. Also, for new projects, business cases were prepared to decide on the use of resources. However, for long term issues, no process existed to assist asset managers in decision-making on the use of resources. Especially in the face of the energy transition and a possible ‘replacement wave’, such a process may prove to be useful for Liander.

A final and more practical limitation concerned the limited availability of reliable information. Liander experienced this as a challenge as well, as described in the discussion on RUL estimations in section 1.3.3. Liander therefore has put great effort in the improvement of the availability and quality of data. Additionally, research projects have been carried out to assess if analyses based on these limited data could still result in useful and reliable outcomes. The research projects of Jongen (2012) and Chmura (2014) showed that this is the case if the data used are consistent and complete, even if only few data are available.

This comparison of the situation faced by Liander and the scientific literature shows that the situation faced by Liander is not just a challenge for one specific company, but has many traits that are acknowledged by the literature as well. Also, it shows that the topics addressed in this research are not just scientifically relevant, but also hold the potential to contribute to practice.

1.4 Research Question and Objective

The previous sections clearly showed the potential value of an approach to Asset Management that fulfils the five criteria of Pudney (2010): Asset Life Cycle management. On the other hand, it has also become clear that a number of challenges and difficulties exists to reach such an approach. Based on these theoretical and practical needs, the following main research question has been developed:

How can a company, based on the knowledge and information available, effectively deal with change in its strategic Asset Life Cycle Management to create sustained stakeholder value with its assets over their complete lifetime?

This question shows that the focus of this research project will lie on assisting a company – owning or using a number of assets – in dealing with change. As the research is about Asset Life Cycle Management, all five characteristics of ALCM will be taken into account in this research. However, its main focus will lie on coping with change, as this is especially challenging for Asset Management organizations as no tools or methods exist to support asset managers to safely and effectively manoeuvre their assets into the future in the face of change. Additionally, all five aspects of ALCM are relevant to dealing with change: change may range from different backgrounds (multidisciplinary), it may impact any moment in the (future of the) asset's lifetime (and even the design of new assets), it may require a (re)alignment with corporate objectives, it may range from the context of the asset, and finally, coping with change will require the use of resources.

In this research, the focus will lie on the strategic planning aspects in ALCM, related to strategic challenges such as a 'replacement wave' or the energy transition. Hence it also relates to strategic decisions regarding the assets, for example related to life extension, functional upgrades or the preventive replacement of assets.

Furthermore, the research will take a practical approach by asking how to make the most of the information currently available to the company, instead of making the assumption that all information needed will somehow be available. Hence the main interest in this research will not lie in statistics and quantitative methods, but rather in the use of qualitative information and the use of the knowledge of experts and incorporating all other kinds of (quantitative) information in this process.

As already discussed earlier, the value of assets lies in the services they deliver. These services can be valuable to the owner or the user of the asset, but also to other stakeholders, such as the customers of the products produced by the asset, or even the society depending on services delivered by the asset. It is this stakeholder value that lies at the heart of strategic ALCM, and thus at the heart of this thesis.

This (stakeholder) value is created by assets, in plural. This is because many companies do not depend on only one asset, but rather use a large number of similar assets (e.g. a fleet of trains, or all transformers in the electricity grid) or even a system of different assets

working together (e.g. the electricity grid, consisting of cables, transformers, switchgear and safety equipment). In this research, the focus will be on large groups of assets, which together perform a function crucial to the company.

Finally, it is important to note that, while the main focus of this research lies on Asset Management and Asset Management organizations, its findings may have theoretical implications for the wider field of operations management, for two main reasons. First, this research puts the physical assets at the centre of the stage, physical assets all manufacturing companies rely on and which play a crucial role in operations management, even though this role is often performed at the backstage rather than at the frontstage. Secondly, whereas dealing with change while depending on limited information may be especially relevant for physical assets due to their long lifetimes and high financial value, this does not mean that in other fields of operations management dealing with change is not important (the recent attention for concepts as agility (e.g. Teece et al., 2016) and resilience (e.g. Hamel and Välikangas, 2003; Bhamra et al., 2011) rather suggests the contrary). Therefore, a deeper understanding in how to deal with change in Asset Management, where this may be especially hard, may yield useful insights for the wider operations management literature.

1.4.1 Practical project aim

In addition to this main question, and more related to the practical contribution this research project aims to deliver, a main objective has been formulated as well:

*to develop methods and tools
for strategic Asset Life Cycle Management in a changeable context.*

This aim is the more practical counterpart of the research question presented earlier. The main difference is that the research project explicitly aims to develop methods and tools, whereas the research question rather focuses how an Asset Management organization needs to deal with change. Of course both are intrinsically related: only when one knows how to deal with change, methods and tools can be developed that assist asset managers in coping with change in their organization. Primarily, the company aimed at is of course Liander, but rather than aiming at Liander specifically, the aim is to develop methods and tools that have practical value for Asset Management organizations in general.

1.5 Methodology

The main methodology used in this research was the Design Science methodology, which is especially suited for the development of design artifacts that address practical problems. In the next sections, the Design Science methodology will be introduced (1.5.1) and its main steps will be described (1.5.2). Section 1.5.3 presents how this dissertation fol-

lows the logic of the steps of the Design Science methodology and how the different chapters and their methodologies fit in this Design Science project.

1.5.1 Design Science

Research in the field of Operations Management (OM), to which this research belongs, has often been accused of being too distant from the managerial practice. As a result, research outcomes had little value for practitioners (Zuber-Skerritt and Perry, 2002; Van Mieghem, 2013; van Aken et al., 2016). To address this deficiency, the dual goal of contributing to science and practice is often stressed in books on OM methodology (e.g. de Leeuw, 2001; Karlsson, 2009). The Design Science methodology explicitly aims to make such a dual contribution (Hevner et al., 2004), and is increasingly gaining attention in the OM field (van Aken et al., 2016).

The basic idea between Design Science research is that scientists must not just evaluate (management) practices developed by practitioners. They must also contribute by developing new ideas and practices, as the practices to be evaluated must start somewhere (Holmström et al., 2009). Therefore, “the design scientist, while ultimately interested in explanation as well, is interested in creating an artifact that solves a practical problem” (Holmström et al., 2009, p. 69). Van Aken et al. (2016) discuss the same idea, arguing that Design Science research “in operations management can be regarded as a conscientious transfer of the strategy used in engineering research, taking into account the fundamental differences between designing and building a material artifact and designing and realizing a sociotechnical system. [...] The engineering-OM transfer here involves specific and important issues, including establishing the pragmatic validity of designs, generalizing the design, and examining the (social) mechanisms producing system performance” (van Aken et al., 2016, p. 2). In engineering and in medicine, Design Science like approaches are common. Here researchers try to improve the current situation by solving a problem (e.g. designing a bridge or curing a patient). This results in a specific solution for a particular situation and a more generic type of solution (van Aken et al., 2016). In this way, Design Science is different from explanatory science, which just aims to understand a particular phenomenon (the ultimate example is physics).

The designed artifact is not the sole outcome of a Design Science project. The design and evaluation of the artifact has led to an understanding of the mechanisms that underlie the artifact and deliver its outcomes. This understanding is crucial to develop a design proposition, which prescribes where and how the design can be applied in other situations (van Aken et al., 2016). A design proposition follows the CIMO logic (Denyer et al., 2008): in a certain problem context, the intervention (i.e. the use of the artifact) sets a generative mechanism into motion, which leads to the desired outcome.

Research quality in Design Science also relates to its focus on the development of practical solutions to real world problems. Design Science research outcomes are to be evaluated in

terms of their effectiveness, rather than in terms of ‘what is true’⁵ (Hevner et al., 2004). To establish the effectiveness of the artifact, testing and evaluating are crucial (van Aken et al., 2016). The outcomes of the test may allow further improvements of the design, which makes Design Science an iterative process (Peffers et al., 2007).

As Boer et al. (Boer et al., 2015) noted, the focus on practical problems in OM must not push aside the need to contribute to theory. Therefore, the designed artifact is not a specific solution to a particular problem in a unique context, but a generic solution to a set of similar problems. In other words: a mid-range theory (Holmström et al., 2009; van Aken et al., 2016). Application in practice always requires contextualization of the generic design to take the particularities of the specific context into account. The contribution to theory lies mainly in the understanding of why the design leads to the desired outcome. Additionally, the design scientist needs to relate his findings to the wider literature and make it theoretical implications explicit (Holmström et al., 2009).

1.5.2 The Design Science research process

A Design Science research project typically consists of two components: 1. a descriptive/explanatory component studying the problem in practice; and 2. a design/testing component to produce the design to address this problem (van Aken et al., 2016). Different authors propose different sets of steps to execute a Design Science research (e.g. Peffers et al., 2007; Holmström et al., 2009; Braaksma, 2012; Meyer et al., 2014; van Aken et al., 2016). In this dissertation, a four-step approach will be used, based on the three phases used by Meyer et al. (2014). These steps include: 1. the exploration of the problem; 2. the search for initial solutions; 3. the development of the final design (i.e. the artifact); and 4. the implementation and test of the design (see Figure 1.5.1).

Figure 1.5.1 - Overview of the four steps of the Design Science as executed in this dissertation

⁵ This does not mean that ‘truth’ is not considered important. Rather, it argues that an intervention or design may be effective even when it is not fully understood, or in the words of Hevner et al.: “the discovery of truth may lag the application of its utility” (2004, p. 98).

Problem exploration

Design Science aims to create a design artifact that solves a practical problem. Therefore, first the problem needs to be explored. These problems tend to be complex and intertwined with organizational and social components (e.g. power relations, culture, behavioural patterns). This turns these into 'ill structured problems': "decision situations where decision makers may not know or agree on the goals of the decision, and even if the goals are known, the means by which these goals are achieved are not known and requisite solution designs (e.g. technologies) to solve the problem may not even exist" (Holmström et al., 2009, p. 67). This research project has addressed such an ill structured problem: the goal is to manage assets effectively in the face of change, but it is not known how this can be done, and tools are not available.

The exploration of the problem leads to an understanding of the problem and its underlying causes. This is an important first step in the process of improving the problem situation, as "solving a problem simply means representing it so as to make the solution transparent" (Simon, 1996; cited in: Hevner et al., 2004, p. 83).

Initial solutions

The next step is to find initial solutions to the problem. As Holmström (2009) states: "[k]ey to the development of genuinely novel ideas lies in the ability to make use and combine the insights of multiple disciplines" (Holmström et al., 2009, p. 72). Hence, this second step relates the problem to theories, frameworks and practices from the literature, including literature from other disciplines. This follows the logic of abduction: an initial solution is inferred that might solve the problem (Van de Ven, 2007). This does not mean that the solution is the only possible solution, but rather: it is a solution that might be effective (but still needs to be tested). Taking these initial solutions – which may take the form of the CIMO-logic (Denyer et al., 2008) – from the scientific literature makes them scientifically-valid pieces of the puzzle to develop a final solution design.

Solution development

The separate initial solutions are combined into a final solution design, the artifact. This may be an iterative design process: a first version of the design is developed, it is discussed with others, adaptations are made, etcetera. Additionally, many others may be involved in this phase, such as fellow researchers and practitioners. Holmstrom et al. (2009) state that the collaborative Action Research methodology may be used in this phase of the Design Science project.

Implementation & Test

The final step is the implementation and test of the solution design in practice. The main goal is to establish the model's effectiveness in addressing the problem. It also explores if the generative mechanisms underlying the solution design work as anticipated. As van

Aken et al. (2016) stated, it is not always possible to evaluate the ultimate outcome of the artifact. For example, the ultimate outcome may lie outside the time span of the research, or other efforts of the organization address the same problem. Rather, one should “test for direct outcomes rather than for ultimate ones” (van Aken et al., 2016, p. 6).

The test of the artifact may take different forms, depending on the type of artifact. Peffers et al. (2012) present different types of evaluation used in Design Science (mainly in information systems and engineering literature), including: logical arguments, technical experiments, case studies and action research. A test in different contexts (e.g. a multiple case study) may be used to establish the effectiveness of the solution in different (but similar) context. This allows the researcher to assess the generalizability of the artifact. The goal is a generic design: “a design that can be transferred (within a certain application domain) to contexts other than the ones in which it has been made and tested without losing its basic effectiveness” (van Aken et al., 2016, p. 5).

Additionally, the evaluation allows to relate the findings back to the literature: why did the solution design ‘work’, and how did it work? By reporting the artifact and its design proposition, scientists and practitioners may benefit from the findings of the research (Peffers et al., 2007).

1.5.3 Application in this research project

This research project started from a practical problem: the management of change in Asset Management. At the inception of the project, this was still an ill structured problem: its underlying causes were unknown and the desired outcome of the solution was still discussed. Additionally, the practical goal of this research was to develop methods and tools for strategic Asset Life Cycle Management. For all of this reasons, the Design Science methodology was applied.

The basic logic of this dissertation follows the steps of Design Science. Its chapters all contribute to one or more phases of the methodology (except for chapter 8), as shown in Table 1.5.1. A number of these chapters apply other methodologies than the Design Science. For example, a survey study was used to explore ALCM practices in Dutch industry (chapter 2), and Action Research was used to study the process of change resulting from the design process (chapter 8). These other methodologies were used for their strengths in addressing specific parts of this Design Science research project. Table 1.5.1 shows the methodologies used in the different chapters (between square brackets) and how these relate to the different phases of the overall Design Science research project. Section 1.7 presents a brief summary of the contents of the chapters.

Table 1.5.1 - the fit of the chapters of this dissertation with the Design Science research

#	Description [methodology]	Problem exploration	Initial solutions	Solution design	Evaluation
1	introduction to the research, including an overview of the literature [-]				
2	assessment of Asset Management approaches in theory and practice [survey]				
3	study of Asset Life Cycle Plans (ALCPs) as a tool for ALCM [case study]				
4	development of the Lifetime Impact Identification Analysis (LIIA: a tool to identify change in ALCM) [design science]				
5	evaluation of the LIIA [case study]				
6	a hands-on instruction for the LIIA and the writing of an ALCP [-]				
7	the development of a method to prioritize and manage change in ALCM [design science]				
8	the development of ALCM capabilities through developing ALCPs [action research]				
9	a study on how Asset Management organizations cope with change [case study]	NA	NA	NA	NA
10	the conclusions of this study [-]				

1.6 Ethical remarks

In research ethics, ethical issues can be divided into three groups, related to three different stakeholders in the research: the research participants, the researcher and the sponsoring organization (Kumar, 2011). Their three most important practical implications for this research will be discussed.

First, the researcher will take care not to harm participants as a consequence of the research. During the research, sensitive information (e.g. disagreement with higher management, dissatisfaction with internal procedures) may be found. Such information will be treated confidentially, in order to prevent harm to this person (e.g. being fired). However, the researcher will not become a ‘voice of the workers’, but remain an objective and impartial observer in such issues. Furthermore, it may be found that certain employees of the company are less willing or able to cooperate than others. In that case, (proportional) feedback on the lack of cooperation to the employee and/or his/her manager will not be regarded as harmful, as being cooperative within the possibilities offered by the company is part of the normal relation between employer and employee and such feedback (and its possible consequences) is thus embedded in normal working life, rather than being an exceptionally harmful consequence of research.

Secondly, the results should in no way be influenced by the interest of the company, or by the interests of certain groups within the company. The goal of the research is to investigate and represent reality in an unbiased (though limited and abstracted) way, irrespec-

tive of who is the actual sponsor of the research. The researcher will also try to be sensitive to misuse or false use of the research results within the company (e.g. if it is used to justify decisions which the research does not support). Therefore, he will be sensitive to correct and precise wording of the research results within the company to prevent that the findings are falsely used to support actions or decisions which are not actually supported by the research.

Interestingly, in the list of ethical issues regarding the sponsoring organization (Kumar, 2011), it is not mentioned that the researcher has an ethical obligation to create value for the sponsoring organization. This gives the feeling that the sponsoring party may only pay and should furthermore keep her hands off the researcher. In my opinion, this is not a fair or ethical perspective on funding scientific research. As I see it, funding research is an exchange, where the funding party pays money to receive the time, capabilities and effort of a researcher and where it may expect to benefit from the potentially valuable outcomes of the research. The researcher should thus, as an ethical obligation to the sponsor, put his or her time and efforts into the research, with the double-sided objective to develop new knowledge as well as to aim at making a practical contribution that is usable and valuable for the sponsor. Due to the nature of scientific research, this practical contribution may however differ from the outcomes anticipated when starting the research.

1.7 Thesis outline

Now the theoretical, practical and methodological background of this research have been introduced, the time has come to start reading the outcomes of this research. To assist the reader in reading through this thesis and seeing the connections between the different chapters, a brief outline of the thesis will now be sketched.

2. A review of Asset Management literature and practice

In the next chapter of this dissertation, an overview will be given of the Asset Management literature. In this overview, the five main requirements of ALCM will be discussed, and used to assess the general Asset Management literature and the three most important maintenance concepts (i.e. Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) and Condition Based Maintenance (CBM)). Additionally, as this research aims to contribute to both the literature and practice, the existing Asset Management practice will be compared to these requirements as well. For this purpose, a survey study has been carried out among Dutch Asset Management organizations. The chapter will conclude that both the existing Asset Management approaches presented in the literature and the applications of Asset Management in practice do not fully comply with the five theoretical requirements of ALCM. Especially the identification and anticipation of change deserves extra attention.

3. Towards a model for effective Asset Life Cycle Management control

As the literature is clear about what ALCM is, but not about how ALCM should be done in practice, the next chapter discusses ALCM from a management perspective. The theory of 'management control' is used to develop a conceptual model of 'ALCM control': 'the active and purposive influence of asset performance over the complete life cycle'. Exerting ALCM control is important, as only by exerting active and purposive influence, the asset owner can be sure value is realized with the assets. The different characteristics of ALCM control are discussed and explained. Then, this theoretical framework is used to guide a case study on ALCM control in practice, studying the Asset Life Cycle Plans (ALCPs) used by the Netherlands Railways. This case study leads to the conclusion that the model may help to research ALCM practices and to point at the limits to control faced by an asset manager (e.g. in information processing capacity).

4. Design of the Lifetime Impact Identification Analysis

Based on the study of the literature and practice on ALCM, chapter 4 presents the development of the first method of this research project: the Lifetime Impact Identification Analysis (LIIA). Based on an exploration of the main challenges faced by Liander in its long-term Asset Management and initial solutions from the literature, a solution design is presented: the LIIA. At the heart of this method lies the concept 'lifetime impacts'. Rather than estimating the remaining useful lifetime (RUL) of an asset, often assuming a static context, in this method the opportunities and threats are considered that may have an impact on the asset during its complete (remaining) life. Such threats and opportunities have been called 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'. The LIIA has been designed to assist asset managers in the timely identification of these lifetime impacts, as only by their timely identification measures can be prepared in time to mitigate the negative consequences of the negative impacts, and to reap the full benefits presented by the positive impacts.

5. Evaluation of the Lifetime Impact Identification Analysis

Complementing the development of the LIIA in chapter 4, chapter 5 proceeds with the test of this method. This test has been carried out at two different Asset Management organizations, both operating in a changeable context. The first organization was Liander, where the method has been designed. A second test has been carried out at Vattenfall Wind Power in Denmark, which in many regards is a contrasting case to Liander: Vattenfall Wind Power is a different company, located in a different country, working in a different sector, and operating very different assets: wind turbine generators (WTGs). These two test applications showed the usefulness of the LIIA for the companies and its potential to assist Asset Management in a changeable context. Furthermore, the evaluation of the LIIA corroborated the 'generative mechanisms' underlying this method, which is an important

scientific outcome of this chapter, as these generic mechanisms can be used in different methods or for different purposes as well.

6. Asset Life Cycle Plans: twelve steps to assist strategic Asset Management decision-making

The next chapter has a slightly different tone of voice and objective than the other chapters in this dissertation. Rather than the scientific community, the Asset Management practitioners have been chosen as the main audience for this chapter. This fits the dual goal of this thesis: contributing to both science and practice. In this chapter, the findings from the chapters 3 to 5 are combined in a hands-on instruction for practitioners to use the LIIA method to develop Asset Life Cycle Plans (ALCPs). The chapter is illustrated with a case from Liander, the ALCP on distribution transformers.

7. Lifetime Impact Centred Asset Management to manage predictable change

The LIIA was the first method designed in this research project, but its evaluation showed that the method did create a new problem: many lifetime impacts were identified, but the method offered no guidance for the selection of the most important lifetime impacts out of this long list, let alone how to manage these impacts in a suitable way. Therefore, this chapter presents a complement to the LIIA, by addressing these two problems. Based on the scientific literature and in analogy with RCM (an important maintenance method), a solution design has been developed, that consists of three steps. The first step is the preparation of the lifetime impacts ranging from the LIIA, to make them suitable for the next step: prioritization. In the next step, the lifetime impacts are prioritized based on their likelihood, their potential effect and the effort required to appropriately manage the lifetime impact. Finally, a decision logic tree is presented to support asset managers in finding the most suitable solution strategy for any identified (high priority) lifetime impact, to reap the full potential of positive lifetime impacts and to reduce the negative consequences of the negative impacts. These steps have been applied in practice at Liander, and the evaluation showed how these steps may yield additional insights in the lifetime impacts and foster discussion on these impacts, structure the decision-making process and help asset managers in spending their time on the most important lifetime impacts.

The LIIA, complemented with these three additional steps, has been called Lifetime Impact Centred Asset Management (LICAM). This method can be regarded as a complement to RCM: RCM focuses on the identification and mitigation of (technical) failure mechanisms in the current operating context, the LICAM focuses on the identification and mitigation of (multidisciplinary) lifetime impacts, resulting from changes in the operating context.

8. Developing Asset Life Cycle Management capabilities

The development of the LICAM method, described in chapters 4, 5 and 7, was an iterative process, as is generally the case following the Design Science methodology (van Aken et

al., 2016). In this chapter, this iterative process is described and studied, using the Action Research methodology. This methodology is a scientific method that aims to study processes of change, especially where the context of the (ill-defined) problem to be solved is complex (Coughlan and Coughlan, 2002). Using this methodology, the development of the LICAM method and the ALCPs (based on this method) is regarded as a process of change, and this change process has been studied. The main focus of this study was not the LICAM method or the ALCPs per se, but rather the underlying capabilities that were developed within the organization through the development of the ALCPs. In other words: the ALCPs were regarded as ‘agents of change’, causing change within the organization. From the study of this change process, five main ALCM capabilities emerged: 1. strategic use of information; 2. vertical alignment between operations and strategy; 3. horizontal alignment between different disciplines; 4. a dual time perspective and 5. exerting influence over the assets outside one’s direct span of control.

9. Agility enabled by physical assets: a multiple case study

During this research, it was found that a singular focus on predictable change was not sufficient. Asset Management organizations do not only have to deal with change that can be anticipated and prepared for (e.g. by means of the LICAM), but also come across unpredictable change. According to the literature, the amount of change is even increasing in the field of Asset Management. This is especially challenging for Asset Management organizations, as their assets by definition have long lifetimes and high values, and often are difficult to adapt to new circumstances (e.g. adding new communication systems to a 25 year old Cold War tank is likely to be very expensive and time-consuming).

In the general management literature, the concept of agility (e.g. Yusuf et al., 1999) concerns the question how organizations may cope with unpredictable change. However, the singularity of physical assets in the face of change, nor the agility that may range from (the use of) physical assets is not considered in this literature. In this chapter, this gap is addressed. Based on the agility and Asset Management literature, a conceptual framework in ‘agile Asset Management’ is presented, to elaborate on the existing agility literature. Using this theoretical framework, three different Asset Management organizations have been studied to investigate how these organizations cope with change: the Defence Materiel Organization of the Royal Netherlands Defence the Netherlands Railways and Liander. Three asset-related agility enablers were found, complementing the organizational agility enablers discussed in the agility literature: the inherent resilience of the assets to cope with changing circumstances, the adaptability of assets and the agility offered by having a larger population of assets to fulfil the same function (agile deployment).

10. Conclusions

In the final chapter of this dissertation presents the answer to the main research question of this research: *‘How can a company, based on the knowledge and information available,*

effectively deal with change in its strategic Asset Life Cycle Management to create sustained stakeholder value with its assets over their complete lifetime?’ The answer to this question comes in three different parts. First, the importance of change – lifetime impacts – in Asset Management needs to be acknowledged, and managing change needs to become a central aspect of Asset Management.

Second, to deal with predictable change in an effective way, the LICAM has been developed to identify, prioritize and effectively manage lifetime impacts. The output of the LICAM can be used to develop Asset Life Cycle Plans (ALCPs) to plan for such predictable change. Additionally, the five ALCM capabilities have found to be important skills for an Asset Management organizations to manage assets in a strategic way.

Apart from the predictable change, there is also unpredictable change, which leads to the third part of the answer to the research question. Unpredictable change can be prepared for by means of agility, ranging from seven agility enablers from three different sources: the assets (asset resilience and asset adaptability), the population of assets (agile deployment) and the Asset Management organization (agile people, linkages, strategy and information & processes). The acknowledgement of the importance of change as well as the planning for predictable change and the preparation for unpredictable change are important to safely and efficiently manoeuvre physical assets into the future.

Apart from the conclusion, this last chapter also discusses the findings of this research in the light of the five requirements of ALCM, presents a number of limitations of the conclusions and methods ranging from this research, and makes a number of recommendations for further research and for practitioners.

1.8 Guide to the reader

One of the main goals of research is to publish, not only because of the well-known and widely feared adage ‘publish or perish’, but also because only by publishing one can join the ‘scientific debate’ and help the progression of science. Publication also helps to receive feedback on one’s work and to get into touch with other scientists. Therefore, the goal of this PhD research project was to publish papers in conference proceedings and journals as soon as they were ready, rather than waiting to publish everything in the dissertation. This has resulted in a number of conference and journal publications resulting from this research (see section 1.8). Most conference papers have first been extended and improved into journal papers, and these journal papers have become chapters in this dissertation. One exception is the conference paper with Maurits Korse (Korse et al., 2016), which does not fall within the scope of this dissertation.

As a result, this PhD dissertation consists of a collection of separate (journal) papers (see section 1.8), which all cover separate parts of the main research question for this PhD project. These separate papers have now become chapters of this dissertation. This suits the

needs of those readers who are solely interested in specific parts of this research. However, for the readers who want to read through the entirety of this dissertation, this would cause a highly repetitive and annoying read. To facilitate both groups of readers, a grey double line in the left margin of the text shows which pieces of text (see the left margin of this paragraph for an example) can be skipped by those readers reading this dissertation cover to cover. Additionally, each chapter will be introduced with a separate 'guide to the reader', to explain how the chapter is embedded in the entirety of this dissertation.

Please allow me one last remark before you start to read, whether this is a specific chapter that has attracted your attention, or the entirety of this dissertation. I would like to thank you in advance for your interest in my research and for your time to read (parts of) this dissertation. I hope you will enjoy your read and will gain new knowledge for your research or your work in Asset Management. My goal at the outset of this research adventure was to contribute to both science and practice: to help scientists to serve practitioners even better with relevant, useable and reliable knowledge and tools, and to assist practitioners in creating even more value with their physical assets throughout the complete life cycle of these assets.

Have a nice read!

1.9 List of publications related to this research

Ruitenbunrg, R.J., Braaksma, A.J.J., van Dongen, L.A.M., 2014. A multidisciplinary approach for the identification of impacts on the useful remaining lifetime of assets. In: *Procedia CIRP - 3rd International Conference on Through-Life Engineering Services*. Elsevier, pp. 204–212.

Petersen, K.R., Ruitenbunrg, R.J., Madsen, E.S., Braaksma, A.J.J., Bilberg, A., 2015. Lifetime Impact Identification for Continuous Improvement of Wind Farm Performance. In: *Proceedings of the 16th Int. CINet Conference*. Stockholm, Sweden, pp. 1–10.

Ruitenbunrg, R.J., Braaksma, A.J.J., van Dongen, L.A.M., 2015. Towards a model for effective Asset Life Cycle Management control – a case study in rolling stock maintenance. In: *Proceedings of the 22nd EurOMA Conference*. Neuchâtel, Switzerland, pp. 1–10.

Ruitenbunrg, R.J., Braaksma, A.J.J., van Dongen, L.A.M., 2016. Asset Life Cycle Plans: Twelve Steps to Assist Strategic Decision-Making in Asset Life Cycle Management. In: *Optimum Decision Making in Asset Management*. IGI Global, pp. 259–287.

* Korse, M., Ruitenbunrg, R.J., Toxopeus, M.E., Braaksma, A.J.J., 2016. Embedding the Circular Economy in Investment Decision-making for Capital Assets - A Business Case Framework. In: *Procedia CIRP*.

- Ruitenburt, R.J., Braaksma, A.J.J., Van Dongen, L.A.M., 2016. Agility in Asset Management, or: how to be flexible with assets designed for stability. In: *Proceedings of the 23rd EurOMA Conference*. Trondheim, Norway, pp. 1–11.
- Ruitenburt, R.J., van Diepen, T., Braaksma, A.J.J., 2016. Setting priorities for the proactive management of longterm challenges and opportunities in Asset Life Cycle Management. In: *Proceedings of the 23rd EurOMA Conference*. Trondheim, Norway, pp. 1–10.
- Ruitenburt, R.J., Braaksma, A.J.J., 2017. Mitigating change in the goals and context of capital assets: Design of the Lifetime Impact Identification Analysis. *CIRP Journal of Manufacturing Science and Technology*. 17, 50–59.
- Ruitenburt, R.J., Braaksma, A.J.J., 2017. Evaluation of the Lifetime Impact Identification Analysis: Two tests in a changeable context. *CIRP Journal of Manufacturing Science and Technology*. 17, 42–49.
- Ruitenburt, R.J., Braaksma, A.J.J., 2017. Developing Asset Life Cycle Management capabilities through the implementation of Asset Life Cycle Plans – an Action Research project. In: *Proceedings of the 24th EurOMA Conference*. Edinburgh, Scotland, the United Kingdom, pp. 1–11.
- Ruitenburt, R.J., Braaksma, A.J.J., [n.d.]. A review of Asset Life Cycle Management in literature and practice [working title]. To be submitted to the *Journal of Quality in Maintenance Engineering*.
- Ruitenburt, R.J., Braaksma, A.J.J., [n.d.]. Developing Asset Life Cycle Management capabilities – an Action Research project [working title]. To be submitted to the *International Journal of Production Management*.
- Ruitenburt, R.J., Braaksma, A.J.J., [n.d.]. Lifetime Impact Centred Asset Management: the development of a decision support tool to manage long-term threats and opportunities in Asset Life Cycle Management. Submitted to the *CIRP Journal of Manufacturing Science and Technology*.
- Ruitenburt, R.J., Braaksma, A.J.J., van Dongen, L.A.M., [n.d.]. Agility enabled by physical assets: a case study. Submitted to the *International Journal of Production Management*.

* This conference publication is not included in the contents of this dissertation.

Publication history

This chapter has not yet been published, but a shortened version will soon be submitted to the *Journal of Quality in Maintenance Engineering*.

2

A review of Asset Management literature and practice

Chapter 2 presents the theoretical and practical background of this research project. By the exploration of the gaps in theory and in practice, this chapter presents the motivation for this research and lies the foundation for the remainder of this dissertation.

2

A review of Asset Management literature and practice

Abstract

Asset Management, the management of physical assets, is increasingly receiving attention in literature and in practice. This has resulted in an increasing understanding of five main characteristics of Asset Management: 1. multidisciplinary; 2. a focus on the complete life cycle; 3. the pursuit of corporate objectives; 4. the consideration of (contextual) change; and 5. the use of resources. This chapter assesses the literature, three important maintenance concepts (Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) and Condition Based Maintenance (CBM)) and Asset Management practice on these five requirements, based on a review of the literature and an exploratory survey. It is concluded that the literature, maintenance concepts and Asset Management practice do not live up to these requirements, as they are largely technical and organizational, short term operational and tactical in nature, not always aligned to the corporate objectives and do generally not consider change. Additionally, the limited availability and reliability of data in practice is often not considered. Therefore, it is concluded that a more strategic, long term and change oriented approach to Asset Management is needed.

Keywords:

Asset Management, Asset Life Cycle Management, maintenance management, ISO 55000, literature review, RCM, TPM, CBM, survey, Asset Management Plan, change, alignment, performance management

2.1 Introduction

Over the last decades, the field of maintenance has undergone a major transformation. Once, maintenance was a 'necessary evil' (Pintelon and Parodi-Herz, 2008), as equipment that broke down needed to be repaired. The unavoidable costs of these repairs meant that maintenance was perceived as a 'cost centre' (Takata et al., 2004). Recently, the understanding of maintenance has changed, as it was realized that maintenance can be a creator of value (Wijnia and Herder, 2010) and that the management of physical assets

was an important precondition for the corporate strategy (Velmurugan and Dhingra, 2015).

This resulted in the development of the Asset Management discipline, which includes maintenance but has a far wider scope. In the literature, the concept is increasingly attracting attention, as can be seen from the growing number of articles on this topic. Also in practice, Asset Management is gaining attention, and recently even an ISO standard on Asset Management has been published, the ISO 55000 (2014).

This attention has resulted in a growing theoretical understanding of what Asset Management is and what it should include. This chapter aims to address the question whether the existing Asset Management literature as well as the current state of Asset Management in practice live up to these latest insights. To answer this question, first Asset Management will be defined and its main characteristics will be introduced (section 2.2). Based on these characteristics, an assessment will be made of the general Asset Management literature (2.3), three important Asset Management methods (Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) and Condition Based Maintenance (CBM)) (2.4) and Asset Management in practice (2.5). This assessment will show the limitations of the current approaches to Asset Management, which will be summarized in section 2.6. Finally, some implications of this assessment for both scientists and practitioners will be presented (2.7).

2.2 Asset Management and Asset Life Cycle Management

In the ISO 55000 standard on Asset Management (2014), Asset Management is defined as the “coordinated activity of an *organization* to realize value from *assets* [italics in original]” (ISO, 2014, p. 14). The ultimate goal of Asset Management is thus the ‘realization of value’ from these assets, which relates to the services the assets provide. To realize value, Asset Management “involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organizational objectives” (ISO, 2014, p. 2). This clearly shows how the value of an asset is related to the organizational objectives. The tank example presented earlier in this dissertation (section 1.2.1) provides a clear example: the value of the tank was larger during the Cold War (where the organizational objective was to defend the Netherlands from Soviet Union aggression) than it is now (as it is less suited for counter-terrorism operations). Therefore, assets are only valuable to the organization as far as they contribute to the (changing) organizational objectives.

This focus on the realization of organizational objectives is also clear in the definition of Asset Management proposed by Pudney (2010), which he based on a comparison of a number of different definitions. According to Pudney, Asset Management can be defined as “an organisation’s coordinated multidisciplinary practice that applies human, equipment and financial resources to physical assets over their whole life cycle to achieve de-

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” (Pudney, 2010, p. 8). This definition shows the breadth of Asset Management: it combines different (technical and non-technical) disciplines to achieve (corporate) objectives with the assets over their complete life and considers the context in which the asset operates (e.g. governance and social regimes). In other words: Asset Management involves both the physical assets and the wider organization in order to create maximum value from the exploitation of the assets over their complete lifetimes. In the remainder of this dissertation, the term Asset Life Cycle Management (ALCM) will be used to refer to an approach to Asset Management that lives up to this definition.

2.3 Assessment of the Asset Management literature

In the previous section, Asset Life Cycle Management has been defined as those approaches of Asset Management that live up to the definition of Asset Management provided by Pudney (2010). Living up to this definition requires fulfilling five criteria, as according to this definition, Asset Management is:

1. a multidisciplinary practice;
2. in which the whole life cycle of a physical asset is taken into account;
3. with the goal of achieving certain specified objectives;
4. within acceptable limits of risk and relevant regimes; and
5. it should determine the allocation of resources.

In this section, the general Asset Management literature will be assessed based on these five criteria.

Asset Management is a multidisciplinary practice

To manage physical assets effectively over their complete lifetimes, many different disciplines should work together. Many lists of relevant disciplines exist, but one rather complete list is given by Amadi-Echendu, who argued that creating value with assets throughout their life cycle “requires a higher level integration of the synergies between the traditional disciplines in accounting, economics, engineering, finance, and humanities; as well as logistics, process and information systems technologies” (Amadi-Echendu, 2004, p. 1157), making it an “interdisciplinary field of endeavour” (Amadi-Echendu et al., 2010, p. 3).

However, in a discussion on Asset Management, Haffejee and Brent concluded that in many current methods “the economic, environmental, social and technical dimensions of Asset Management are not explicitly depicted” (2008, p. 286). For example, many approaches are limited to the technical aspects of the asset. These are often related to the

more technical field of maintenance management (more on maintenance management in section 2.4), but also more general Asset Management literature has this tendency (e.g. Campbell et al., 2010; Frangopol et al., 2012). The importance of non-technical issues in Asset Management has also been acknowledged in a study on Asset Management practices: “[e]ven though Asset Management was generally considered to be an engineering discipline, most asset managers recognized the importance of the non-technical issues like economics and social elements” (Wijnia and Herder, 2010, p. 271). Next to the technical aspects, numerous Asset Management approaches focus on the financial aspects of the asset, for example related to life cycle costing (LCC) (Asiedu and Gu, 1998; Márquez et al., 2012).

The acknowledgement of the relevance of different disciplines for Asset Management is however not sufficient. These different disciplines also need to work together, which in practice is often hindered by an organizational ‘island culture’ (Zoeteman, 2006) and a ‘silo mentality’ (Amadi-Echendu et al., 2007). This shows that even though the literature is clear about Asset Management being a multidisciplinary practice, truly multidisciplinary approaches are rare in the literature, which is the first limitation found in the Asset Management literature.

Asset Management takes the complete life cycle of an asset into account

As discussed in section 1.2.1, the costs of maintenance of physical assets may exceed their initial purchase price. As many assets simply cannot perform without maintenance, these costs are more or less fixed in their design. Schuman and Brent (2005) stated that about 65% of the costs accrued during the life of an asset are already fixed in the assets design. Therefore, the complete life cycle of an asset should be taken into account. Different classifications of this life cycle have been proposed, ranging from only three phases (‘acquisition phase, utilization phase, recycling phase’ (Asiedu and Gu, 1998)) to as many as eight (“strategy, plan, evaluate/design, create/procure, operate, maintain, modify, dispose” (Campbell et al., 2010, p. 3)). But irrespective of the number of phases, what is clear is that there is more than just a ‘utilization phase’ or the phases ‘operate and maintain’. However, generally these are the phases that receive most attention, and where most of the (maintenance) optimization efforts are spend (even though only 35% of the costs can then still be influenced). The relatively new discipline of ‘design for maintenance’ (see for example Mulder (2016)) tries to address this deficiency.

Relatedly, while a large literature exists on the estimation of the remaining useful life (see for example the review by Si et al. (2011)) and asset replacement decision making (refer to Das and Sarmah (2010) for a review), little attention has been spent on the last life cycle phase of the assets life: disposal & recycling. Only few authors have addressed this life cycle phase in relation to Asset Management (see for example Niekamp et al. (2015) or Korse et al. (2016)).

Next to the limited attention to the first and last phase(s) of the asset's life cycle, the literature also indicates that the Asset Management literature tends to focus on the short term and operational and tactical issues, rather than the long term and strategic matters (Murthy et al., 2002; Amadi-Echendu et al., 2007; Komonen et al., 2012). The same is noted in Asset Management practice: "Asset Management is mainly limited to the operational level, but is developing into the tactical domain. Few organizations have moved Asset Management into the strategic domain" (Wijnia and Herder, 2010, p. 268). Zoeteman (2006) also acknowledged this tendency, and shows how the short term focus of stakeholders (e.g. requiring short payback periods on investments or quick performance improvements) may conflict with the long term strategic focus that is necessary in Asset Management. However, only by taking the complete life cycle of the physical asset into account, starting with its earliest design requirements and also considering the long term, the costs and performance of physical assets can be managed effectively.

Asset Management aims at the achievement of specific objectives

This long term, strategic aspect of Asset Management relates to the third characteristic of Asset Management: the realization of objectives. It is the contribution the function of the asset makes to the achievement to the corporate objectives that makes the asset valuable. Therefore, it is important that in the management of the assets, the corporate objectives are both known and pursued. However, Pintelon and Parodi-Herz (2008) stated that one of the most important challenges for maintenance is to close the "threatening gap between the top management level and the overall maintenance strategy determination and the tactical level on which the maintenance concepts are designed, detailed and implemented" (2008, p. 45). In other words: "alignment is needed between organizational goals and technical norms and standards, but this is lacking in many organization[s]" (Wijnia and Herder, 2010, p. 271). The same problem is noted by Haarman and Delahay (2004), Komonen et al. (2012) and Laue et al.(2014). Pinjala et al. (2006) addressed this problem and found that companies with different competitive priorities (e.g. quality or cost) tend to use different maintenance strategies, which is an example of how this translation from corporate strategy to maintenance may be done in practice.

This relates to the concept of alignment (also known as 'line of sight'): "a key principle in Asset Management is a line of sight [or: alignment - added], which means an approach within an organisation that looks to line up the work that is done directly on assets with the objectives of the organisation" (Shah et al., 2017, p. 232). Alignment requires that on all levels of the organization, the same objectives are pursued. However, the literature shows the maintenance and the production department (Iravani and Duenyas, 2002) and the maintenance technicians and the maintenance managers (Xerri et al., 2015) are often far from aligned.

Asset Management considers risks and relevant regimes

Due to the long lifetimes of the assets and the strategic nature of Asset Management, the asset manager should be aware of the wider context in which the assets operate. Rather than operating in a vacuum, the assets are dependent on a wider 'ecosystem' to create value. This starts with the spare parts needed to execute maintenance tasks and the knowledge and skills of the technicians (Moubray, 1997). But many other contextual aspects are relevant as well: regulations, market demand, technological innovations, information technology, societal expectations, etcetera (Tsang, 2002; Al-Turki, 2011). It is such contextual factors that Pudney (2010) calls 'regimes'. These factors are of crucial importance, as the context in which the assets operates may change, which may require large scale adaptations of the use of the asset and possibly even of its physical characteristics (Herder and Wijnia, 2012). However, oftentimes, such contextual changes are not considered (Arja et al., 2009; Komonen et al., 2012). This is also noted by Laue et al., who state that "current models exhibit a distinct weakness in that they focus primarily on the operational and technical level and neglect the levels of strategy, policy and governance as well as the social dimensions" (Laue et al., 2014). Similarly, Kusumawardhani et al. (2017) proposed that strategic planning is important in Asset Management, and that this should "begin with an assessment of the asset's business environments, which consist of the organization's internal and external environments" (2017, p. 174).

Asset Management determines the use of resources

Physical assets require maintenance, and to carry out maintenance, many resources are needed: spare parts, tools and equipment, manpower, knowledge, etcetera. As the budgets for Asset Management are generally limited, the most needs to be made of these limited budgets. Therefore, many different methods and tools are available to help asset managers make the best choices, as literature reviews on maintenance policy selection (Hong et al., 2012) and the optimization of maintenance policies (Ding and Kamaruddin, 2015) show (see also chapter 7, section 7.2.5 (p.166) for a review of a number of decision support tools in the Asset Management literature). However, these methods and tools primarily focus on operational or tactical decisions rather than strategic decisions, and do generally not consider changes in the goals or context of the asset over their complete life cycles.

Availability of reliable information

Apart from the five requirements of ALCM discussed here, another important topic in the Asset Management literature is the availability of reliable information. Many authors report all sorts of data related problems in practice, while the models presented in theory largely assume that all data required is either available or can be gathered relatively easy. Wortmann (2014) called this the information assumption, which may be a strong assumption to make in Asset Management. A revealing illustration is presented by the case study

on Asset Management practices presented by Wijnia and Herder (2010), who reported: “The data exist but are not accessible”. This was the central theme of all interviews. [...] Some asset owners could not even tell for certain how much assets they owned” (Wijnia and Herder, 2010, p. 169). Similarly, in their review of statistical models for remaining life-time estimation, Si et al. (2011) concluded that many quantitative attempts fail because of the lack of quality and availability of data, and hence argue that methods based on the knowledge of experts may be a solution. Similar findings are reported by Garg and Deshmukh (2006), Lin et al. (2006), Mathew and Hargreaves (2008), Jongen (2012), Kerkhof et al. (2014) and Shah (2017), just to mention a few.

A different aspect of the availability of data is captured by Ding and Kamarudin, who argued that not every condition can be translated into algebraic form and replicated accurately. Consequently, it may lead to wrong maintenance policy decision making” (2015, p. 1277). The review of 120 quantitative papers by Si et al. (2011) provides an example: even though all these papers aim to provide estimations of the remaining useful life (RUL), none of them considers other aspects than technical failures. All other reasons for the end of life of an asset – issues like safety, regulations, market demand, production cost, spare part availability – are therefore overlooked.

Conclusion

The assessment of the general Asset Management literature using the five criteria of Asset Life Cycle Management resulted in the following limitations:

1. many approaches to Asset Management lack a truly multidisciplinary approach;
2. the complete life cycle of a physical asset is not always taken into account;
3. the corporate objectives are not always pursued throughout the entirety of the organization;
4. (contextual) changes relevant to the asset are generally not considered;
5. little support is offered to decide on the allocation of resources in a changeable context; and – from a more practical point of view –
6. the limited availability and reliability of data and information often limits the use of theoretical Asset Management tools in practice.

So even though the literature is clear about what Asset Life Cycle Management is and what characteristics it should fulfil, the literature does not provide guidance as to how such an ‘ideal’ approach should look like, let alone how it should be reached. Additionally, the recent ISO 55000 standard on Asset Management stresses the importance of a strategic ‘life cycle management approach’ towards Asset Management, of alignment and of adopting a multidisciplinary approach. However, again only guidelines are provided, but no guidance (Jooste and Vlok, 2015).

2.4 Assessment of RCM, TPM and CBM

In the previous section, the general literature on Asset Management has been discussed in the light of the five ALCM requirements. Next to the general literature on Asset Management, many different methods and tools are available to effectively manage assets over their complete life cycle. Many of these methods and tools are discussed under the heading of maintenance management, for example in the literature reviews of Garg and Deshmukh (2006) or Fraser et al (2015). Neither of these reviews gives a definition of maintenance management, but the European Committee for Standardization (2010) presents the following definition: “all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics” (2010, p. 5), an earlier version was proposed by Márquez (2007). This definition shows the broad scope of maintenance management, which is similar to older definitions of Asset Management. The resemblance of maintenance management and Asset Management becomes even more clear from the following statement: “[t]raditionally, maintenance management was dealt with the short-term issues like resources, cost, manpower etc. Recent past, maintenance management has changed its concerns towards the consideration of long-term goals like competitive, sustainability and strategy [...]. Therefore, maintenance management needs to be viewed in a strategic perspective” (Velmurugan and Dhingra, 2015, p. 1623). The use of the concept ‘asset maintenance management’ (e.g. Hassanain et al., 2003; Zoeteman, 2006; Abiri-Jahromi et al., 2013) also shows this.

The most encompassing methods within maintenance management are called ‘maintenance concepts’⁶: “structured way[s] to plan and control the various maintenance policies [“prescribe which parameter triggers a maintenance action”] and actions, as well as to improve [these]” (Goossens, 2015, p. 21). Based on an extensive review of 37 maintenance concepts, Fraser et al. (2015) concluded that most important and popular maintenance concepts are Reliability Centred Maintenance, Total Productive Maintenance and Condition Based Maintenance⁷ (Fraser et al., 2015). With respect to the remaining 34 arti-

⁶ Many different words are used in the literature, for example ‘maintenance strategy’ (Murthy et al., 2002), ‘maintenance management model’ (Fraser et al., 2015), ‘maintenance approach/tactic’ (Velmurugan and Dhingra, 2015) and ‘maintenance technique’ (Garg and Deshmukh, 2006).

⁷ One might argue that CBM is a maintenance policy (which “prescribe[s] which parameter triggers a maintenance action” (Goossens, 2015, p. 21)), rather than a maintenance concept, as (prognostic) CBM is basically about doing maintenance based on the (current or predicted) condition of the asset, and thus does not consider various maintenance policies. However, as many authors discuss CBM (also) as a maintenance concept (see Fraser et al. (2015) for an overview), it has been chosen to assess CBM as a maintenance concept, together with RCM and TPM. The results of this assessment should be interpreted with care however, as one may argue that CBM is not intended to be used as a maintenance concept of its own.

cles, they conclude that “many [of the remaining 34] models are a direct extension or based on the platform of the three prominent models identified, TPM, RCM, and CBM” (Fraser et al., 2015, p. 640).

For each of these three maintenance concepts, a short description will be presented, including the main tools used in these concepts and their main limitations according to the literature. Based on these descriptions, each of these concepts will be assessed based on the five ALCM requirements in Table 2.4.1, which will be briefly discussed in section 0.

2.4.1 Reliability Centred Maintenance (RCM)

Reliability Centred Maintenance (RCM) was developed in the aviation industry, to assess the reliability of the designs of new airplanes (Smith and Hinchcliffe, 2003). RCM can be defined as “[a] process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context” (Moubray, 1997, p. 7). The four main principles underlying RCM are summarized by Smith and Hinchcliff (2003), who stated that RCM is about 1. the preservation of asset functions; 2. the identification of failures modes that can defeat these functions; 3. the prioritization of these failure modes; and 4. the selection of the right preventive maintenance task for each high priority failure mode.

Main tools of RCM

To assist asset managers in finding the right maintenance actions to upkeep the asset’s functionality, different tools are available. The main process within RCM is the Failure Mode Effect Analysis (FMEA) (Smith and Hinchcliffe, 2003), where the different possible functional failure modes of an asset are identified using expert sessions (Moubray (1997) calls these ‘RCM review groups’). In these expert sessions, engineers, operators and technical specialists from different technical disciplines come together to discuss potential failure modes. Many failure modes generally result from these sessions, and a Risk Priority Number (RPN) – based on likelihood, effect and detectability – can be assigned to each failure mode to prioritize these (Dieter and Schmidt, 2008). Finally, a decision tree is used to find the most suitable preventive maintenance action for each failure mode (Moubray, 1997; Smith and Hinchcliffe, 2003).

Many different versions of RCM exist, as the review of Gupta and Mishra (2016) showed. These follow roughly the same logic, even though some add additional aspects, such as failure rate modelling, cost-benefit analysis of preventive maintenance or uncertainty analysis (Gupta and Mishra, 2016). Additionally, RCM can generally be executed in two different ways: traditional and streamlined (Smith and Hinchcliffe, 2003; Pintelon and Parodi-Herz, 2008).

Limitations

In the literature, a number of limitations of the RCM is discussed. First, it is argued that RCM is complex (Waeyenbergh and Pintelon, 2002) and time consuming (Pintelon et al., 1999; Cheng et al., 2008). Also, its focus is mainly on operational and short-term issues, rather than strategic matters (Murthy et al., 2002). Furthermore, it is argued that RCM regards maintenance as a reliability rather than an economic problem (Waeyenbergh and Pintelon, 2002) and that it is unclear how RCM may lead to cost reduction (Gupta and Mishra, 2016). Additionally, RCM is mainly based on expert judgement, and its neglect of quantitative data is considered a weakness (Teoh and Case, 2005), which has also been addressed by more quantitative approaches to RCM (see for example Braaksma et al. (2012) or the approaches listed in 'group B' in the review of Gupta and Mishra (2016, p. 140)). However, it has also been acknowledged that the availability of useable quantitative data is often limited in practice (Braaksma et al., 2013). Finally, "RCM is basically a static exercise in framing a PM [preventive maintenance] program. This needs to be made dynamic [...] by revising the program based on changing circumstances in the field" (Syamsundar, 2016, p. 417). Even though RCM was designed as a 'living program' in which such changes would lead to a review of the maintenance practices (Moubray, 1997), this often is not the case in practice (Braaksma et al., 2013).

2.4.2 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) was developed to limit the disruptive consequences of equipment failures in production systems organized according to Just in Time (JIT) and Total Quality Management (TQM) principles (Cua et al., 2001), as an efficient manufacturing process without buffers and with consistent high quality depends on highly reliable equipment. TPM can be described as "a system of maintenance covering the entire life of the equipment in every division including planning, manufacturing, and maintenance" (Jain et al., 2014, p. 298). Its main aim is the maximization of the 'Overall Equipment Effectiveness' (OEE). The logic behind the OEE is that there are 'six big losses' that reduce the output of manufacturing equipment, and that the OEE can be used to reveal these 'hidden costs' (Nakajima, 1988). The six losses can be divided over three different categories: I. downtime losses (1. equipment failure; 2. set-up and adjustment losses); II. speed losses (3. idling and minor stoppage; 4. reduced speed); and III. defect losses (5. defects in process; and 6. reduced yield) (Jain et al., 2014). To maximize the OEE, TPM is focused on the "realization of zero breakdowns, zero defects, zero rework, zero machine stoppages and zero accidents" (Jain et al., 2014, p. 298). For each factory, production line or piece of equipment, the OEE can be calculated, allowing benchmarking and focused improvement efforts (Dal et al., 2000).

Main tools of TPM

To improve manufacturing effectiveness, TPM is based on eight so-called pillars: Autonomous Maintenance; Focused Maintenance; Planned Maintenance; Quality Maintenance; Education and Training; Office TPM; Development Management; and Safety, Health and Environment (Ahuja and Khamba, 2008, p. 721). For each of these pillars, numerous tools and improvement activities are available, as listed by Ahuja and Khamba (2008, p. 722). One of these tools is Failure Mode Effect Analysis (FMEA), which lies at the heart of the RCM maintenance concept. This shows that TPM builds upon many existing methods and tools (Bakri et al., 2014), or even stronger: “derives to the greater part of its substance from a variety of non-Japanese management structures and practices, which were adapted by the Japanese to fit their culture” (Pintelon and Parodi-Herz, 2008, p. 37).

Rather than discussing the individual tools in depth, it is useful to have a look at some of the key elements of TPM (Jain et al., 2014). First, “TPM brings maintenance into focus as a necessary and vitally important part of the business” (Ahuja and Khamba, 2008, p. 715), as equipment failure has a profound negative effect on the OEE. Therefore, preventive maintenance is key in TPM, and its importance should be acknowledged throughout the entire organization (Piechniki et al., 2015). Second, TPM is cross-functional, as in the co-operation between engineering, operations and maintenance large OEE improvements can be realized. Third, every single employee is involved in TPM, and (preventive) maintenance becomes one of the core tasks of the operators. This requires additional training, which is an important success factor for TPM implementation (Piechniki et al., 2015). Finally, autonomous small groups work constantly at the further improvement of the OEE.

From these characteristics, it becomes clear that TPM is more than just a maintenance concept. Rather, it is a ‘maintenance philosophy’ (Pintelon and Parodi-Herz, 2008), a ‘manufacturing strategy’ (Ahuja and Khamba, 2008) or even a ‘manufacturing paradigm’ (Hooi and Leong, 2017). Ahuja and Khamba even go as far as stating that “TPM is not a maintenance specific policy, it is a culture, a philosophy and a new attitude towards maintenance” (Ahuja and Khamba, 2008, p. 717).

Limitations

The literature discusses a number of limitations of TPM which are relevant for the topic of this paper. First, it is acknowledged that TPM does not consider context. This is most clear from the OEE target presented by Nakajima (1988), which is set at 85%. However, from studies in practice this value does not seem to be realistic in all industries, and therefore Dal et al. concluded that “due to the varying norms in every industry, it would appear difficult to establish an optimum OEE figure for reference” (Dal et al., 2000, p. 1492). Related to that, McKone et al. noted that “companies’ concerns about the applicability of TPM to all operating environments are legitimate” (McKone et al., 1999, p. 124). However, they limit themselves to the operating environment in terms of country, industry, type and age

of equipment and company size. Other contextual factors, such as changes in customer demand, corporate objectives or regulations are not considered. It may well be that a high OEE may be a profitable strategy for a company in a fast growing market where a higher production can easily be sold and thus leads to a higher profit (Gupta and Vardhan, 2016), but not in a declining market. Sousa and Voss (2001) considered that quality management practices are context dependent. This was also found by Pinjala et al. (2006), who showed that different business strategies relate to different maintenance strategies, where TPM-practices were found to relate to a focus on quality.

Secondly, the main focus of TPM lies on short term, operational and tactical issues (Murthy et al., 2002). Similarly, it is noted that TPM does not include a strategic planning aspect (Cua et al., 2001). Finally, TPM has been found to be dependent on accurate performance data (Dal et al., 2000), while it does not sufficiently address how these data need to be collected (Ljungberg, 1998).

2.4.3 Condition Based Maintenance (CBM)

Where RCM and TPM are clearly defined maintenance concepts, Condition Based Maintenance (CBM) is rather a large collection of different but similar approaches to maintenance (Veldman et al., 2011b)⁸. CBM can be defined as “a maintenance program that recommends maintenance actions based on the information collected through condition monitoring” (Jardine et al., 2006, p. 1484). This distinguishes CBM from RCM and TPM: where RCM and TPM recommend maintenance actions directly based on numerous tools, data and expert knowledge, CBM starts with condition monitoring. This is the first step of CBM: data acquisition. The information gathered using all sorts of devices and sensors to monitor the relevant variables (e.g. vibration, temperature, contaminants, noise levels (Ahmad and Kamaruddin, 2012)), is then processed and analysed. Third, based on the analysis of the condition information decisions can be made regarding the most effective maintenance for the asset, which is executed in the fourth and final step (Veldman et al., 2011a). The reasoning is that this allows ‘just in time maintenance’ (Tiddens et al., 2017); not too early, which would be inefficient as the remaining useful life of the component to be repaired would be wasted, and not too late, which would result in a failure. The main underlying assumption for CBM is that “that 99 per cent of equipment failures are preceded by certain signs, conditions, or indications that a failure is going to occur” (Bloch and Geitner, 1983; Ahmad and Kamaruddin, 2012).

⁸ A number of disciplines exist that are closely related to – and may even be argued to fall within the broad category of – CBM. For example, Tinga and Loendersloot (2014) discuss how CBM, SHM (Structural Health Monitoring, which is mainly used on structures such as bridges) and PHM (Prognostic Health Monitoring, which originates from military aeronautics) share a number of characteristics and can be integrated. However, for reasons of simplicity and brevity, in this review only CBM will be discussed.

Table 2.4.1 – Assessment of RCM, TPM and CBM on the five requirements of ALCM and the practical theme of information use (light grey)

	multidisciplinary	complete life cycle	strategic objectives	risks and regimes	use of resources	use of information	remarks
RCM	RCM is mainly an operational and technical maintenance concept. Generally, only operators, engineers and technical specialists are involved.	The use phase of the asset life cycle is taken into account. Design changes are considered to prevent failures. Its focus lies mainly on short term, operational and tactical issues.	RCM is about preserving the asset's functions for its users. However, it does only focus on functional failures, and does not consider costs or other (tactical and strategic) objectives.	The maintenance program ranging from RCM is meant for a stable operating context. Change is acknowledged as important to be aware of, but no tools to identify change exist.	Resources are used for preventive maintenance. The RCM logic tree helps asset managers to find the most suitable preventive maintenance strategy for each failure mode.	RCM is largely based on qualitative expert knowledge. Tools exist to complement this with quantitative data, or even to base RCM primarily on quantitative data.	One of the important uses of RCM is to design highly reliable assets. RCM can therefore also be considered to be a design tool, next to a maintenance concept.
TPM	TPM combines maintenance, engineering and operations (Jain et al., 2014). The main focus lies on technical and organizational aspects. Costs and profits are not considered (Waeyenbergh and Pintelon, 2002).	The complete life of equipment is taken into account, starting with its design (McKone et al., 2001). However, its focus is mainly on short term, operational and tactical issues (Murthy et al., 2002).	The focus lies on the maximization of the OEE (Nakajima, 1988). Corporate strategy is not considered, but assumed to benefit from a high OEE. TPM contributes to manufacturing performance (Garg and Deshmukh, 2006).	Safety, health and environment is taken into account (Jain et al., 2014), but no other regimes. No guidance is offered as to how to identify and manage change.	Resources are spend on preventive maintenance. Tools are available to decide where efforts are most beneficial. No decision rules are offered for basic maintenance policies (Waeyenbergh and Pintelon, 2002).	The OEE needs to be calculated, which requires quantitative information (which is not always readily available or reliable).	TPM is mainly applicable to assets used in production processes, and less useful for other types of assets (e.g. infrastructure). Continuous improvement is an important aspect of TPM.
CBM	CBM diagnoses and prognoses failures based on condition data, and is therefore largely technical and data-driven in nature. Further integration with process engineering (Veldman et al., 2011b) and managerial aspects is needed (Tiddens et al., 2017).	CBM focuses only on the remainder of the asset's life cycle. Its focus is either on the short and medium term (failure prediction) or the estimation of the end of life (RUL estimation). Few applications exist that support long term decisions (Tiddens et al., 2017).	Its main focus lies on the determination of the asset condition and to use this information for just in time maintenance, to reduce failures and (maintenance) costs. Corporate strategy is generally not considered, but assumed to benefit from this focus.	Uncertainties are taken into account, and changes in the use of the asset or its operating conditions may be considered in prognostic models. Non-technical aspects such as regulation or market demand are generally not taken into account.	CBM aims to create condition-information that may be used to reduce the use of resources by doing only 'just in time' (preventive) maintenance. Generally, it is assumed that all resources are available, which tend to be limited in practice (Olde Keizer et al., 2017).	The main input for CBM is (quantitative) condition data. This data needs to be stored, cleaned, processed and analysed. Many difficulties exist with the availability and reliability of these data. Additionally, deep technical knowledge is needed to interpret the data.	CBM is a large collection of tools, models and algorithms, rather than single maintenance concept. Little guidance exists on which tool to use under which circumstances (Tiddens et al., 2015). It could be integrated with RCM and TPM (Fraser et al., 2015).

Main tools of CBM

To allow such ‘just in time maintenance’, CBM is dependent on knowing the actual condition of the asset: condition monitoring. Many different types exist, such as continuous or periodical (e.g. periodic inspections) and online (while the asset is operating) or offline (Ahmad and Kamaruddin, 2012). Additionally, often historic event data (e.g. failure data and maintenance data) are used. Based on this information, two main types of applications exist: diagnostics and prognostics. Diagnostics concerns the detection, isolation and identification of faults when they occur, while prognostics (also known as ‘predictive maintenance’ (Velmurugan and Dhingra, 2015)) deals with the prediction of faults before they occur (Jardine et al., 2006). Most relevant for this paper is the remaining useful lifetime (RUL) estimation, which belongs to prognostics. In RUL estimation, based on historical data, the current condition and statistical models an estimation is made of the moment where the asset will fail (Si et al., 2011). An underlying assumption in most of these models is that “the future usage of the system is similar to the past usage, [...] [therefore] these methods are mainly applied in static concepts” (Tinga, 2010, p. 1063).

An extensive literature exists relating to the methods, tools and algorithms to be used for the different phases of CBM, for applications on different types of assets and for both diagnostics and prognostics (review papers on these tools are presented by many authors, including Venkatasubramanian (2003a, 2003b, 2003c), Jardine et al. (2006), Peng et al. (2010), Si et al. (2011), Lee et al. (2014), Goyal and Pabla (2015) and Alaswad and Xiang (2017)). The availability of such a large amount of tools has given rise to the need for further classification, which have been proposed by many authors recently (e.g. Tinga, 2010; Veldman et al., 2011b; Alaswad and Xiang, 2017).

Limitations

This wide variety of tools is also a limitation of the CBM concept, as most CBM applications are only suitable for very specific applications (particular assets in particular settings) (Peng et al., 2010; Veldman et al., 2011b) and no guidance is available as to which CBM application to use in what situation (Tiddens et al., 2017). Additionally, applications of CBM lag behind scientific advances (Peng et al., 2010; Olde Keizer et al., 2017), which may be because many CBM applications tend to oversimplify the complexity of practice (Olde Keizer et al., 2017). The literature presents many different aspects of this oversimplification, for example the tendency to overlook organizational and business aspects of CBM (Veldman et al., 2011a; van de Kerkhof et al., 2014; de Jonge et al., 2017), to overlook (mainly resource) dependencies (Olde Keizer et al., 2017), the assumption of stable operating conditions (Tinga, 2010), the need for training (Veldman et al., 2011a) and all sorts of data problems (Jardine et al., 2006; Si et al., 2011; Ahmad and Kamaruddin, 2012; van de Kerkhof et al., 2014). This may also explain why practical applications of CBM do not always deliver the value anticipated (Grubic et al., 2011). Finally, it is noted that, even

though the support of long term decision making has the largest potential value for Asset Management, most prognostic techniques have short time horizons, and only “few examples of prognostic approaches that improve decision making on the long term are available” (Tiddens et al., 2017, p. 305).

2.4.4 Conclusions

RCM, TPM and CBM are the three most often used maintenance concepts. For each of these concepts, its main characteristics, tools and limitations have been discussed. In Table 2.4.1, they were assessed on the five ALCM requirements, as well as on the more practical theme of information use. From this table, it becomes clear that the three maintenance concepts do not live up to the definition of ALCM:

1. rather than multidisciplinary, their focus lies dominantly on technical and organizational issues, and mainly engineering, operations and maintenance specialists are involved;
2. rather than the complete life cycle, they focus on short and medium term operational and tactical issues;
3. their focus lies on the maximization of reliability, equipment effectiveness or the reduction of failures and maintenance costs, which may or may not be (indirectly) related to the pursuit of corporate objectives;
4. change in these goals or in the context of the assets (e.g. operating context, regulations or market demand) is not considered, which is crucial in ALCM;
5. resources are mainly used for preventive maintenance (and condition monitoring), but the limited availability of resources (in terms of spare parts, equipment, manpower and money) are not always taken into account; and – from a more practical point of view –
6. TPM and CBM (and some versions of RCM) suffer from limitations of the available data, even though it is well-known that data availability and reliability is a challenge in practice.

This discussion shows that the most important maintenance concepts are not suited to assist Asset Management organizations in the implementation of ALCM practices. Additionally, they do not sufficiently take into account the limitations of unavailable and unreliable data. This does not mean that these maintenance concepts are wrong and should not be used. On the contrary, these concepts are very useful for many applications. Rather, it shows that these concepts were not designed for ALCM purposes, and hence from an ALCM perspective they are incomplete. Therefore, for an ALCM approach that fulfils all

requirements, these technical and rather operational concepts need to be complemented with specific methods or tools that do fulfil the criteria of ALCM.

2.5 Assessment of Asset Management practice

In the previous two sections, the literature on Asset Management and the three most important maintenance concepts have been assessed according to the five ALCM requirements and the additional issue of data availability. However, there is more to Asset Management than just theory: Asset Management happens in practice. As this research aims to contribute to both theory and practice, a gap in theory is not sufficient to merit further research, a practical motivation is also necessary. Therefore, the Asset Management practice will be explored and assessed using the same requirements. To do so, a survey has been developed and carried out among asset managers in the Netherlands. First, the survey methodology will be introduced and the design and execution of this survey study will be discussed (section 2.5.1), then the general characteristics of the sample will be presented (sections 2.5.3) and finally, section 2.5.4 will present an assessment of Asset Management practice on the ALCM criteria based on the survey data.

2.5.1 Methodology

Survey research

Survey research “involves the collection of information from individuals (through mailed questionnaires, telephone calls, personal interview, etc.) about themselves or about the social units to which they belong” (Rossi et al., 1983; cited in: Forza, 2009, p. 85). An important characteristic of survey research is that information is only collected about a subset of the entire population the researcher investigates. Through the careful design of a sample and the logic of statistical generalization, the findings of the survey research can be applied to the entire population (Kumar, 2011).

Three different types of survey research can be distinguished, including exploratory, confirmatory and descriptive survey research (Forza, 2002). **Exploratory survey research** aims to gain a preliminary understanding of a phenomenon and is usually followed up by more in-depth research. As the topic is new, there is no model and no established way of measuring the concepts of interest. **Confirmatory survey research**, also known as theory-testing, is based on a theoretical model, established concepts and propositions derived from this model. The outcome of a confirmatory survey (and its analysis) is the establishment of the validity of the model. **Descriptive survey research** is used to describe a phenomenon. Its main aim is not to develop theory, but to understand the relevance of a phenomenon (e.g. the adoption of a particular practice or the profitability of a sector).

The survey research proces⁹

A survey research typically follows a six step process, including: 1. link to the theoretical level; 2. design; 3. pilot test; 4. collect data; 5. analyse data; and 6. generate report (Forza, 2009).

In the first step, the theory is used to establish the unit of analysis and population, the constructs and the propositions (if any). Especially for confirmatory survey research, the translation of the theoretical model into measurable constructs is of great importance. However, all types of survey research benefit from a **link to the theoretical level** to guide the development of questions and the analysis of the results.

The **design** of the survey includes the definition of the target sample, the data collection method and the measurement instruments. The target sample is the selection of the population of interest about which data will be collected. The sample design is important to allow (statistical) generalization of the results to the entire population of interest. The data collection method is the means by which the data are collected, typically surveys (mailed or electronic) or interviews (personal or telephone). Each of these have different advantages and disadvantages (as discussed by Forza (2009, pp. 119–122)). The measurement instrument consists of the questions and answer options (e.g. scaling) used to measure the constructs of interest. These measurement instrument must fit the characteristics of the respondent (e.g. language, knowledge) as well as the requirements of the analysis of the data (i.e. type of data and scaling).

The questionnaire design is then to be tested in a **pilot test**. This includes the discussion of the questionnaire with colleagues, industry experts and target respondents (Forza, 2009). Based on the feedback from these three types of people, the clarity of the questions and the ease of filling the questionnaire out can be assessed. Additionally, a pre-test sample can be carried out to gather test data to assess the measurement instrument.

In the **data collection** phase the respondents in the sample are approached to fill out the survey. Typically, a number of reminders is sent to increase the response rate. Dillman (2007) notes that a survey study must be regarded as a social exchange: the respondents shares his experience and knowledge in exchange for a reward (e.g. a gift, information or gratitude). The invitation letter for joining the survey must describe the reward for the respondent.

The **data analysis** starts with the inspection and cleaning of the data, for example: excessive missing values, typing errors and outliers. Also, the potential influence of non-response needs to be considered. Additionally, the researcher needs “to get a feeling for the data, in order to better interpret the results of the tests” (Forza, 2009, p. 143). This includes inspecting the descriptives and inter-correlation matrix of the variables. Before statistical tests are performed, the data need to be tested on the assumptions underlying

⁹ This paragraph is mainly based on Forza (2009).

the tests, e.g. the normality of the distribution of the data. If the data are not normally distributed, the data may need to be modified or non-parametric tests need to be performed. Lastly, the hypotheses can be tested using the data and its results need to be interpreted.

Finally, the outcomes of the study need to be reported. In the **report**, information must be given to allow the readers to 1. understand the work; 2. evaluate its quality and outcomes; and 3. replicate the study (Forza, 2009). Especially for theory testing survey research, a large amount of information needs to be presented on the preparation, execution and analysis of the study (an overview is presented by Forza (2009, p. 151)). Additionally, the researcher must present the limitations of his research.

2.5.2 Survey execution

A survey study was executed to assess Asset Management practices in the Netherlands on the five criteria of ALCM. Survey studies aim to get an understanding of a particular phenomenon in a specific population, which suited the purpose of this research well. Additionally, it allows reaching large numbers of respondents and comparison between the (reported) characteristics of these respondents. As no pre-existing constructs of measurements exist about ALCM, an exploratory approach was adopted.

Link with the theoretical level

To establish a firm **link with the theoretical level**, the development of the survey started from the literature on Asset Management and ALCM, as discussed earlier in this chapter. The disciplines and life cycle phases discussed there were used to assess the extent to which Asset Management practice was indeed a multidisciplinary practice taking the whole life cycle of the asset into account. Additionally, the theory of effective control¹⁰ (de Leeuw, 1979) was used to operationalize the questions on performance management and the consideration of risks and regimes (i.e. change management). Questions on the use of resources and data were not asked as it was considered these would make the questionnaire unnecessarily long: it was assumed that every Asset Management organization does use resources and has found ways to decide on the best use of these resources. Additionally, the problem of data availability and reliability in practice has been mentioned so often in the literature that questions about this issue were considered redundant. Finally, the general questions were as much as possible based on an existing survey on Asset Management in the Netherlands (Sumo et al., 2016).

Study design

The next step was the design of the survey study. First, the **target sample** was to be selected. As the aim was to explore Asset Management practice, a non-random sampling

¹⁰ This theory is introduced in Chapter 3 (section 3.2.2 - page 85).

strategy was adopted: purposive sampling (Kumar, 2011). This strategy allows the researcher to aim for knowledgeable and willing respondents. To gain access to a willing and knowledgeable sample, the NVDO (the Dutch Association for Maintenance Services) was approached. The NVDO is by far the largest Dutch maintenance association, holding a database of over 1600 member companies. The NVDO was willing to cooperate in this research by sending the survey to their members. Additionally, the invitation was shared using the LinkedIn network of the WCM (World Class Maintenance), the second largest Dutch maintenance association. Furthermore, the personal networks of the researchers were asked to join in the survey (snowball sampling). To ensure that only knowledgeable respondents would take the survey, the invitation described the desired characteristics of a respondent. Additionally, the questionnaire was designed in such a way that candidates that did not fit the desired profile were routed to a disqualification message.

The electronic survey was chosen as the most suitable **data collection method** for this target group and the time available for the research. The questionnaire was digitized in SurveyMonkey[®], an online survey tool. Regarding the **scaling**, most questions were 5 point Likert scale questions, as these have been found to be easier for respondents to comprehend and more suitable for European respondents than a seven point Likert scale (Bouranta et al., 2009).

Pilot test

The draft questionnaire was discussed with other researchers to ensure the quality of the questions, and with a number of industry experts to assess the applicability and comprehensibility of the questions for practitioners (4 experts in a 4 hour session). Based on their feedback, a second draft was developed, which again was reviewed by four experts from the field. The final draft questionnaire was then tested with four potential respondents in different roles (2 asset managers, 1 asset user and 1 service provider). The feedback from this test was used to create the final questionnaire. The questionnaire was then digitized in SurveyMonkey[®], an online survey tool. The final digital version was tested again by 2 experts in the field and 2 researchers. The complete final survey can be found in Appendix A.10 (p.322), which also shows the exact phrasing used for each question.

Data collection

The invitation for the survey was sent out in May 2015, using e-mail and LinkedIn. In this invitation, the goal and motivation of the study were described, as well as the desired respondent characteristics (including the question to forward the questionnaire to a more suitable candidate if needed), the reward for the respondent (i.e. a sizable discount on the next NVDO event) and a personal endorsement of the NVDO chairman. Two reminders were sent by email, and after three weeks a number of respondents were reminded by telephone to increase the number of respondents.

Data analysis

The data were first assessed on their usefulness for this research to **clean the data**. From the 250 responses, 52 (20,8%) were discarded due to excessive missing values and 30 (12,0%) were disqualified (e.g. due to not answering any open-ended questions). Furthermore, the responses were assessed on their applicability for this study on ALCM practices, and some cases (25 – 10%) were discarded due to the short design lifetimes of their assets (<10 years), low replacement values (<5 million euros) or low yearly maintenance costs (<0,1 million euros), as in these cases the application of Asset Management practices may not be worthwhile. Finally, the suitability of the role of the respondents regarding strategic Asset Management was assessed, by asking if they were involved in the performance management of their assets. Of the respondents, 101 (40,4%) were involved in the performance management of their assets, and therefore included in the final sample. 15 (6,0%) were only involved in decisions about the efficiency of the maintenance execution and therefore discarded, as were the remaining 27 (10,8%) respondents, who were not involved in either two fields of decision making.

Due to the different means of inviting respondents, a **response rate** cannot be calculated. However, comparing the number of useful responses with the total member base of the NVDO (1600; useful response rate 6,3%) gives a rough indication. The usable response of a similar survey a year earlier, carried out with a similar target group and using the same database, was 106 (Sumo et al., 2016), which also indicates a fair response to this survey. After a close inspection of the remaining data (e.g. for outliers), the general characteristics of the respondents and their assets were assessed, to get a feeling for the data. Also, the characteristics of the variables were inspected, to check for outliers and other issues that might harm further analyses.

Then, in the **data preparation and modification** the data were prepared for further analysis. For each of the four ALCM requirements a Likert scale variable was constructed based on at least five items, each covering a different aspect of the requirement. To create this variable, the average value of the underlying items was calculated¹¹. Before this combined variable was constructed, correlations and Cronbach's Alpha values were checked to assess the reliability of the scale, as well as the contents of each question to ensure each question did indeed cover a different aspect of the same overarching concept. The resulting combined variable was then used to assess whether or not Asset Management fulfilled the requirement in practice.

Statistical tests were used to assess the Likert scale variables and their underlying items. Even though these items contained ordinal data and were not normally distributed, Norman (2010) showed that parametric tests can still be trusted to come to the right conclusion. The assessment of the underlying items gave additional insights in Asset Manage-

¹¹ In case of missing values of the underlying items, the average of the remaining values was used.

ment practice, as each individual item covered a different aspect of the overarching ALCM requirement and showed which aspects were well-developed and which might require additional attention.

As a test value for these tests, the value of 3,5 was chosen. All questions were answered on a 5 point Likert scale, in which the value of 1 indicated the lowest score. Based on the literature, a score of 1 was decided to be insufficient, as this would indicate that for that particular question the practices described by the respondent did not live up to the criteria of ALCM. To prevent that the high scores might offset these insufficient scores (e.g. a 5 compensates for a 1), the cut-off point was set at 3,5 rather than at 3,0. Additionally, for some variables a score of 3 indicated a neutral value (e.g. 'not disagree, not agree'), which – based on the literature – was not considered to be sufficient to state that the practitioner fulfilled the relevant ALCM criterion. This was a second reason for the choice of 3,5 as the test value.

Each variable was tested using a one-sample t-test (also known as one-sample Student's t-test), starting from the assumption that Asset Management practice fulfils all the relevant ALCM criteria. In other words: each null-hypothesis was that the mean score of the variable would be 3,5, and only if the data showed that this mean value was lower than 3,5 at a significance level of 0,05, this hypothesis was rejected (i.e. a one-sided test). Apart from the p-value of each test, also the confidence interval of the estimate will be reported, as proposed by Cohen (1994).

As the test-value of 3,5 is highly influential on the outcomes of the tests, the average value and frequencies of each variable will be presented in the Appendix of this dissertation (see A.1, page 301) to allow the reader a deeper look into the data underlying the tests and their outcomes.

After the statistical analysis of the data, the preliminary results were discussed with a number of maintenance practitioner experts in two different sessions, and finally at an event organized by the NVDO for about 100 maintenance experts. This has been helpful in **interpreting the data**, as well as in assessing their applicability to Asset Management practices in general.

2.5.3 General characteristics

The 101 useful respondents work in different industries: the process industry (42,2%), infrastructure or real estate (27,4%), manufacturing and food (12,6%), fleet (8,4%) and building-related installations (e.g. elevators, climate control) (7,7%). They perform different roles within the management of their assets. About two thirds are asset owners or asset managers (65,3%), the remaining third are service providers (34,7%), who do have an influence in the performance management of the assets. 82,3% of the respondents has at least 10 years of experience in the field of maintenance, only 4,2% fewer than five

years. This indicates that generally the respondents are highly experienced and comparably senior asset managers.

Next to the characteristics of the respondents, a description of the assets they manage is important for the interpretation of the results. On average, the replacement value of the assets amounts to 687,8 million euros, with a minimum value of 10 million and a maximum of 7 billion euros (see Table 2.5.1 for the descriptives). The yearly expenses on preventive and corrective maintenance are on average 12,3 million euros. When comparing the yearly maintenance costs to the total replacement value, the average lies at 3,8%. On average 29,2% of the maintenance is corrective in nature, while planned preventive maintenance accounts for 44,5% and the remaining 26,4% is condition-based preventive maintenance. Regarding the design life, most of the assets are designed for 20-30 (32,7%) or 30-50 (36,6%) years, 20,8% has a design life of 10-20 years, and only 9,9% a design life of more than 50 years. About two thirds (65,0%) of the assets are at the begin or middle of this design life, the remainder has reached the end of the design life (18,8%) or has exceeded the design life and has received a life extension (16,3%).

Table 2.5.1 - the descriptives (number of responses, average, standard deviation and minimum and maximum value) of the continuous variables describing the general characteristics of the respondents (the other variables were nominal or ordinal)

	N	unit	Ave.	St. Dev.	min.	max.
replacement value	95	million euros	687,8	1283,2	10	7000
yearly maintenance expenses	94	million euros	12,3	22,1	0,1	120
% corrective maintenance	96	% of total maintenance	29,15	15,38	3	70
% planned preventive maintenance	96	% of total maintenance	44,49	19,55	0	80
% condition-based preventive maintenance	96	% of total maintenance	26,36	21,14	0	95

2.5.4 Results

Asset Management is a multidisciplinary practice

To test whether Asset Management is approached in a multidisciplinary way in practice, the respondents were asked to indicate the amount of active collaboration with people from other disciplines in the management of their assets, ranging from ‘never’ to ‘continuously’. Based on the literature and the discussion with practitioners, 12 disciplines were asked about (see Table A.1.1, page 302). The average values of these 12 individual scores were combined into one variable called multidisciplinaryity (Cronbach’s Alpha = 0,828, which indicates an acceptable inter-item reliability). The variability of the resulting variable is graphically shown in Figure 2.5.1, and its descriptives are presented in Table A.1.1, page 302). The average value of this variable was 3,40, which – according to the single-sample Student’s t-test – is significantly lower ($P = 0,049 < 0,05$) than the test value of 3,5.

This indicates that, based on the 12 disciplines asked about, the null-hypothesis that Asset Management is a multidisciplinary practice is rejected.

Upon closer inspection, it turns out that for 6 disciplines, the null-hypothesis could be rejected: sales, strategy, sustainability, purchasing, supplier and innovation. For engineering, finance, compliance, data management, maintenance planning & execution and operations the null-hypothesis was not rejected. This shows that in practice Asset Management is largely focused on technical and financial disciplines, rather than more strategic and market-oriented.

Figure 2.5.1 - Boxplots depicting the variability of the four Likert scale variables

Asset Management takes the complete life cycle of an asset into account

For Asset Management to be effective, it is important that the asset manager does not only exert influence on the maintenance of the asset, but on all choices made throughout its life cycle of the asset. Therefore, the respondents were asked to indicate the amount of influence their department had on decisions made in each life cycle phase, if applicable. The answer options ranged from 'no influence at all' to 'a very large influence'. The 9 items (Table A.1.2, page 303) were combined into one Likert scale variable 'whole life cycle' (Cronbach's Alpha = 0,840). The variability of this variable is presented in Figure 2.5.1. The average value of this variable was 3,512, which did not significantly differ from 3,5 (single-sample Student's t-test, $P = 0,575 > 0,05$). Therefore, the null-hypothesis cannot be rejected, indicating that based on the current sample, it is reasonable to state that Asset

Management organization do exert influence on the complete life cycle of assets in practice.

When taking a closer look at the underlying items, it becomes clear that the main influence of the asset managers lies in the middle part of the asset's life cycle, and not at its beginning (the values for design, purchase and build are significantly lower than 3,5) nor at its very end (recycle/resale lies significantly below 3,5). This indicates that a larger focus on the extremities of the asset's life cycle may need to be considered. Additionally, a focus on the complete life cycle implicates a focus on both operational and tactical/strategic matters. Therefore, the respondents were asked to indicate the percentage of their time they spend on operational, tactical and strategic matters. To assess the fit of this time division, they were also asked if they were satisfied with this division. This resulted in two different groups: a group satisfied with the current time spending (44,8% of the respondents), and a group wanting to spend more time on tactical or strategic matters (55,2%). The time division of these two groups differed significantly: the independent samples Student's t-test shows that the satisfied respondents spend on average 20,9% of their time on operational matters and 32,3% on strategic matters. On the contrary, the unsatisfied respondents spend 33,8% of their time on operational matters ($P_{\text{difference, two tailed}} = 0,004 < 0,05$) and 23,3% on strategic matters ($P_{\text{difference, two tailed}} = 0,023 < 0,05$). On tactical matters, the difference was minimal and non-significant (46,7% vs 42,9%). This indicates that 1. a majority of the respondents would like to spend more time on tactical and strategic matters; and 2. that these unsatisfied respondents spend significantly less time on strategic matters (and more on operational matters) than their satisfied colleagues.

One of the ways focus on long term, strategic matters is the use of plans about the future of the assets, or 'Asset Management Plans' in the terms of ISO 55000 (2014). Therefore, a question was asked about the existence of such plans. The answers showed that a quarter (25,0%) of the respondents does not make such plans, or plans that only cover the short term (up to two years into the future). Only 22,9% makes plans that cover ten years or more, up to the complete remaining life of the assets.

Asset Management aims at the achievement of specific objectives

The respondents were asked for the main (corporate) objective they pursued in their Asset Management. For most, this was reliability & availability (48,4%) or safety (21,6%). Some chose for customer satisfaction (8,2%), financial goals (7,2%), compliance with regulation (7,2%) or other (7,2%). Based on five items (Table A.1.3, page 304), based on the theory of effective management control (de Leeuw, 1979; Omta and de Leeuw, 1997) (see also chapter 3), a Likert scale variable 'performance management' was created (Cronbach's Alpha = 0,792) to assess the level of active management of the performance of the assets regarding these objectives (see Figure 2.5.1). The single-sample Student's t-test of 'performance management' showed that the null-hypothesis cannot be rejected (P

= 0,468 > 0,05), which indicates that the (future) performance of the assets is sufficiently managed in this sample.

When inspecting the underlying items, it is notable that the understanding of the asset's future performance is limited: 30,2% of the respondents disagrees with the statement 'we exactly know how our assets will perform in 5 years', which is also the only variable scoring significantly below the test value ($P = 0,000$). On its own, this is not a very insightful statement. However, it becomes more valuable if related to the influence the asset manager can exert on the future performance of the asset: the more direct this influence is (e.g. the performance next month can be changed with 20%), the lower the importance of knowing the performance in the far future. The data show that 33,3% of the respondents can influence the performance with 3% or less within a year, and on a five year period this is still 13,8% of the respondents. Especially for these respondents, it is important to have a good understanding of future performance, as the influence on this performance is limited (or more precisely: the impact of any actions requires a long lead time to materialize). However, the data do not show a significant (negative) correlation between the understanding of future performance (5 years) and the influence on this performance ($r_{\text{Pearson}} = -0,043$, $P_{\text{twotailed}} = 0,695$), nor between any other of the understanding and influence variables (Pearson correlation ranges from -0,051 to 0,090, $P_{\text{twotailed}}$ from 0,398 to 0,988). This shows that asset managers with a low influence on the future performance of the assets do not have a (significantly) higher understanding of this future performance, which limits their ability to actively manage the asset's future performance.

Asset Management considers risks and relevant regimes

Long term performance management also depends on an understanding of the potential changes relating to the goals and context of the assets. As the literature tends to overlook this influence, the respondents were asked to indicate the importance of a number of developments on the usability and expected remaining life of the assets. This showed that all six types of change (Table A.1., page 305) have a larger than average influence, and for all the null-hypothesis that this influence is above average cannot be rejected. This indicates that the ability to cope with change in Asset Management is important, even if the literature tends to overlook the importance of change.

Questions were also asked about the management of change. Five different items were combined into one Likert scale variable 'management of change' (Cronbach's Alpha = 0,783), of which the mean value (3,430) was not significantly lower than 3,5 (single-sample Student's t-test, $P = 0,140 > 0,05$). This shows that the null-hypothesis that long term changes are managed in practice cannot be rejected.

A closer look at the underlying items shows a more nuanced story, as three of these items score significantly below 3,5. The relevant long term developments are generally known, but their consequences are not ($P = 0,030 < 0,05$), nor is there sufficient information about

these developments to allow performance management in the face of these changes ($P = 0,048 < 0,05$). Nevertheless, preparatory actions are taken to prepare for these developments. Long term scenarios are generally not used to gain a better understanding of future change ($P = 0,029 < 0,05$). This indicates that, even as the combined variable 'management of change' did not score significantly below the test value of 3,5, still certain aspects of the management of change in Asset Management require additional attention in practice.

2.5.5 Conclusion

The survey results indicated that Asset Management practice largely fulfils the four ALCM requirements it was assessed on. It also showed how on different underlying aspects, practice does not seem to live up to the standards presented in the literature:

- Regarding multidisciplinary, engineering, maintenance planning & execution and operations – all rather technical and operational – are the main collaboration partners for the Asset Management organizations covered in this survey. Especially innovation, sustainability and sales are less often collaborated with. This finding corresponds with the technical and organizational focus of the literature and the three main maintenance concepts.
- In accordance with the literature and the three maintenance concepts, also in practice the focus of ALCM lies on the middle phases of the assets life (i.e. operate, maintain and modify), rather than on the beginning or the end of the life cycle. Additionally, a majority of the respondents would like to spend more time on strategic matters at the cost of time spent on operational issues, which shows that the operational and tactical focus of the three maintenance concepts may need to be complemented with a more strategic approach.
- The respondents pursue the corporate objectives, but admit that both the understanding of future performance and their influence on this performance are limited. This may make it difficult to manage future performance in an effective way.
- Finally, regarding the management of change, the respondents clearly show that different types of change have a large influence in their Asset Management. This contrasts with the assumption in the literature, that the goals and the context of the assets are stable. Even though the Asset Management literature does not offer tools to manage change, practitioners seem to be able to cope with the impact of these changes, even though there is clearly room for improvement on a number of aspects (e.g. the use of long term scenarios).

These findings show that even though Asset Management practice largely fulfils the ALCM requirements, there is ample room for improvement. Interestingly, the improvement po-

tential seems to lie in the same aspects as the gaps in the literature and the limitations of the three maintenance concepts.

2.5.6 Discussion

Three main remarks can be made about the conclusions just presented, which will be discussed now. First, the sample used to collect this data was not random, but consisted of those members of the NVDO interested in spending time on this survey (self-selection) and the asset managers in the networks of the researchers. Therefore, the results cannot be (statistically) generalized to all Dutch Asset Management organizations. However, the results were corroborated in the discussions with practitioners (including those not taking part in the survey) on the findings of this research, which indicates that the findings have value outside the sample as well.

Additionally, from all respondents only those respondents were selected that had an influence on the performance of the assets. Based on this criterion, 42 of the 143 respondents that suited the previous selection criteria (e.g. an asset design life of >10 years) were discarded. This indicates that a substantial part of the Asset Management practitioners did not live up to this basic requirement of ALCM. The results of this survey should therefore be regarded as a rather positive view on Asset Management practice, an upper bound to the average values that may be expected from all Dutch Asset Management organizations. Secondly, it is important to stress the influence of the chosen test value on the results. Even though the value of 3,5 was thoughtfully chosen, in a sense it remains an arbitrary decision. In some cases, the value might have been set lower (e.g. should an asset manager cooperate with sustainability colleagues more than 'regularly' on average?). In other cases, it might have been set higher (e.g. should the answer 'not agree' (value: 2) not be regarded as insufficient as well?). Additionally, each specific situation is different, and there may be excellent reasons why future scenarios are not used, even though in general it is a useful way to deal with an uncertain future. Therefore, the conclusions should be interpreted with caution: the results are not primarily about the exact outcomes of the tests, but rather about the general story they present. To assist the reader in gaining this nuanced picture, the frequencies of all tested variables have been presented as well.

Finally, it may be very well possible that the results differ between different Asset Management roles and across sectors. For example, service providers may be more inclined to focus on the short term, due to the length of the contract they work in. Or organizations in the process industry may have a larger focus on sustainability. As the goal of this survey was to assess Asset Management practices in general, these differences have not been investigated. However, this may be an interesting opportunity for further research.

2.6 Conclusion

The literature indicates that Asset Management has five important characteristics: it is 1. a multidisciplinary practice; 2. in which the whole life cycle of a physical asset is taken into account; 3. with the goal of achieving certain specified objectives; 4. within acceptable limits of risk and relevant regimes; and 5. it should determine the allocation of resources. Asset Management approaches fulfilling these requirements have been labelled Asset Life Cycle Management (ALCM). In this chapter, the Asset Management literature in general, three important maintenance concepts and Asset Management practice have been assessed on these five requirements.

This assessment showed that Asset Management, rather than being a multidisciplinary practice, often tends to focus on technical and financial aspects of the assets, and that mainly engineers, operators and maintenance staff are involved. Secondly, the focus of Asset Management lies often mainly on the operation and use phase of the asset's life cycle, or on the estimation of the end-of-life of the asset, rather than on the complete life of the asset. Relatedly, Asset Management tends to focus on operational and short-term aspects of the assets, rather than the more long term and strategic issues. Thirdly, the pursuit of corporate objectives throughout the entirety of the (Asset Management) organization is often limited: there is a gap between the strategic level and the maintenance organization, goals are not aligned, the organization is assumed to benefit from a high reliability and the understanding of and influence on future performance is restricted. Fourth, often it seems to be assumed that the context in which the assets operate is stable, and any changes will not influence the remaining lifetime or the value of the asset. However, the survey results indicated that changes in market demand, regulation or finances do importantly influence the usability of the assets. Fifth, Asset Management organizations do clearly decide about the use of resources. However, little support is offered for decision-making on strategic decision making in a changeable context. Additionally, the literature showed that the availability and reliability of information often is an issue, but still many Asset Management tools are highly dependent on reliable data.

The literature does thus clearly prescribe the main characteristics of ALCM, but offers only limited guidance and tools as to how to fulfil these characteristics in practice. In practice, Asset Management organizations seem to fulfil these criteria, but on the underlying aspects of these criteria improvement can still be made. In the remainder of this dissertation, methods and tools will be developed and tested to assist asset managers in doing strategic Asset Life Cycle Management in a changeable context.

2.7 Implications

This study has a number of important implications. For scientists, the main implication is that the availability of general Asset Management methods and tools is lagging behind on

the understanding of Asset (Life Cycle) Management in theory. Also, the available maintenance concepts are useful for the purposes they were designed for, but they need to be complemented with additional tools to address their limitations. Alignment between strategic and operational Asset Management, multidisciplinary collaboration, a focus on the early phases in the asset life cycle and the development of tools that are not dependent on the complete availability of reliable data may be important and relevant topics for future study, as for the remainder of this dissertation.

For practitioners, the requirements of ALCM and the survey results offer ample opportunity to assess one's Asset Management practices and to determine the most promising areas for further development. Additionally, this study shows that a technical, operational and short term approach to Asset Management is often applied, but this severely limits the potential to create value with the assets over their complete lifetimes. Finally, well-known and often-used maintenance concepts cannot solely be relied on to fulfil the five requirements of ALCM. Therefore, in the remainder of this research methods and tools will be developed to assist practitioners to develop a multidisciplinary, long term and strategic Asset Management, as well as the capabilities that are necessary for ALCM.

2.8 Acknowledgements

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Publication history

This chapter was written as a conference paper for the EurOMA conference in June 2015, together with my colleagues dr. A.J.J. Braaksma and prof.dr.ir. L.A.M. van Dongen. This chapter presents the original version of this conference paper, and thus reflects an earlier stage of this research (for example: the O for organization had not yet been added to TECCO).

Reference to previous publication

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3

Towards a model for effective Asset Life Cycle Management control

This chapter takes a closer look at the management aspect of Asset Life Cycle Management (ALCM). It explores the theory of 'effective management control', and combines this with the characteristics of ALCM. A case study of ALCM of rolling stock is presented, and the role of Asset Life Cycle Plans (ALCPs) is explored. An important issue in this chapter are the limitations to effective control.

Skippable text

The characteristics of ALCM have also been presented in chapter 2.

3

Towards a model for effective Asset Life Cycle Management control

Abstract

The maintenance of physical assets is indispensable for sustainable competitiveness. The discipline of Asset Life Cycle Management (ALCM) shows that assets should be managed in a multidisciplinary way over their complete life cycle. This paper asks how these assets can be managed effectively. The concept of management control is used to develop a conceptual model for ALCM control. This model has guided our case study of ALCM in practice. We conclude that the model allows us to gain a deeper insight in ALCM control and to identify the limits to control faced by an asset manager.

Keywords: Asset Management, Asset Life Cycle Management, Maintenance Management, maintenance, performance management, management control

3.1 Introduction

Maintenance is indispensable to create maximum value with physical assets. This holds for long lasting consumer goods such as cars, but even more so for the assets used in industry and infrastructure. An estimate of their value for lies around 400 billion (milliard) euros the Netherlands alone (Veenman and Besselink, 2010). Next to the financial value, these assets fulfil vital functions in our daily lives, such as bridges and roads for transportation or water treatment plants for drinking water. Hence, the effective management of these assets is of huge importance for sustainable competitiveness.

3.1.1 Outline

This paper aims to contribute to our understanding of the effective management of physical assets. First an overview will be given of the field of Asset Management (section 3.2.1). The ideas found here will be supplemented by the requirements for effective control (REC) taken from the paradigm of ‘management as control’, presented in section 3.2.2. This will

result in a conceptual model of effective Asset Life Cycle Management (ALCM) control (section 3.3). This conceptual model will be used in a case study on ALCM: the management of the rolling stock by the means of Asset Life Cycle Plans. Section 3.4 will present the details of the methodology used in this investigation. The results of this case study will be presented in section 3.5, structured by the five requirements of effective ALCM control. Section 3.6 presents the conclusions of this paper. Finally, a discussion of the results (section 3.7) and the implications for practitioners and theorists in the field of Asset Management (section 3.8) will be presented.

3.2 Theoretical Background

3.2.1 Asset Management

The management of physical assets is addressed by the discipline of Asset Management. In the recent international standard on Asset Management, it is defined as a “coordinated activity of an organization to realize value from assets” (ISO, 2014, p. 16). Value is realized by balancing costs, risks, opportunities and performance (ISO, 2014).

Somewhat more elaborate and precise is the definition of Pudney (2010): “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” (Pudney, 2010, p. 8). This definition adds that Asset Management is a *multidisciplinary* practice that should cover the *whole life cycle* of the asset.

Asset Life Cycle Management (ALCM) pays explicit attention to these two aspects: “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 and Brent, 2008, p. 286). However, as Haffejee and Brent conclude, a multidisciplinary approach is often lacking (we discuss this issue in more detail in Ruitenburg et al., 2014b). Secondly, the focus is often rather on the short and medium term, than on the full life cycle of the asset (Komonen et al., 2012).

To summarize, ALCM should fulfil at least five requirements: 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. it should determine the allocation of resources. An effective management of assets should thus take these requirements into account.

3.2.2 Management control

Now we know *what* Asset (Life Cycle) Management exactly is, it is of course important to know *how* to do it. The question on how to manage, or more specifically: how to exert control, is discussed in great depth by De Leeuw (2002). In his approach to management, control is “any way of purposive influence” (1979, p. 95). This implies a person or organization exerting control and something or someone that is being controlled: a controlling body and a target system (de Leeuw and Volberda, 1996).

The controlling body tries to exert influence on the target system in such a way that the target system does what the controlling body wants it to do. But for such an exertion of purposive influence to succeed, a number of requirements have to be fulfilled. De Leeuw (2002) calls these the ‘requirements for effective control’ (REC).

The first requirement for purposive influence to succeed is that there exists *a purpose* that is aimed for. This implies that a goal has been set (either explicitly or implicitly) and that there is a way to evaluate whether this goal is being reached or not. Next, there is a need for *an understanding of the target system*. If one wants to reach a certain goal with the system, one needs to know how the system will behave. In other words: one needs a model of the target system in order to predict its behaviour. Thirdly, there is the need for *information on the target system and its environment*. Only if one knows the current state of the system, one will be able to exert the right influence on the system. Otherwise one cannot know what the result of a control measure will be. The fourth requirement is that the controlling body has a *sufficient number of control measures* at its disposal. Or more specifically: at least one control measure for every state of the target system. If this is not the case for a particular state, the target system can be called uncontrollable. Finally, there is the need for a sufficient *capacity to process information*. This is related to all previous requirements: information on the current state of the system, capacity to compare this state with the goals that apply, etcetera.

3.3 Asset Life Cycle Management control

When the description of ALCM as a ‘coordinated activity of an organization to realize value from assets’ is combined with the concept of control, we get the concept of Asset Life Cycle Management control: ‘the active and purposive influence of asset performance over the complete life cycle’. Only by exerting active and purposive influence, the asset owner can be sure value is realized with the assets. For this control to be effective, the asset manager(s) as the controlling body should fulfil the REC, while at the same time the five characteristics of ALCM should be covered.

By combining the five requirements for effective control with the five characteristics of ALCM, an imaginary 5 by 5 matrix arises. To simplify and operationalize this matrix into a clear and workable conceptual model, we remove two characteristics of ALCM. Objectives

can be removed as these are covered by the goal-requirement in the REC. We remove resource allocation, as we assume that every control measure will deploy at least some resources. To continue, we will apply the remaining ALCM characteristics to the five requirements for effective control, which will result in a verbal description of our conceptual model, which is summarized in Table 3.3.1.

To start, the model of the system should be understood as a description of the asset(s) to be controlled, including an understanding of its behaviour. As the value of the asset lies in its functions, we will limit ourselves to the performance of the asset.

For the performance, certain goals will exist, which the asset has to fulfil. These goals need to be multidisciplinary, which we take to cover at least technical, economical, compliancy and commercial (TECC) perspectives (Ruitenburg et al., 2014b). The technical perspective is operationalized further into reliability, availability, maintainability and safety (RAMS) (Smit, 2011), while we expect the economical perspective to cover different types of costs, including operational, maintenance and project cost. Furthermore, these targets need to cover the asset's whole life cycle, operationalized as both the short (<5 years) and long (>5 years) term.

To reach these targets, it is important that sufficient information is available: on the current and expected future performance of the system and its environment. For the performance, we expect that all the same disciplines and timeframes are covered as discussed before. For the environment of the system we will limit ourselves to the (identification of) risks limiting the value realization with the asset.

If the expected future state of the system does not match the desired future state of the system, control measures will be needed. Finally, the information processing capacity of the controlling body should be sufficient to identify these mismatches and to come up with suitable control measures in time.

The conceptual model of ALCM control as described in this section and shown in Table 3.3.1 covers both the five requirements of effective control as well as the five characteristics of ALCM. This model will serve as the foundation for our case study of ALCM in practice, which will be presented now.

Table 3.3.1 - The conceptual model for ALCM control

	Requirements for Effective Control	ALCM specifics
1	model of the system	an understanding of the performance of the asset
2	goal	multidisciplinary (TECC), short and long term
3	information on the performance	multidisciplinary (TECC), short and long term
	and the environment of the system	the identification of risks
4	control measures	measures to influence the asset's performance
5	information processing capacity	capacity to process all relevant information

3.4 Methodology

To study Asset Life Cycle Management control in practice, we have carried out a case study (refer to Chapter 9 section 9.3 (p. 240) for an extensive introduction to case study research). Case studies are highly suitable for understanding complex phenomena and for charting new areas of study (Kumar, 2011). Both of these properties fit nicely with this exploratory research project on Asset Life Cycle Management control.

To study ALCM control, we have looked for a case where experience has been gained in ALCM and where access is easy. Hence we have selected the organization responsible for the maintenance and Asset Management of the rolling stock (i.e. trains) used by the Netherlands Railways¹², which holds over ten years of experience with ALCM. Different types of trains in different life cycle phases are maintained (stopping trains vs. intercity trains), all with expected lifetimes of 30 years. This allows us to study ALCM control for different assets of different ages within the same setting.

Asset Life Cycle Management within the Netherlands Railways (NR) is concentrated in one type of document, the so-called Asset Life Cycle Plan. This plan mainly describes the outlook of the asset manager on the future of a train series and its performance. It is this document that has been selected as the core object of this study and has been studied as 'artefact of ALCM control'. Eight of these ALCPs have been selected, covering the different life cycle phases and train types the NR works with, see Table 3.4.1.

Table 3.4.1 - Overview of the ALCPs selected for this research

code	train type	bought	revision	life cycle phase	ALCPs selected
TST	traditional stopping train	1975-84	2002-09	securing - phasing-out	2013, 2015
MST	mod. stopping train	2009-13	-	investing	2012, 2015
ICT	intercity train	1983-93	2006-11	securing	2005, '10, '12, '15

To study these ALCPs in a sound and structured way, a coding scheme has been developed based on the conceptual model introduced earlier in this paper. Based on the conceptual model we have coded the ALCPs using top-down coding (Silverman, 2006).

The findings from the document study have been supplemented with three semi-structured interviews (from 1 to 2 hours) with the asset managers responsible for writing these ALCPs (the interview guide is presented in Appendix A.2, p. 306). These interviews were held in February and March of 2015. The interviews have been transcribed and analysed. Furthermore, three group meetings on the development, strengths and weaknesses

¹² Within Netherlands Railways the two management teams of the legal entities *NedTrain*, responsible for maintenance, management and modernization of rolling stock, and *NS Reizigers*, responsible for daily train scheduling and operations, recently merged to one team in the new organization *NS Operations*, leading both daily train operations and maintenance.

of the current ALCPs have been attended (all sessions lasted between 2 and 4 hours). Finally, some additional relevant company documents have been read to triangulate the findings of this study. A description of the execution of this case study research is presented in Table 3.4.2.

Table 3.4.2 - Description of the execution of the case study research steps in this research

Case study research step	Description of execution in this case study research
1. Developing the research framework	A conceptual framework was developed based on the ALCM literature and the theory of effective control (Table 3.3.1). Its main concepts were operationalized. This framework was used to study ALCM control in practice, to establish the completeness of the framework and to study limits to ALCM control.
2. Case selection	The maintenance organization of the Netherlands Railways (NR) was selected, due to its knowledge and experience with ALCM and the possibility to get access. Within the case company, the ALCM control on three different types of rolling stock was studied, as three embedded cases.
3. Developing research instruments and protocols	The main object of ALCM at the NR is the ALCP. This document was studied as an 'artefact of ALCM control'. Additionally, an interview guide (Appendix A.2, p. 306) was written for the semi-structured interviews with three asset managers responsible for writing the ALCPs.
4. Conducting field research	A number of ALCPs was received, of which 10 were selected for further analysis. Three interviews (1-2 hours, March-April 2015) were held (and recorded) with asset managers, based on the interview guide as well as the ALCPs studied (follow-up questions). Three group meetings (2-4 hours, June 2014 – January 2015) about the development of the ALCPs were organized and attended, and notes were taken. Some additional documents were received.
5. Data documentation and coding	The ALCPs were coded using a combination of top-down coding (based on the conceptual model) and bottom-up coding (using the additional KPI categories used in the ALCPs). The interviews were transcribed and sent to the respondents for their agreement. An early version of the report was discussed with a key informant of the organization.
6. Data analysis	General descriptives of the ALCP were inspected (Figure 3.5.1) and interpreted using the data. The display of the data (Table 3.6.1) showed patterns over time as well. The (cross-case) analysis of the three different train types showed differences in the (limits to) control experienced by the organization. The interview data allowed a deeper understanding of the data and the practice of ALCM control. The findings were related to the enfolded literature.

3.5 Introduction to the case study and the ALCPs

Within the Netherlands Railways (NR), a separate department is responsible for the maintenance, management and performance of the trains. In other words: the Netherlands Railways at large are the owner and user of the assets, while this department operates as their primary service provider. For each train type, there are two asset managers: one from the maintenance department and one from the Netherlands Railways. In this way, both asset owner and service provider are represented. The asset managers are supported by a dedicated rolling stock team, consisting of a number of experts, amongst oth-

ers a maintenance engineer, a reliability engineer, a supply chain manager, a production manager and a business analyst. It is the asset managers, supported by the rolling stock team, who write the ALCP.

3.5.1 The Asset Life Cycle Plan

The first ALCP has been written in 2004 on the ICT. It was introduced as follows: *“The Asset Life Cycle Plan (ALCP) is a plan that describes which performance objectives will be realised at what costs in the coming ten years. And what measures will be necessary to realise this performance”*. The ALCP was explicitly introduced as a ‘living document’ which needed updating each year with the latest insights and choices. Since its introduction, ALCPs have been (re)written every year. The ALCP is still in development, as the needs of the company change and further improvements are made.

Figure 3.5.1 - Overview of the contents of the ALCPs studied for this paper

Figure 3.5.1 shows the contents of the different ALCPs studied for this paper. When comparing the first (ICT2005) ALCP with the 2015 ALCPs, we see that in ICT2005 no management summary, strategy chapter or risks were given. However, what was given in (only) this ALCP is an overview of the characteristics of the train: static information. In later ALCPs this information was given in the appendix (not shown in the figure). In 2015 on no appendices were included in the ALCP. Here we see clearly how the ALCP developed from a ‘handbook’ for the asset manager, including design information, to a strategic document with a chapter on strategy and a summary for the management as the target audience. This also explains the reduction in length: from an average of 37 pages (excluding appendices) for the first 2 ALCPs listed to an average of 20,3 pages in 2015. A second explana-

tion for this reduction can be found in the status of the ALCP: where in the early years a lot of elaboration and substantiation was needed, currently the reputation of the asset managers and their teams allows them to keep it short.

Over the years, the ALCP has gained a prominent role in the Asset Management at the NR and its maintenance department. Starting with a request from the asset owner for a certain deployment for the next year, the feasibility and costs of this request are given in the ALCP. This is an input for the budget and deployment planning process, where the performance and costs of all train series are combined and optimized. The resulting performance for the next year is used in a performance contract between both companies.

3.6 Results

In this section, the main results from our case study will be presented, addressing the five requirements for effective control from an ALCM perspective. Our focus will lie on the performance of the train series as discussed in the different ALCPs.

3.6.1 A model of the target system

An important requirement is that the asset manager has a model of the target system that has to be controlled. The target system managed in this case is the train series including all scheduled maintenance. It is assumed that the train series will continue to operate as it currently does, based on the current operating instructions and the current maintenance activity descriptions. In case the performance of the train series or external developments ask for it, control measures are needed to alter the target system.

What we find here is that control may be limited by the understanding of the target system. An example of this is the newest train series, the MST, which been purchased from 2009 till 2013. In MST2012, this train was described by the asset manager as *“in many respects still a black box”*. Not only does this hold for the software in the train, but also for the physical design, as the NR were less involved in the design of this train than for previous trains. This has important consequences for the control that can be exerted: making design changes is more difficult and more risky, which has caused the asset managers to choose the slogan ‘keep it standard’ for this train series.

A different type of model of the target system is the prediction of performance in relation to a control measure. Interestingly, in two of the 2015 ALCPs it is stated that one does not understand the relation between customer satisfaction and its *“underlying (suggestible) factors such as cleanliness”* (MST2015). This finding has led to the development of a new KPI, namely the number of ‘comfort failures’ instead of customer satisfaction itself (see Table 3.6.1).

3.6.2 Targets

In the ALCP three types of targets are mentioned: 1. general company ambitions; 2. life cycle strategies for specific train series; and 3. targets on the different KPIs.

The first type of targets are general company ambitions, such as cost reduction or customer intimacy. These descriptions are used as inputs for more specific KPI targets.

The second type of targets are specifically life cycle related. The NR use three different 'life cycle strategies': investing, securing and phasing-out. For each of these different life cycle phases, different targets apply. For the investment phase, the goal is to increase performance. For the securing phase, the goal is to secure performances while reducing costs. For phasing-out, the focus shifts even more to cost-savings and design changes are to be avoided, even if this may result in lower performance. Each train series is assigned to a certain life cycle phase, primarily based on its age. These 'life cycle strategies' are translated to specific KPI-targets as well. But they also set a specific mind-set and priorities for the Asset Management of the train series.

Finally, there are KPIs as specific targets. Based on the conceptual model, we expect multidisciplinary targets, at least covering technical, economical/financial, compliancy and customer aspects. Table 3.6.1 shows the performance areas covered in the ALCPs.

Table 3.6.1 - Overview of the targets (codes) and performance (formatting) covered in the ALCPs (see the second table for the explanation of the codes and formatting)

	Production	Technical	Economical	Compliance	Commercial	Operator	Sustainability
	km	R A M S	M O P o		C S F o	satisfaction	E N W
ICT2005	-	q <u>Q</u> - Q	- - - -	-	d - - -	-	- - -
ICT2010	Q	Q Q - Q	- - <u>Q</u> -	-	Q Q - Q	d	d d d
MST2012	Q	Q Q - Q	Q Q Q Q	-	Q d - -	d	d d d
ICT2012	Q	Q Q - Q	Q Q Q Q	-	Q Q - -	d	Q d d
TST2013	Q	Q Q - Q	Q Q Q Q	-	<u>Q</u> Q - <u>Q</u>	d	d d d
ICT2015	Q	Q Q - Q	- Q Q Q	-	Q - <u>Q</u> -	-	- - -
MST2015	Q	Q Q - Q	- Q Q Q	-	Q - <u>Q</u> -	d	d - -
TST2015	Q	Q Q - Q	- Q Q Q	-	Q - <u>Q</u> -	-	- - -

Legend									
Codes		Technical		Economical		Commercial		Sustainability	
d	description	R	reliability	M	maintenance	C	cleanliness	E	energy consumption
q	partly quant.	A	availability	O	operational	S	customer satisfaction	N	noise production
Q	quantitative	M	maintainab.	P	project costs	F	comfort failures	W	waste
		S	safety	o	other costs	o	other		
Formatting									
B	current and expected performance			i	only current		U	only expected performance	

Table 3.6.1 shows that the performance areas covered are clearly multidisciplinary. From the technical perspective, maintainability is not covered in the ALCP, which is not surprising as this is more a characteristic of the design than a dynamic performance characteristic. Compliancy targets are not stated explicitly, the implicit goals seems to comply with all legislation. The final performance area we expected is the commercial perspective, which is covered by cleanliness, customer satisfaction and comfort failures.

Next to these targets expected from the conceptual model, some additional targets are mentioned in the ALCP. The most important is the 'production' of the train: the amount of kilometres the train will drive throughout the year. Next to this target, there are targets for the operator satisfaction and sustainability. Sustainability is in most ALCPs divided in noise, energy and waste. Interestingly, one can see that the ALCP started as a predominantly technical document, while other perspectives were included later. Sustainability is still covered in the 2015 ALCPs, but no targets are given here. Clear quantitative goals are given for most areas. For operator satisfaction and sustainability, descriptions of the desired situation are given, e.g. the satisfaction of operators.

All these KPI targets are set for the next five years. As discussed earlier, for the first year this target is fixed and used in a performance contract. The next four years the targets set are less solid, and should be interpreted as in between targets and performance prognosis. It is the figure the asset manager aims for and which may be expected by the Netherlands Railways. But if different demands are made, these target values may change. In that way these values are a way to communicate what future performance may be expected, to allow tuning with other departments.

The targets are thus clearly multidisciplinary, and cover all the performance areas we had expected. However, all KPI targets only cover the short term (<5 years). It is only the general company ambitions and the life cycle strategies that may cover the long term. Here it is mainly the life cycle strategies that give direction. But as these are rather mind-sets – how do we manage the trains – than targets – what do we aim for – we may conclude that long term targets are less well-developed than the short term targets.

3.6.3 Information on the system's state and its environment

For the system to be controllable, one does not only need targets, but also a description of the performance. Table 3.6.1 shows what performance information is given in the ALCPs. From the table it becomes clear that the production and technical performance are covered in nearly all ALCPs. For the cost performance, numbers are sometimes missing, e.g. for the maintenance costs in the 2015 ALCPs. The commercial perspective is less developed, followed by operator satisfaction and sustainability.

The financial performance deserves some additional attention. The asset managers all agreed that cost control is currently relatively limited. This can be seen in the ALCPs, as hardly any control measures are listed in the cost chapters. This can partly be explained by

the fact that for a long time the maintenance department of the NR was predominantly focused on the technical aspects of the management of the assets. A new accounting system has recently been implemented to increase the insight in the financial performance. This will allow the asset managers to exert more control over the costs.

Regarding the time-perspective, performance prognoses cover the first five years into the future. Prognoses on the performance on the long term are scarce, and take the form of descriptions, such as a decrease in customer satisfaction with the ageing of the train.

Next to performance, the potential risks ranging from the environment are important to know about. The ALCPs written before 2015 all had a separate chapter on risks. In the latest review of the ALCP format, this chapter was taken out to reduce length as most (if not all) issues mentioned in this chapter were already covered in the ALCP. However, two of the asset managers stated not to be completely satisfied with this solution: *“I kind of liked to have it in [the ALCP], as you had to think about the risks explicitly”*. The role of risks in the ALCPs is still in development, and is one of the main priorities for the next years. Currently, no structured way of identifying risks is used, although all three asset managers showed to be aware of the importance of risk identification and showed how they had been pursuing this recently.

To conclude, information on the performance of the system is given for most of the perspectives. The long term performance is only treated marginally. Risks are mentioned in the ALCP, but not collected in a structured or regular way.

3.6.4 Control measures

In case differences are detected between the targets and the current or expected performance, control measures are taken. The asset managers generally stated to have three different control measures at their disposal: 1. changes in the quality of the maintenance execution; 2. changes in the maintenance concept; and 3. changes in the design of the train. The first is the easiest, takes the least time to implement, is used most often and is least expensive. Their impact on the performance of the train does however not necessarily follow the same pattern. This highly depends on the life cycle of the train series and the measures that already have been taken before. The manager of the intercity train series stated that for design changes in his train ‘all the low hanging fruit has already been picked’. For him, most impact could be made with changes in the maintenance concept. As his train is in the securing phase, the focus is on saving costs, and extending maintenance intervals is a good way to achieve this.

The life cycle phase of the train series also influences the control measures available to the asset manager. The shorter the remaining lifetime of the asset, the shorter the pay-back time on new investments. Hence the importance of design changes decreases over the lifetime of the train, limiting the margins within which influence can be exerted. Obsolescence of parts limits these margins even further.

Interestingly, two additional control measures were found. The first is changing the instructions for the operators of the trains. Only one of the asset managers mentioned this measure explicitly – even though the other two implicitly acknowledged it as well. The one asset manager explicitly aware of this type of control stated that *“this is a large influencer”*, which the maintenance department has paid limited attention to thus far, as it had its primary focus on the technical aspects of the train. Hence *“the exploitation of the physical side has gone very far, but now one has to turn to the side of the user to influence this [the performance]”*. Interestingly, we see here how a limited model of the system – the train as a technical system excluding the human operator – limits the control over the system. A broader, albeit more complex, model may be worthwhile as this allows for additional control measures and performance improvements.

Goal adjustment can be regarded as a fifth control measure. As De Leeuw (2002) states, one way of making sure one reaches one’s goals is by adapting these. Interesting is the fact that goal adjustment is part of the process of writing the ALCP. As already explained, the process starts with a kilometre production desired by the asset owner. It is then up to the asset manager to see if this production is feasible, and if so, at what price. Making this ‘feasibility check’ explicitly allows for a discussion between asset owner and service provider, as the manager of the ageing ICT shows: *“then you get the discussion [...] and in the end it has been decided to let it [the performance] decrease”*. This allows for deliberate decisions to be made and to adjust the goals if needed.

To conclude: many different control measures are at the disposal of the asset managers. However, their usability depends highly upon the age of the asset. Including the operation explicitly in the model of the target system may make additional measures possible. Goal adjustment is already part of the Asset Management process, which prevents setting unfeasibly high targets resulting in unnecessary costs.

3.6.5 Capacity to process information

The final REC is the capacity to process information, and the ALCP is an important means in this. Writing the ALCP forces the asset manager to step back from the issues at hand and to focus on the future of the assets. The three asset managers all state that without an ALCP they would be firefighting all day, being overwhelmed by the daily business without the possibility to step back. In this way the ALCP is a means to allow the asset manager to think about the long(er) term and to take control over the asset.

Furthermore, the asset managers mentioned that the ALCP helps them to set an agenda for themselves and the entire organization. The ALCP can be seen as a ‘priority list’ for the coming years: *“you receive questions all the time, and without an ALCP you cannot filter which question you should get down to and which are not that important”*. Not only does this help to keep the right focus, but it also helps to communicate this to the organization and to harmonize the different departments.

Table 3.6.1 showed that in a number of ALCPs at least some performance values are missing. The most recent example can be found in all three 2015 ALCPs. Here the data on the maintenance costs are lacking, due to a change in the accounting structure used. This shows a limit to information processing capacity.

Finally, an interesting remark was made by the asset manager of the ICT. He stated that for the current KPIs large improvements have been made which makes it hard to improve any further. By choosing different KPIs, new improvements could be made that would benefit the traveller even more. However, as the information collection is adapted to the current KPIs limited information is available on these issues. He and his team have meetings to dig into these issues, but these take a lot of time and effort and hence cannot be held frequently. This shows that the type of information that is received may strain the information processing capacity, which negatively influences the ability to exert control. In this way, choosing KPIs can be seen as a control measure in itself, as it increases the information on a particular issue which makes improvement more likely.

To conclude, the ALCP plays an important role in information processing, by giving focus on the long(er) term and setting priorities. However, not all information is readily available at the desired level of detail, which puts a limit to control.

3.7 Conclusion

This paper has set out to contribute to our understanding of the effective management of assets. To do this, a conceptual model of ALCM control has been introduced. Through a case study in rolling stock maintenance, this model has been put to practice. Only if all the requirements for effective control have been fulfilled both at the short and the long term, from a multidisciplinary perspective and including the identification of risks effective ALCM control can be exerted. It has been found that the model may help us to research ALCM practices and to point at the limits to control faced by an asset manager.

The ALCM control framework as proposed in this paper does not just increase our understanding of the practice of ALCM, it leads to practical recommendations as well. For example, it asks whether multidisciplinary goals exist for the short and long term, if information on performance and risks are available and where control may be limited.

3.8 Discussion

This paper discussed the development and application of the ALCM control model. Even though this model seemed to work well in the study of ALCM at the NR, further study is needed to investigate whether it may be applicable in other contexts.

The case study covered in this paper has shown that even in an Asset Life Cycle Plan the emphasis on the long term was limited at the NR. The asset manager of the ICT explained

that within five years so many things can happen that it would be a waste of time to spend too much time thinking about the long term. An interesting topic for further research would thus be how to deal with the long term – up to the end of the lifetime of the asset – in an efficient way. Adopting different mind-sets or strategies for different life cycle phases, such as the NR do in their maintenance, seems a promising way to go. Finally, this study operationalized the influence from the system's environment to risks, while this influence may be much larger, e.g. by changing demands and contexts over the lifetime of the asset. That may be an interesting topic for study as well.

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Publication history

The earliest version of this chapter was written as a conference paper for the TESConf in November 2014, together with my colleagues dr. A.J.J. Braaksma and prof.dr.ir. L.A.M. van Dongen. In 2015, a full paper was submitted to the *CIRP Journal of Manufacturing Science and Technology*, which was published in 2017. This full paper is presented in this chapter.

Reference to previous publications

Ruitenburt, R.J., Braaksma, A.J.J., van Dongen, L.A.M., 2014. A multidisciplinary approach for the identification of impacts on the useful remaining lifetime of assets. In: *Procedia CIRP - 3rd International Conference on Through-Life Engineering Services*. Elsevier, pp. 204–212.

Ruitenburt, R.J., Braaksma, A.J.J., 2017. Mitigating change in the goals and context of capital assets: Design of the Lifetime Impact Identification Analysis. *CIRP Journal of Manufacturing Science and Technology*. 17, 50–59.

4

Design of the Lifetime Impact Identification Analysis

Chapters 2 and 3 showed the importance of change in Asset Life Cycle Management. This chapter introduces the concept of lifetime impacts to describe change relevant for assets. Based on this concept, it presents the development of a tool to identify changes relevant to the assets: the Lifetime Impact Identification Analysis (LIIA). The evaluation of this tool will be presented in chapter 5. Only in this test, the need arose to add the O to TECCO to include the organizational perspective on change, hence in this chapter the acronym TECC (for technical, economic, compliance and commercial change) is still used.

Skippable text

The importance of change in ALCM has been discussed in more detail in chapter 2. Liander has been introduced in chapter 1.

4

Design of the Lifetime Impact Identification Analysis

Abstract

Physical assets are essential in manufacturing, and typically have lifetimes of several decades. Over such a period, many changes in goals and context may occur. Such changes should be dealt with to prevent a premature end to the asset's useful life. However, current maintenance methodologies focus mainly on the short term and on operation in a stable context. Based on a case study of Asset Management practices and the literature, we developed the Lifetime Impact Identification Analysis (LIIA) method. The method uses Technical, Economic, Compliance and Commercial perspectives to identify long-term challenges and opportunities for the asset.

Keywords: Asset Management; Asset Life Cycle Management; ISO 55000; Maintenance Management; lifetime impacts; Lifetime Impact Identification Analysis; Reliability Centred Maintenance; remaining useful life

4.1 Introduction

Physical assets fulfil indispensable roles in manufacturing. Machinery, production lines, buildings and infrastructure need to perform in safe, cost-effective and reliable ways to produce a steady supply of high-quality products. These assets represent a significant financial value for their owners and typically perform vital functions in our modern society. Therefore, effective maintenance and management of these assets is essential.

Physical assets typically have lifetimes of several decades. Therefore, many assets designed and constructed decades ago still fulfil crucial roles in production processes. Over the years, the functions these assets are expected to fulfil may change dramatically. Chemical plants are common examples, since they have to comply with increasingly tight regulations and sustainability objectives. This may necessitate drastic interventions, such as a change of the maintenance program, modernization or even the premature decom-

missioning of the asset. According to the literature as well as to the recent ISO 55000 standard, the goal of Asset Management is to create maximum value from the exploitation of assets over their complete lifetimes. Therefore, adapting the assets and their operation to ever changing contexts and demands is a key challenge in the management of assets.

In the literature, it is argued that asset managers currently experience ever increasing changes in the context in which the assets operate. Tsang (2002) lists four areas of change: new operations management strategies (e.g. Lean, agile, JIT), ever stricter societal expectations (e.g. regarding safety and the environment), technological change and organizational change. Other authors have mentioned external developments such as increasing global competition, lean manufacturing, volatile markets and increasing environmental awareness, which necessitate profound changes in the field of maintenance (Al-Turki, 2011; Komonen et al., 2012). Additionally, servitization (Neely, 2009) and the advances in ICT and outsourcing (Smit, 2014) have added additional challenges and opportunities to maintenance.

Changes are not limited to the context in which the assets need to create value, also the corporate objectives with the asset may change. The use of the assets only produces value for the company if their operation is aligned with the corporate objectives (Komonen et al., 2012; Velmurugan and Dhingra, 2015). During the lifetime of the assets, the corporate objectives are likely to change, even more so in the ever increasing market turbulence currently experienced (Tsang, 2002; Al-Turki, 2011; Komonen et al., 2012). Therefore, the management of the assets and the asset's performance objectives must continually be aligned to these variable circumstances.

The need to consider the complete life cycle of an asset is clearly expressed in the literature on Asset Management, and even more so in the sub discipline of Asset Life Cycle Management. For example, Haffejee and Brent (2008) define Asset Life Cycle Management as "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" (p.286). Additionally, the recently published ISO 55000 standard on Asset Management explicitly asks for a 'life cycle approach' to Asset Management (ISO, 2014).

However, the literature does not discuss how to effectively manage assets in the case of changing objectives or changing contexts, nor does the ISO 55000 standard clarify how to adopt a 'life cycle approach'. Many existing approaches to maintenance and Asset Management focus primarily on the short term, as is concluded about RCM (Coetzee, 1999; Murthy et al., 2002) or about traditional approaches to maintenance management (Velmurugan and Dhingra, 2015). But more importantly, many of these approaches implicitly assume a stable operating and production context. For example RCM may be used to identify a failure mode that may cause a failure after 20 years of operations, but it does not consider a different operation mode or the impact of a change of corporate objec-

tives. Additionally, even though RCM is meant to be a means to continuously improve maintenance, in practice it is often carried out as a one-off exercise, not being updated in case of changes in the operation or context of the asset (Braaksma et al., 2013).

Furthermore, even if changes are taken into account, only changes from one background are taken into account, as most current approaches to Asset Management lack a multidisciplinary approach (Haffejee and Brent, 2008). A technical approach, such as RCM and TPM (Waeyenbergh and Pintelon, 2002), may consider technical changes, ageing and issues like obsolescence. Other approaches are mainly based on statistics (e.g. Si et al., 2011; Jongen, 2012) or focus on the financial aspects of the asset, for example related to life cycle costing (LCC) (Asiedu and Gu, 1998; Márquez et al., 2012). But none of these takes a multidisciplinary perspective towards the asset, let alone a multidisciplinary perspective towards the future changes that may have an impact on the asset.

To summarize, Asset Management should be a multidisciplinary practice that manages physical assets in such a way that their exploitation contributes to the variable corporate objectives of a company over their complete life cycle, in a changeable context. In the remainder of this article, such a comprehensive approach towards Asset Management will be called Asset Life Cycle Management (ALCM). Currently, the literature does not offer a framework or tool to support Asset Life Cycle Management in a changing context. Therefore, our aim with this article is twofold: 1. to investigate the main problems in applying Asset Life Cycle Management in practice in a real life context full of change; and 2. to design a method to identify the changes in the goals and context of the asset relevant to Asset Life Cycle Management.

4.1.1 Outline

To do this, we will use three phases of the Design Science methodology, which will be introduced in the next section (4.2). These three phases will structure this paper. First, the main problems in applying ALCM in practice will be explored by means of a case study at Liander, the largest electricity and gas network operator in the Netherlands (section 4.3). The changes in context of Liander range from the ageing of their assets and the changes in the production and consumption of energy: the energy transition. These developments increase the need for a long-term focus in their Asset Management on the one hand, but on the other hand they make it exceedingly difficult to develop a good understanding of the whole life cycles of their assets. From the case study, we will abstract three main challenges for ALCM in a changing context, specifically at Liander: 1. a limited availability of data; 2. information being dispersed throughout the organization; and 3. a limited ability of asset managers to focus on long-term questions.

Second, for each of these challenges identified, an initial solution will be presented based on the literature (section 4.4). We will argue that 1. expert knowledge can be used to complete limited data availability, that 2. dispersed information can be brought together

by means of expert sessions including experts from Technical, Economic, Compliance and Commercial backgrounds, and that 3. an overview of the most important threats and opportunities may help asset managers to set the right priorities and spend more time on long-term problems.

In the third phase, these three initial solutions will be brought together to create the final solution design (section 4.5), the Lifetime Impact Identification Analysis (LIIA), which resembles the Failure Mode and Effect Analysis (FMEA) in RCM. Both the development of the LIIA and its contents will be described. This article will close with a discussion of the results and a conclusion (section 4.6), including topics for further research and implications for practitioners in the field of Asset Management.

4.2 Methodology

With this article, we aim to develop a practically relevant method for Asset Life Cycle Management based on rigorous scientific research (Van de Ven and Johnson, 2006). Well-suited for such a purpose is the Design Science methodology, which aims to solve a problem relevant to both science and practice in a scientific and rigorous way (Hevner et al., 2004). We will follow the Design Science methodology in this article (for a general introduction of the methodology, see Section 1.5, page 17), using the approach of Meyer et al. (2014) in a slightly adapted form. Accordingly, this article will be structured around three phases: 1. problem exploration; 2. initial solutions; and 3. development of the solution.

Figure 4.2.1- overview of the methodology, both from a process and an output perspective

In the problem exploration we study the practical problems of ALCM in practice by means of a case study, which we will summarize in three main challenges. For each of these challenges, initial solutions will be sought in the literature. These initial solutions will be summarized by focusing on their generative mechanisms, using the format of the CIMO-logic. In the third phase, a solution will be developed that incorporates these three generative

mechanisms: the Lifetime Impact Identification Analysis (LIIA). Figure 4.2.1 graphically summarizes the process and output of the methodology used in this paper.

Normally, the methodology includes a fourth phase testing the solution. However, the test of the method is outside the scope of the current paper, but we will report about the implementation and evaluation of the method in a second publication in this issue (Ruitenburg and Braaksma, 2017a). In the following sections, we will introduce the methodology used in each of these phases.

4.2.1 Phase I - Problem exploration

In the first phase, the practical problems in Asset Life Cycle Management in a changing context will be explored by means of a case study at a Dutch network operator, Liander. Liander has issued and funded this research project as they regard Asset Life Cycle Management as an important and promising practice. An exploration of the problems faced by Liander will be the basis for to design a solution, as “solving a problem simply means representing it so as to make the solution transparent” (Simon, 1996; cited in: Hevner et al., 2004, p. 83). An exploratory case study is well-suited for such an investigation, as it allows the researcher to gain a deep understanding of the phenomenon studied in a specific context (Kumar, 2011).

The case study was carried out in 2013 and 2014, in the division of Asset Management of Liander, which manages the electricity and gas grids owned and operated by Liander. The investigation focused on the management of the electricity assets, as the electricity grid is more complex than the gas grid. The goal of the case study was to identify the main challenges in ALCM as experienced by the department.

Data were collected using semi-structured interviews (see Appendix A.3 (page 309) for the interview questions), attending meetings, informal conversations, the study of company documents, observations and keeping field notes over a period of 1,5 years, as the first author has spent one day per week at the Liander’s office during this period. The use of multiple sources reduces the bias from the data through the mechanism of triangulation (Silverman, 2006). The main findings have been discussed with the management of the department to validate the conclusions of the case study.

4.2.2 Phase II - Initial solutions

In the second phase, the literature will be used to identify initial solutions for each of the main problems identified in the case study. These initial solutions will represent scientifically valid ‘pieces of the puzzle’ for the final solution design. These initial solutions will be structured according to the CIMO-logic, as described by Denyer *et al.* (2008). This logic gives a specific format to a hypothesis in a design context: it argues that, within a certain Context (C), a specific Intervention (I) puts a certain Mechanism (M) into motion, which will result in a specific Outcome (O). In other words, in context C, action I will lead to O

because of M. By making the CIMO hypotheses explicit, the design process will be more transparent and therefore replicable. As a result, the final solution will be easier to evaluate by the scientific community at large.

4.2.3 Phase III - Development of the solution

The third phase will describe the ALCM method and its development, which is based on the CIMO hypotheses and design criteria. The main goal of this phase is to explain the method and to make the main decisions during its development explicit and transparent. By doing this, a clear and strong ‘chain of evidence’ is built to show the validity of the design (Sousa and Voss, 2001; Voss et al., 2002).

4.3 Phase I - Problem Exploration

4.3.1 Introduction to Liander

Liander is one of the three main Dutch network operators, responsible for the safe, reliable and affordable distribution of electricity to 3.1 million and gas to 2.5 million customers (Alliander N.V., 2017). Liander operates and maintains the transportation and distribution networks from high (150 kV) to low voltage, representing a replacement value of around 10 billion (milliard) euros. The reliability of these grids is good compared to the Dutch average (ACM, 2016), and above average compared to other modern countries (Rouse and Kelly, 2011). Our case study has focused on the Asset Management division, certified with ISO 55000 and ISO 9001, specifically on the department of Policy & Standardization, which is responsible for setting the rules and guidelines for the design, purchase, construction, operation, maintenance and disposal of the assets of Liander.

Liander’s asset managers currently face two important external developments. One of these is the ageing of Liander’s assets, a problem widely recognized regarding infrastructure assets in Western Europe and the USA (Brown and Humphrey, 2005; Jongepier, 2007). Due to the age of the electricity grid, a significant number of assets is approaching their expected end of life, which may result in a so-called ‘replacement wave’.

A second external development regards the changes in the use and production of energy, often termed the ‘energy transition’ (see for example Verbong and Geels, 2007). The production of sustainable energy is growing steadily, which has two important implications for the electricity grid. First, energy production is increasingly distributed over the grid (e.g. PV panels on roofs, wind turbines installed at farmers), compared to the large-scale production in electricity plants. Secondly, the production of energy from renewable sources – especially solar and wind power – is much harder to manage than the production from traditional sources (International Energy Agency, 2011; Morales et al., 2014). Hence a need arises for new ways to manage the grid, for example by means of storage

facilities (e.g. Carbajales-Dale et al., 2014) or flexible pricing (Finn and Fitzpatrick, 2014). This will have important implications for the assets as well as for the role and tasks of Liander on the long term.

4.3.2 Main challenges in long-term ALCM at Liander

The ageing assets and the energy transition may necessitate large-scale adaptations of the existing grid, which may result in operational capacity problems (in terms of time, money and human capacity) and the application of new technologies for which Liander currently not has suitable knowledge and competences. To anticipate these changes, Liander has a need for an increased long-term perspective in its Asset Management activities (please refer to chapter 1, section 1.3.3 (p. 13) for an overview of Liander's main long term Asset Management practices). The current research project was initiated to address this need. At the inception of the project, the management of the Policy & Standardization department concluded that Liander currently has a "limited and scattered insight in the remaining useful lifetime of her assets", which limits Liander's ability to effectively manage their assets on the long term.

In our research, we have investigated the reasons underlying this limited insight using a case study. In this case study, three main challenges were identified. Each of these challenges will be discussed and will be briefly related to the literature, to investigate whether these challenges are typical for the situation of Liander, or rather an indication of more a general challenge recognized in the Asset Management literature.

Challenge 1: the availability of data and information is limited

The first ALCM challenge experienced by Liander relates to the availability of information. The information available is insufficient to gain a complete and shared insight in the remaining lifetime of the assets. This is caused by a number of reasons. First of all, this relates to the history of the electricity grid. The grid has been built decades ago, by many local grid companies. Over the years, these local companies combined to become Liander. In this process, data was lost or found to be non-interoperable due to the use of different registration systems. A second reason relates to the collection of information: it may happen that one only knows in hindsight what data should have been collected years ago, as new questions arise over time. A third reason is caused by the reliability of the assets used by Liander: as they only seldom fail, only little failure data are available, making analyses based on these data – such as Weibull analysis or bathtub curves – hard to execute in a reliable way. Finally, the impact of future changes as the energy transition is hard to predict. However, such data are needed to reliably predict the future without making the (implicit) assumption of a stable context.

These data and information challenges often led the asset managers of Liander to the idea that the available data are of no value. However, several studies carried out by Liander

have concluded that firm and reliable conclusions can be drawn even from these data (see, for example, the Ph.D. dissertations of Jongen (2012) and Chmura (2014), both funded by Liander). Additionally, Liander engaged in several projects to make better use of the available data and to make the most of the existing data, for example by cleaning and enriching historical data and making ‘data-driven maintenance’ one of the key priorities for the coming years.

However, at the time of the case study the first Asset Management challenge can be summarized as:

Case study challenge 1: *Due to a limitation of readily available data, Liander has difficulties in getting insight in the remaining lifetime of its assets.*

This first challenge abstracted from the case study at Liander can easily be related to the maintenance literature, as the challenge of limited data availability is widely-recognized here. A clear example of this can be found in a recent literature review of over 120 papers using various statistical approaches to estimate the Remaining Useful Lifetime (RUL) of assets (Si et al., 2011). One of their conclusions is that “[i]t is desirable to develop a RUL estimation model based on very few or no data situations” (Si et al., 2011, p. 11). Other instances where data problems have been recognized are Braaksma *et al.* (2012), Kumar and Patnaikuni (2012), Jongen (2012) and Denkena *et al.* (2014).

Challenge 2: information is distributed throughout the organization

The statement that Liander has ‘limited and scattered insight’ hints at a second challenge: the information may be available within the organization or at one of its main partners (e.g. other Dutch network operators or service providers), but not available at the right person at the right time. In other words, the knowledge and information available is not always put to optimal use.

A first reason for this is that knowledge on the assets is dispersed over more than a hundred documents, written by different Asset Management departments. These documents cover different specific problems or populations, and are not always fully aligned with all existing documents. This makes it difficult to get a holistic overview of the quality of the assets and the main relevant trends. Hence, Liander started a project to improve this situation at the end of the case study. Secondly, the department of Policy & Standardization is dependent on information from a large number of other divisions. Due to the size of the company it happens that not all information relevant to the Policy & Standardization department is also known at the department. Thirdly, the maintenance is carried out by service providers and external contractors. These partners are mainly focused on making the repair of the failure as fast as possible and consider the registration of the details of the failure – which is vital information for the Asset Management department – to be a sec-

ondary matter. This difference in operational versus strategic focus limits the collection and exchange of reliable information.

This distribution of information and the related (information) dependencies limits the ability of the asset managers to gain an integral, holistic view on their assets. This limitation became most clear when strategic questions were asked by higher management. These questions often required an integral and holistic overview of the most important issues and developments for the assets. Answering these questions in a timely manner turned out to be difficult, as this necessitated the collection and combination of information from different systems and departments into an integral overview.

Case study 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.*

This challenge of dispersed information is acknowledged in the literature as well. Haffajee and Brent (2008) state that a multidisciplinary approach to Asset Management is often lacking. Some authors argue that for example the designers of the assets (Schuman and Brent, 2005; van Dongen, 2011b) and the operations department (Al-Turki, 2011) should be involved in Asset Management. Also, it has been argued that integrating maintenance and operations in maintenance decision-making leads to better performance than when these are considered separately (Celen and Djurdjanovic, 2012; Kröning and Denkena, 2013). In the general management literature, the topic of information exchange problems as a consequence of functional silos is well-known (Ensor, 1988; Beer and Eisenstat, 2000). Hence, it may be concluded that the management of information flows within an organization, especially if different disciplines need to be combined, is a problem more widely recognized in the literature.

Challenge 3: the time available for strategic matters is (perceived to be) limited

The third challenge is less related to the availability of data, but rather to the capacity of the asset managers to process information. Developments such as the energy transition and the ageing assets increasingly ask for their time, for example in answering the questions of higher management. However, much of the time of the asset managers is inevitably consumed by all kinds of specific, operational problems that need to be solved. These operational issues often ask for immediate responses, one of the asset managers described this situation as ‘firefighting’.

Clearly, many operational challenges do need a quick response. However, answering these questions distracts their attention from working on the long-term and the complete life cycle of the assets, which seems to ask for a different mental mode. As one of the asset managers put it: “strategic ALCM is like making policy with your feet up”. But the daily

operational issues often limit the ability of the asset managers to consider the long term in the management of their assets. One of the side effects of this firefighting is that it limits the time available for continuous improvement, as preventing negative things on the short term is always more urgent than improving the good things on the long run.

However, it is possible to approach this challenge from a different perspective. It is possible that solving immediate problems is felt to be more rewarding than working on strategic matters. This may be because the benefits are easier to see, for example when colleagues are grateful when their problem has been solved. Another reason may be that these problems are (perceived to be) easier to solve, for example because the asset managers are used to work on these kinds of problems or because the information and processes needed to solve these problems are readily available (compare challenge 1 and 2). Whatever the exact underlying reason, the asset managers at Liander clearly indicated that they perceived to have limited time available for long-term and strategic matters.

Case study challenge 3: *Many urgent and pressing operational matters limit the (perceived) ability of the asset managers to focus on long-term and strategic challenges.*

The third challenge identified at Liander is the *short term focus* in the management of their assets. Many authors emphasize the fact that a long-term and strategic focus is needed in Asset Management (Schuman and Brent, 2005; Haffejee and Brent, 2008; Al-Turki, 2011; Komonen et al., 2012), which may indicate that such a focus is currently often lacking. In earlier research, we have researched other Asset Management divisions in different industries, where the same idea of ‘firefighting’ was mentioned as an important issue and challenge (Petersen et al., 2015a; Ruitenburg et al., 2015).

Bohn (2000) discusses the concept of ‘firefighting’ in the context of manufacturing. He argues that “firefighting is one of the most serious problems facing many managers of complex, change-driven processes” (p.82) and basically states that firefighting is the result of setting wrong priorities when tasks are accumulating. He also states that “[i]n most U.S. organizations, the hero is the one who puts out the biggest fires” (p.97), which points at how rewarding it can be to put out fires, instead of preventing fires in the first place. ‘Firefighting’ is also discussed by Covey (1989), albeit in a more general way. He argues that ‘always putting out fires’ is a problem for people with too many urgent and important issues at hand. They are working frantically to solve crises and to prevent near-crises, creating a ‘short term focus’. Even though his findings are not directly related to Asset Management, they may yield insight in the reasons behind firefighting.

To conclude, the case study showed how Liander experiences changes in the electricity distribution industry and the ageing of its assets. This caused Liander to pay increased attention to the long-term perspective in the management of its assets. However, three main challenges arose: not all data is always available, information is dispersed through-

out the organization and the asset managers (perceive to) have only limited time available to consider long-term and strategic matters. Liander has recognized these difficulties and has started several projects to improve this situation, one of which being the current research project.

These three challenges faced by Liander are also described in the literature. Therefore, it can be concluded that these challenges are not typical for Liander, but rather more general problems related to Asset Life Cycle Management in real life, changing contexts. Therefore, there is a theoretical and practical need to assist asset managers in organizations like Liander in their long-term and strategic Asset Management.

4.4 Phase II - Initial solutions

In the previous section, we studied the practical challenges in Asset Management at Liander, and related these to the literature. To develop a solution design for these challenges, we will now review the literature in search of initial solutions for these three difficulties.

4.4.1 Initial solution 1: an expert-based approach

The first difficulty encountered in ALCM practice is the limited availability of reliable data. It is important to realize that this is a challenge almost by definition: failures are an important source of information, but most failures need to be prevented. Therefore, a method is needed to develop a suitable preventive maintenance plan without the use of failure data.

Reliability Centred Maintenance (RCM) (Moubray, 1997; Smith and Hinchcliffe, 2003) is a maintenance concept that addresses exactly this problem. RCM is used in the design phase of a new asset. While designing the asset, the asset does not yet exist and hence no failure data are yet available. RCM can be described by four unique features (Smith and Hinchcliffe, 2003): RCM focuses on 1. preserving the asset function; 2. the identification of failure modes that would disrupt this function; 3 the prioritization of these failure modes; and 4. the selection of appropriate design changes or maintenance tasks for the high priority failure modes.

In RCM, the problem of limited data availability is solved by means of expert sessions. In these sessions, experts identify and discuss possible failures based on their expertise with similar assets. Different experts from different backgrounds bring in their knowledge and expertise (Smith and Hinchcliffe, 2003). By bringing different experts together also tacit knowledge (Polanyi, 1966) can be deployed: knowledge and expertise stored in the minds of people, rather than in documents or databases. Based on the discussion between the experts, an 'educated guess' can be made of the main failure modes to be expected in the asset, based on the information available (e.g. design drawings and personal expertise).

Based on the failure modes as well as their likelihood and severity, a suitable measure can be proposed: a change in the design or a (preventive or corrective) maintenance action. RCM has shown a way to deal with information problems in the context of maintenance, and is currently widely acknowledged and prescribed as a maintenance concept (Braaksma et al., 2013). Therefore, we may conclude that the generative mechanism underlying RCM may be useful for our solution design. This mechanism can be made explicit when expressed according to the CIMO-logic: in the context of maintenance (C), bringing together experts from different backgrounds (I) will start a mechanism of discussing ideas from their diverse experience whereby their tacit knowledge is elicited (M), which results in an 'educated guess' of potential failure modes based on the information and expertise that is available (O) [CIMO 1].

4.4.2 Initial solution 2: multidisciplinary expert sessions

The second challenge in Asset Management we discovered in the case study concerns the difficulty of combining knowledge, as it is dispersed over different departments within and outside of the organization. As we have seen in the discussion on initial solution 1, Reliability Centred Maintenance (RCM) brings experts from different technical backgrounds together into expert sessions to combine their knowledge. This may be a suitable way to combine knowledge from different disciplines. However, the question remains which 'different disciplines' are relevant for Asset Life Cycle Management. Or more precisely: from which backgrounds originate the changes that are most important for ALCM?

In the literature, multiple lists of relevant disciplines can be found (see Table 3.4.1), ranging from different backgrounds. For example, the PEST analysis (Healey, 1994; Brown et al., 2013) has been developed in the strategic management literature. It is a tool for the identification of external developments that are relevant to a business, covering Political, Economic, Social and Technological changes.

Another list of relevant disciplines has resulted from a study by Rob van Dongen and a number of large asset-intensive companies in the Netherlands (2011c). Based on the realisation that the Dutch industry depends on rapidly ageing physical assets, these companies have tried to come up with a multidisciplinary way to look at life extension of physical assets and the external developments that may be relevant. For this purpose, they have come up with a set of four dimensions of ageing: Technical, Economic, Compliance and Commercial (TECC) (van Dongen, 2011). Each of these dimensions cover important but different perspectives on the asset, and cover the different perspectives mentioned in the literature (see Table 3.4.1). The commercial perspective may deserve a short explanation: it covers the fit of the asset and its production to the market. It thus relates to economic aspects, but also to social and demographic changes (e.g. a growing customer base). As we aim to design a tool for use in practice, the four TECC perspectives developed with practi-

tioners will be used as the main relevant aspects for a multidisciplinary approach¹³. We will now briefly discuss each of these perspectives.

Figure 4.4.1- overview of the relevant disciplines for ALCM, structured using TECC¹⁴

	Background	Technical	Economic	Compliance	Commercial
Pudney (2010) [regimes]	Asset Management	Technological	Economic	Governance, Geo-political, Social, Demographic	Economic, Social, Demographic
Pudney (2010) [performance]	Asset Management	Technical	Economic	Social, Environmental	Economic, Social
Woodward (1997)	Asset Management	Functional, Physical, Technological	Economic	Social, Legal	Functional, Economic, Social
Haffejee & Brent (2008)	Asset Management	Technical	Economic	Environmental, Social	Economic, Social
Datta & Roy (2010)	Industrial Product- Service Systems (IPSS)	Technology development	Global competition, Revenue generation opportunity	Environmental sustainability	Customer affordability, Revenue generation opportunity, Global competition
PEST-analysis	Strategic Management	Technological	Economic	Political, Social	Economic, Social

The **Technical perspective** is common in traditional maintenance. It is about the physical asset, its condition and its (potential) failures. Simply put, it asks if the physical asset and its output comply with the technical specifications it was designed for. An example of a well-known practice in Asset Management that covers the technical perspective is RCM with its focus on ‘failure modes’, but many others exist, such as specific applications of condition monitoring (e.g. Musselman and Djurdjanovic, 2012) or degradation modelling (e.g. Heng et al., 2009). Additionally, the estimation of the remaining useful life (RUL) (Si et al., 2011) fits this perspective. Additionally, technical changes such as innovations may be relevant.

Secondly, there is the **Economic perspective**, which is all about finance. It is about the costs of operating and maintaining the asset. The value of the asset for its owner may be hampered by changes such as increasing maintenance costs, higher costs of spare parts or

¹³ In the evaluation of the method developed in this paper, it was found that the four perspectives of TECC did not cover all relevant changes for the assets. Therefore, a fifth perspective – the organizational perspective – was added. Please refer to chapter 5 for more information on this additional perspective.

¹⁴ When using TECCO (see footnote 13) to structure these disciplines, especially the ‘demographic’ regime of Pudney (2010) would fall in the organizational category, as demographics may have a large influence on the availability of employees. Environmental performance may also fall into the organizational category, in case it is the desire of the organization rather than regulation or social acceptance that makes the organization to consider sustainability.

the availability of lower cost alternatives. This perspective relates to the existing literature on Life Cycle Costing (LCC) (Asiedu and Gu, 1998; Márquez et al., 2012), but is broader, as it also includes changes that influence the costs of operating the asset.

The third perspective is the **Compliance perspective**. This has to do with the 'license to operate' (see for example Prno and Scott Slocombe, 2012) of the company: is the use of the asset still allowed by law, sectoral and internal regulations? This perspective covers a broad range of topics, ranging from working conditions, occupational health and safety to sustainability and Corporate Social Responsibility (CSR). All of these topics may have an impact on the value the assets can deliver to its owner (Haffejee and Brent, 2008; Woodhouse, 2010).

Finally, the **Commercial perspective** asks whether the asset and its production are still able to fulfil the demands of the market and the customer. This is different from the technical perspective: the technical perspective asks if the asset still fulfils the specifications of the output, the commercial perspective adds that the technical specifications themselves may be outdated. This could be the case with production equipment for products like a disc man or an mp3-player, but also for power plants fuelled by coal in a market asking for green energy. This commercial perspective is related to the idea of technical obsolescence (e.g. Bartels et al., 2012). It also takes the competitive environment of the company into account (Komonen et al., 2012).

To summarize, the four TECC dimensions represent the main perspectives relevant to the management of the asset over its complete life, as changes may range from each of these perspectives that will impact the value production potential of the asset. When we combine these perspectives with the idea of RCM to bring experts from different disciplines together in an expert session, we have an initial solution to the second challenge. Hence as expressed in CIMO-logic: in the multidisciplinary context of Asset Management (C), bringing together people from the four TECC perspectives (I) will start a process of knowledge exchange and integration (M) that leads to a shared view on the potential changes relevant to the asset (O) [CIMO 2]. Such a shared view on the asset may again enable integrated decision-making on the asset.

4.4.3 Initial solution 3: identification of priority changes

According to Covey (1989), firefighting can be reduced by setting the right priorities. He argues that setting priorities should happen by focusing on what is important, rather than what is urgent (Covey, 1989). As Asset Management is ultimately about the creation of value with assets (Institute of Asset Management and British Standards Institution, 2008; ISO, 2014), priority should be given to those problems that endanger value creation over the life cycle, or to the opportunities that may increase the creation of value. A clear understanding of what these threats and opportunities are would allow the asset managers

to set the right priorities and to spend more time on long-term concerns. Earlier research by the authors (Ruitenburg et al., 2015) showed that asset managers may need to be taken out of the daily urgencies in order to focus on the long term and to establish the right priorities. This fits with the ideas from Covey (1989), who argues that setting time apart may help to set the right long-term priorities. Additionally, the development of a clear and structured tool to assist the asset managers in the identification of the most important changes may make this process easier and more rewarding, making it more attractive to create time to work on long-term matters.

Once again in terms of CIMO: in the context of being overwhelmed with urgent and important issues (C), creating an overview of the main long-term threats and opportunities (I) may help to decide where to invest one's limited time resources (M), which will result in less firefighting and a possibility to spend more time on long-term concerns (O) [CIMO 3].

Table 4.4.1 - overview of the three initial solutions to the three main challenges in ALCM, presented in CIMO-logic

CIMO	Context	Intervention	Mechanism	Outcome
	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 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 that is available
	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	will start a process of knowledge exchange and integration	that leads to a shared view on the potential changes relevant to the asset
	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

4.5 Phase III - Solution Design

In the previous section, we have presented initial solutions to the three main challenges in ALCM, based on the literature (see Table 4.4.1). These initial solutions need to be embedded in a final solution design: a method to assist the multidisciplinary management of as-

sets over their complete life cycles in a changing context. For this method, a clear objective is needed.

In RCM, the objective is the preservation of the asset function, and therefore the method aims at the identification of the failure modes that threaten the function of the asset. In ALCM, the focus is wider, it namely aims to preserve the (stakeholder) value created using the asset. In different contexts, value may be operationalized in different ways, for example in terms of profits or social value.

Failure modes prevent an asset from fulfilling its function. Likewise, there are certain external developments that prevent the asset from producing value for its owner. The solution design will focus on these changes, which will be called ‘lifetime impacts’, as they have an impact on the actual or potential lifetime of the asset. Lifetime impacts can be defined as ‘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’. We will now briefly discuss a few main characteristics of lifetime impacts, based on this definition.

Lifetime impacts focus on the creation of value. Value is created by the complete physical asset, the system as a whole, rather than by its main components. Hence the focus lies on the complete asset, and the components only become relevant if they limit the value creation potential of the asset. As lifetime impacts focus on the creation of value, they may be negative as well as positive.

Examples of positive lifetime impacts would be innovations that allow for savings on maintenance costs, new information systems that allow a better understanding of future failures or a more sustainable operation of the asset. This also implies that knowing lifetime impacts is not enough; suitable measures must be taken to prevent negative impacts or to reap the full potential of positive impacts. Furthermore, lifetime impacts are explicitly multidisciplinary, and thus can be both technical as well as non-technical. They can be the result of sudden events or lengthy trends: a sudden breakdown of a critical component or the gradual decline of spare part availability in the market. Either way, lifetime impacts are impacts on the medium or long term, as it is assumed that all the short term threats and opportunities are already taken into account in the existing maintenance programs, as the short term can be considered stable. Even if that is not (yet) the case, it is assumed that a company already has methods or processes in place to deal with these short term threats and opportunities.

4.5.1 Lifetime Impact Identification Analysis (LIIA)

In RCM, the goal is to identify the most critical failure modes and to assign suitable maintenance actions to each of these. Likewise, for ALCM, a method is needed to identify lifetime impacts. To fulfil this need, we developed the Lifetime Impact Identification Analysis (LIIA), based upon the initial solutions and the additional design criteria. The LIIA con-

sists of five steps, which bear resemblance to the first steps in RCM (Smith and Hinchcliffe, 2003). These five steps are:

1. asset selection;
2. collection of general asset information;
3. expert session(s);
4. writing the Lifetime Impact Report (LIR); and
5. evaluation.

We will now introduce each of these five steps, and will explain the main decisions made during the development of the LIIA. For a more practical and detailed explanation of the LIIA, please refer to Ruitenburg et al. (2016b).

1. Asset selection

The very first step of the LIIA is the selection of the asset to be analysed. This selection may be based on all kinds of considerations, for example, criticality, cost or age of the asset. It may be recommended to carry out a LIIA for all assets. But for a start, it may be considered to select those assets on which important strategic decisions are about to be made (e.g. overhauls or modernization) or where the context is especially volatile.

Additionally, a decision should be made on the scope of the analysis. Thus far, we have used the LIIA for large populations of similar assets. The keyword here is ‘similar’: which types or designs are included in the analysis, and which are considered to be too different? A key aspect to take into account is the function of the asset: different systems may perform the same functions and hence are identical to the asset owner regarding the value they create, therefore they may be combined into one LIIA.

2. Collection of general asset information

The next step of the LIIA concerns the collection of general asset information. This should result in a description of the asset (population), in terms of physical characteristics, population characteristics, function, current performance, strategic objectives and current maintenance policies. Additionally, available information on the remainder of the asset’s life may be collected, including potential changes in the context or the objectives. This may be failure data, bathtub curves, RUL estimations or any other quantitative or qualitative data that may be a useful input for the expert session. Additionally, future scenarios describing what the future may look like may be useful to think about potential changes in the asset’s context.

Ultimately, this second step prepares for the expert session. The collection of asset information makes sure all existing information is taken into account in the expert session. Furthermore, it prepares a thorough background on the asset for the different experts that are invited to the expert session.

3. Expert session(s)

The expert session lies at the heart of the LIIA. It is in the expert session that the expertise of experts from different disciplines is brought together. In the expert session the experts exchange information, interact and discuss the lifetime impacts they consider to be relevant. Table 4.5.1 gives an overview of the contents of the expert session.

The expert session is prepared thoroughly by an asset expert and a facilitator. The first brings the information gathered in the previous steps into the expert session. The latter is responsible for the effective execution of the expert session, which includes the introduction of lifetime impacts.

Table 4.5.1 - overview of the contents and the topics to discuss in the expert session

Stage	Description	Topics to discuss
1. Introduction	Introduction of the expert session	<ul style="list-style-type: none"> - Getting to know each other (not all experts may be familiar with each other) - Contents of the expert session - Introduction to ALCM, the LIIA and the 5 TECCO-perspectives - Introduction of the main characteristics of the asset
2. Evaluation of current maintenance program	Evaluation of the current maintenance program and its execution	<ul style="list-style-type: none"> - Short explanation of the current maintenance program - Critical discussion of the current maintenance program (e.g. are all relevant problems and topics covered?) - Critical discussion of the execution of the maintenance program
3. Identification of lifetime impacts	Discussion of the 5 TECCO-perspectives in order to elicit lifetime impacts	<ul style="list-style-type: none"> - This stage may be started with a short individual brainstorm to identify lifetime impacts, for example using sticky notes which are collected on the wall. - For each perspective, the following topics are discussed: - Short presentation of the main information on the relevant perspective available within the company (e.g. failure data, cost data) - Introductory statement of an expert on the relevant perspective to start the discussion - Discussion of the potential lifetime impacts on the relevant perspective (including an indication of the main effects and the likelihood of each impact) - Concluding summary of the relevant perspective
4. Discussion of future scenarios	Discussion of future scenarios available within the company (if any)	<ul style="list-style-type: none"> - For each future scenario, the following topics are discussed: - Discussion to identify new (potential) lifetime impacts for the relevant future scenario - Discussion of the relevance of the previously identified lifetime impacts for the relevant future scenario
5. Closure	Closure of the expert session	<ul style="list-style-type: none"> - Explanation of the next steps that will be taken in the LIIA - Evaluation of the expert session

During the expert session, each TECCO perspective is discussed separately, with the purpose to identify the main lifetime impacts for each dimension. In the discussion, different kinds of information (ranging from tacit knowledge such as gut feelings to statistical data) are brought together, interpreted and – through this – a shared understanding of the main lifetime impacts develops. The discussion also gives an idea about the reliability of the

information; the more agreement there is among the experts, the more reliable the information may be expected to be (compare for example the Delphi analysis (Okoli and Pawlowski, 2004)).

During the development of the method at Liander, it was found that some lifetime impacts may be 'hidden' in the current maintenance program. The potential problems covered in the maintenance program are outside the scope of the LIIA, because measures have already been taken to manage these. However, it may be the case that there are some gaps in the current maintenance program, or that new opportunities may be identified. Hence, the LIIA starts off with a discussion of the current maintenance program, to identify lifetime impacts 'hidden' in the current maintenance.

4. Writing the Lifetime Impact Report (LIR)

Based on the information gathered in step 2 and the lifetime impacts identified in step 3, a Lifetime Impact Report (LIR) is written. This report discusses the value created from the exploitation of the asset from a long-term perspective, focusing on the (strategic) objectives, current performance and the lifetime impacts (both positive and negative) that may have an effect on the value created with the asset. The structured presentation of this information facilitates long-term decision-making on the asset, for example, decisions on how to prevent negative lifetime impacts or how to grasp the full potential of positive lifetime impacts. Additionally, it allows asset managers to set the right priorities for the assets as well as for how they spend their own time.

5. Evaluation

The last step of the LIIA is the evaluation of the LIR with the experts. This allows them to check the interpretation and representation of the discussions in the expert session as written down in the LIR. Additionally, it gives an opportunity to come up with additional insights or remarks to further improve and extend the insight in the lifetime of the asset as presented by the LIR. This may lead to a revision of the LIR and, if necessary, an additional evaluation of the revised LIR.

4.6 Conclusion

To create maximum value from the use of physical assets, it is essential to consider their complete lifetimes, as the scientific literature and standards such as ISO 55.000 (2014) prescribe. More importantly, it is important to consider the changes in the asset's context and the corporate objectives that may happen during the useful life of the asset. However, the scientific literature and standards such as ISO 55.000 offer little guidance as to how to manage assets in a changing context. Therefore, this article has set out to investigate the main challenges of Asset Life Cycle Management (ALCM) in a changing context through the medium of a case study.

The study of ALCM at Liander showed three main challenges in their long-term Asset Management. The first challenge we found was the limited availability of reliable asset data. Secondly, as the available information is dispersed throughout different departments within and even outside the company, not all relevant information was taken into account in ALCM. Thirdly, the time asset managers perceived to have available for long-term problems and opportunities was limited because of the large number of operational issues they had to cope with.

Knowing these difficulties, we designed a method to assist the multidisciplinary management of assets over their complete life cycle. Based on the literature – and especially the concept of Reliability Centred Maintenance (RCM) (Moubray, 1997; Smith and Hinchcliffe, 2003) – we developed the Lifetime Impact Identification Analysis (LIIA) method. We defined lifetime impacts as ‘probable (technical and non-technical) events or trends that may have a positive or negative influence on the value creation from the use of the asset in the intermediate or long term’.

The LIIA depends on three main generative mechanisms. The first mechanism states that bringing together experts from different backgrounds in a discussion meeting will tap their tacit knowledge, which results in an ‘educated guess’ of potential lifetime impacts, based on the information and expertise that is available in the company. The second generative mechanism states that the discussion of lifetime impacts from four different perspectives – Technical, Economic, Compliance and Commercial (TECC) – will result in an integrated and holistic overview of the asset’s future and the main changes relevant to the asset. The third mechanism describes that such an overview of the main future threats and opportunities to deal within ALCM will allow the asset managers to effectively set priorities for their Asset Management efforts, which is expected to reduce the need for firefighting on the long term.

The LIIA aims to assist long-term and strategic Asset Management, by identifying the relevant changes in the context and objectives of the asset. By knowing the most important lifetime impacts, asset managers can prepare suitable measures to prevent negative lifetime impacts and to reap the full benefits of positive impacts. Additionally, knowing the most important lifetime impacts is expected to help them to set the right priorities for the asset as well as for their own time.

The method has been developed in close collaboration with practitioners. In a next paper, we will report on two tests of the LIIA (Ruitenburg and Braaksma, 2017a). 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 (Moubray, 1997).

For practitioners, this research has three important implications. The first is the realization that Asset Management does not happen in a vacuum, but in a changing context. These

changes are important to consider to create maximum value from the exploitation of the assets. Secondly, even though there is limited information available, the combined knowledge of experts may help to identify these changes. Thirdly, the LIIA – as presented in this paper – may help practitioners to identify these lifetime impacts in a structured way.

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Publication history

The test of the LIIA at Vattenfall Wind Power was first published as a conference paper for the CINet conference 2016. This conference paper was written together with Kristian Pettersen, the industrial PhD fellow with whom I carried out this test at Vattenfall. In 2015, the full paper was submitted to the *CIRP Journal of Manufacturing Science and Technology*, which was published in 2017.

Reference to previous publications

Petersen, K.R., Ruitenburt, R.J., Madsen, E.S., Braaksma, A.J.J., Bilberg, A., 2015. Lifetime Impact Identification for Continuous Improvement of Wind Farm Performance. In: *Proceedings of the 16th International CINet Conference*. Stockholm, Sweden, p. 10.

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5

Evaluation of the Lifetime Impact Identification Analysis

In chapter 4, the Lifetime Impact Identification Analysis (LIIA) was developed to identify change relevant to assets (so-called lifetime impacts). In this chapter, the LIIA is tested by two applications in practice: at Liander, a Dutch network operator, and at Vattenfall Wind Power. The results of these applications are presented and discussed. These evaluations showed that technical, economic, compliance and commercial perspectives did not cover all relevant types of change, therefore the O for organizational lifetime impacts was added to TECC, turning it into TECCO.

Skippable text

The (development of the) LIIA is presented in the first pages of this chapter, which is largely a summary of chapter 4.

5

Evaluation of the Lifetime Impact Identification Analysis

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.

Keywords: Asset Management; Asset Life Cycle Management; ISO 55000; Maintenance Management; lifetime impacts; Lifetime Impact Identification Analysis; Reliability Centred Maintenance

5.1 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 (Pintelon and Parodi-Herz, 2008). 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 (Tsang, 2002; Al-Turki, 2011; Komonen et al., 2012).

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 (van Dongen, 2011a) – 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. Schuman and Brent, 2005; Pudney, 2010), which is even more emphasized in the concept of Asset Life Cycle Management (Haffejee and Brent, 2008). The need to adopt a ‘life cycle approach’ is also acknowledged by the recent ISO standard on Asset Management (ISO, 2014)

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) (Ruitenburg and Braaksma, 2017b). 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 Wind Power).

5.1.1 Outline

The next section will introduce the LIIA and its underlying generative mechanisms (section 5.2). Then, the methodology used for the development and test of the LIIA will be presented: the Design Science methodology (section 0). The Design Science methodology prescribes the test of a method in practice, to allow further refinement of the solution design. Therefore, we have implemented the LIIA in two different companies, and evaluated the practical application of the method critically (section 5.4 describes the application at Liander, section 5.5 the application at Vattenfall Wind Power). 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 (section 5.6).

5.2 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 (Ruitenburg and Braaksma,

2017b). 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” (Ruitenburg and Braaksma, 2017b, p. 56). 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) (Moubray, 1997; Smith and Hinchcliffe, 2003). 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 4.5.1*), 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.

Table 5.2.1 - a short explanation of the five steps of the LIIA (Ruitenburg and Braaksma, 2017b)

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.

As ALCM is a multidisciplinary practice (Haffejee and Brent, 2008; Pudney, 2010; Ruitenburg and Braaksma, 2017b), 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.

Table 5.2.2 - overview of the three initial solutions to the three main challenges in ALCM, presented in CIMO-logic (Ruitenburg and Braaksma, 2017b)

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 the exchange of 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) (Moubray, 1997; Smith and Hinchcliffe, 2003)
	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	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 (Moubray, 1997; Smith and Hinchcliffe, 2003), the four TECC dimensions (van Dongen, 2011c)
	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 more time to spend on long-term concerns	priority-setting is discussed by Covey (1989) as a solution to firefighting

The LIA 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 (Ruitenburg and Braaksma, 2017b). The three challenges and the initial solutions to these are presented in Table 4.4.1, 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 (Denyer et al., 2008).

5.3 Methodology

The development of the Lifetime Impact Identification Analysis (LIIA) was guided by the Design Science methodology (Hevner et al., 2004). 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 (Meyer et al., 2014). A general introduction to this methodology was presented in Section 1.5 (page 17). In our previous publication (Ruitenburg and Braaksma, 2017b), we reported on the first three phases. Therefore, this paper will focus on the test of the solution design: the LIIA. Figure 5.3.1 shows the four phases of the research.

Figure 5.3.1 - overview of the methodology, both from a process and an output perspective (adapted from Ruitenburg and Braaksma (2017b))

To test the LIIA, we implemented the method in practice. To increase the generalizability of the test, we selected two different 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 could be expected that the LIIA suited their needs. Therefore, the second test was carried out at a very different company as a contrasting case, namely Vattenfall Wind Power. The specific case was one of the offshore wind farms they operate in Denmark. This was 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 versus hundreds or thousands) while the (replacement) costs per asset are much higher (tens to hundreds of thousands versus 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 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 (Yin, 2014), allowing for a deep understanding of the context in which the company operated and a thorough evaluation of the LIIA.

The evaluation aimed to establish the effectiveness of the design (i.e. does it deliver the expected results), as well as an understanding of the mechanisms leading to the desired results. Therefore, the LIIA was adapted to the particularities of the two case companies (as Van Aken (2016) proposed). After the implementation and use of the LIIA, its outcomes were evaluated with a number of respondents from the companies by means of interviews. Additionally, for the test at Vattenfall a short evaluation form was used (similar to the form presented in Appendix A.6, page 314). We focused our evaluation of the design on the CIMO-statements, as these focus on the generative mechanisms underlying the LIIA method and allow us to abstract the evaluation from the particularities of the companies and the LIIA design to the general traits of the designed artifact.

In the next section, the test results will be presented. 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.

5.4 Test at Liander: a LIIA on a population of switch-gear

5.4.1 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 (Brown and Humphrey, 2005; Jongepier, 2007). 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 Verbong and Geels, 2007).

Table 5.4.1 - 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 1.5h 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 hours (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 hours (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 hours (6 experts present) - Rewriting of the LIR to include the proposed revisions.

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.

5.4.2 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 2,500 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 hour) and company documents were studied. Table 5.4.1 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 5.4.2.

Table 5.4.2 - 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

5.4.3 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 organized 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 (van Aken, 2004). 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 5.5.3*).

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.

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

5.5.1 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 (Petersen et al., 2015b). 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.

Table 5.5.1 - 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 hours (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 hours)
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 hour interviews). - A questionnaire has been handed out to evaluate the LIR. - Rewriting of the LIR to include the proposed revisions.

5.5.2 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 5.5.1. 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 5.5.2.

Table 5.5.2 - 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

5.5.3 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 asset managers for HR1. They assessed the LIR with an average score of 6,0. To get a deeper understanding of the 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 5.5.3.

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.

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 LIA 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.

Table 5.5.3 - 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 the exchange of ideas from their diverse experience in which 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

5.6 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 pre-

sented in a previous article (Ruitenburg and Braaksma, 2017b). 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 5.5.3), 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 (Moubray, 1997).

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 Schuh et al., 2014). 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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6

Asset Life Cycle Plans: twelve steps to assist strategic Asset Manage- ment decision-making

This chapter presents a practical twelve step approach to write Asset Life Cycle Plans (ALCPs). The chapter can be seen as the practical counterpart of the Lifetime Impact Identification Analysis as presented in chapters 4 and 5. The chapter was mainly aimed at practitioners and hence includes fewer references and more examples and practical advice.

Skippable text

The background on ALCM and the LIIA were presented in the chapters 2 and 4. However, as this chapter was mainly aimed at practitioners, the tone of voice of these sections is slightly different and more examples are offered than in the earlier chapters discussing the same topics.

6

Asset Life Cycle Plans : twelve steps to assist strategic Asset Manage- ment decision-making

Abstract

Effective management of physical assets should deliver maximum business value. Therefore, Asset Management standards such as PAS 55 and ISO 55000 ask for a life cycle approach. However, most existing methods focus only on the short-term of the asset's life or the estimation of its remaining life. These methods do not consider alignment to changing corporate objectives in a variable context, nor do they adopt a multidisciplinary perspective. This chapter argues that to create maximum value, Asset Management should be a multidisciplinary and strategic practice, considering the complete life cycle of the asset: Asset Life Cycle Management. A practical twelve-step approach is presented to develop an Asset Life Cycle Plan (ALCP), in which expert sessions are used to identify the main lifetime impacts that influence the creation of business value from the use of the asset. The steps are illustrated with an example from practice. The chapter concludes that the ALCP supports asset managers in taking long-term strategic decisions in a timely and effective manner.

Keywords:

Strategic Asset Management, Long-term, Multidisciplinary, Asset Life Cycle Management, Asset Life Cycle Plan, Lifetime Impact, TECCO, Qualitative information, Life cycle, Strategic Alignment

6.1 Introduction

Physical assets are indispensable for society. Oftentimes the assets are not even noticed, until a seemingly minor technical failure disrupts daily life. At these moments, it becomes clear that these assets fulfil vital functions in our lives. Examples are bridges and roads for transportation, the electricity grid to keep the lights on, and water treatment plants for drinking water. Next to their societal value, the financial (replacement) value of these assets is substantial as well. An estimate of this value in the Netherlands lies around 400 billion (milliard) euros (Veenman and Besselink, 2010), which is around 50% of the Dutch yearly GDP. This clearly shows the large financial value represented by physical assets in a modern Western country. Additionally, the costs of the maintenance needed to keep

these assets fit for use are considerable. In the Netherlands, the maintenance costs amount to a yearly spending of 30 to 35 billion euros (NVDO, 2015). As such high financial and social values are at stake, the effective management of these assets is important for asset owners and society alike.

The importance of effective Asset Management is made greater by the fact that the end of the expected functional lives of many assets is approaching. This applies to Dutch infrastructure assets (Wetzer and Bouwman, 2007; Jongepier, 2007; de Leeuw and Pries, 2014). The same applies to Western Europe and the USA (Allan, 2005; Brown and Humphrey, 2005). Assets reaching the end of their useful life tend to need more intensive maintenance, and modernization or life extension may be worthwhile. On the other hand, timely disposal may be necessary to prevent excessive costs, or risks for health, safety, and the environment (Rouse and Chiu, 2009; Jongen, 2012). Additionally, these ageing assets often have to fulfil different functions from those they were originally designed for, often decades ago. The assets have to comply with new regulations, satisfy changing market demands, and may be needed to produce higher quantities than anticipated (Al-Turki, 2011).

It is in this complex context that the asset manager operates. The management of ageing assets in a changeable context asks for strategic decisions, next to the daily work of maintenance and tactical planning. Strategic decisions directly impact corporate objectives, by asking questions such as: “How long can the operation of asset X be continued?” “What modifications need to be made to asset Y at the next overhaul?” “How can we convince management that the purchase of asset Z is worthwhile, even though its price is higher than all other alternatives?” “How can we keep the operation and maintenance of the assets aligned with changing corporate objectives?” “What external developments may have an effect on the business value created with the operation of the assets?”

Such a strategic focus on the complete life cycle of the asset is also required by recent Asset Management standards such as PAS 55 (Institute of Asset Management and British Standards Institution, 2008) and ISO 55000 (ISO, 2014). These require a life cycle approach. However, these standards do not provide much guidance as to how such a life cycle approach should be implemented. The same applies to well-known maintenance concepts, such as Reliability Centred Maintenance (RCM), which focus primarily on the short-term (Coetzee, 1999; Murthy et al., 2002). In other words: there are many strategic Asset Management decisions to be made, but there is very little guidance available for asset managers that need to take these decisions. Therefore, the aim of this chapter is to present a tool to assist strategic decision-making in Asset Management.

6.1.1 Outline

The next section (6.2) will present a theoretical background on Asset Management. It will conclude that Asset Management should be a strategic and multidisciplinary practice, fo-

cusing on the complete lifetime of an asset. Such an approach to Asset Management will be termed “Asset Life Cycle Management” (ALCM). Current maintenance approaches often limit themselves to a focus on the short-term and do not adopt a multidisciplinary approach. These approaches do not address changes in the environment in which the asset operates, changes in regulation, or new corporate objectives. To address these limitations, the concept of ‘lifetime impacts’ will be introduced in the next section (6.3). These lifetime impacts are a key ingredient for an Asset Life Cycle Plan (ALCP), which is a tool developed to support strategic decision-making in Asset Management. An ALCP does so by presenting a holistic view of the current and expected performance, costs of the assets, and main challenges that may affect the performance over the lifetime (section 6.4). Section 6.5 presents an extensive and practical twelve-step approach to develop such an ALCP, illustrated with an ALCP on distribution transformers from a Dutch network operator. The chapter concludes that the ALCP aids asset managers in making strategic decisions in a timely and effective manner (section 6.6). In the last sections (6.7 and 6.8), the implications for further research and for practitioners will be presented.

6.2 Background on Asset Management

Before the presentation of the tool that assists strategic decision-making in Asset Management, it may be worthwhile to investigate the concept of Asset Management in some more detail. Pudney (2010) proposes an elaborate definition of Asset Management, based on a study of Asset Management literature. He defines Asset Management 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” (Pudney, 2010, p. 8). From this definition, five characteristics of Asset Management stand out. Asset Management (AM):

1. is a multidisciplinary practice,
2. takes the whole life cycle of a physical asset into account,
3. achieves certain objectives,
4. considers the limits of risk and relevant regimes, and
5. determines the allocation of resources (Ruitenburt et al., 2015).

Each of these five characteristics will be discussed in more detail.

Management is a multidisciplinary practice

Many different disciplines should be combined in Asset Management. This applies to technical disciplines such as engineering and maintenance. Additionally, a financial perspective on the assets should be included in Asset Management. However, there are addi-

tional disciplines that play a crucial role, such as data collection and analysis, planning and scheduling, operational excellence, rules and regulation, IT, human resources, and innovation (Smit, 2014). To create maximum value from the exploitation of an asset, all these disciplines may play a role. One should understand degradation processes that deteriorate the condition of the asset. One should know what maintenance actions may be performed to counter this deterioration. Based on the costs of the possible interventions, a choice has to be made for the most cost-effective solution. This intervention should comply with existing regulations and fit with the capabilities of the engineers and operators employed by the company. The innovation department may have sought out new technologies that can be implemented while making the intervention. The implementation of the intervention needs to be scheduled, taking the production planning into account to ensure a good fit with the ongoing operations.

In spite of the importance of the involvement of many disciplines in Asset Management, Haffejee and Brent (2008) conclude that “the economic, environmental, social and technical dimensions of Asset Management are not explicitly depicted.” Rather, approaches are often limited to the technical aspects of the asset (Garg and Deshmukh, 2006; Frangopol et al., 2012), or focus mainly on the financial performance of the asset (Asiedu and Gu, 1998; Márquez et al., 2012). To conclude, multidisciplinary approaches to Asset Management are scarce.

Asset Management takes the complete life cycle of the asset into account

Asset Management should consider the asset’s complete life cycle. Different reasons for this are given in the literature. One of these is that most of the life cycle costs are already fixed in the design of the asset, hence, it is important to take the complete life cycle of the asset into account from the moment of design onwards (Schuman and Brent, 2005; van Dongen, 2011a). In the design, a large part of the future performance of an asset is already fixed. One may be able to change the asset’s throughput, operation speed, or safety during its service life, but often at considerably larger costs than if it had been part of the original design. Van Dongen (van Dongen, 2011a) illustrates this with a figure (refer to A second reason to consider the complete life cycle of the asset is the increasing market turbulence in many sectors. This requires the asset manager to take the right strategic decisions to make sure the asset will remain valuable to the company even in a changed market (Komonen et al., 2012). Additionally, many external developments (e.g. new regulations) may have an impact on the asset (Al-Turki, 2011) and should be taken into account as early as possible in the asset’s life. However, the same authors stressing the importance of considering the asset’s complete life cycle also state that a focus on the complete life cycle is often lacking. This also applies to well-known Asset Management methods, such as Reliability Centred Maintenance (RCM), which is considered to focus primarily on the short-term (Coetzee, 1999; Murthy et al., 2002).

Figure 6.2.1). The figure shows the influence the asset manager may exert over the performance of an asset during its life cycle, in this case the life cycle of a train. Future performance requirements should be considered as early as possible, to prevent unnecessary high refurbishment costs later in the asset's life. In other words, the complete life cycle of the asset should be taken into account.

A second reason to consider the complete life cycle of the asset is the increasing market turbulence in many sectors. This requires the asset manager to take the right strategic decisions to make sure the asset will remain valuable to the company even in a changed market (Komonen et al., 2012). Additionally, many external developments (e.g. new regulations) may have an impact on the asset (Al-Turki, 2011) and should be taken into account as early as possible in the asset's life. However, the same authors stressing the importance of considering the asset's complete life cycle also state that a focus on the complete life cycle is often lacking. This also applies to well-known Asset Management methods, such as Reliability Centred Maintenance (RCM), which is considered to focus primarily on the short-term (Coetzee, 1999; Murthy et al., 2002).

Figure 6.2.1 - Overview of a typical life cycle at the Netherlands Railways (van Dongen, 2011a)

Asset Management aims to achieve specific objectives

The third characteristic of Asset Management shows that Asset Management aims to reach certain objectives. These objectives should relate to the objectives of the asset owner and thus ultimately to the corporate strategy. The asset is not valuable to the company in its own right (apart from its potential resale or scrap value), but only if the asset fulfils a function that fits the strategic goals of the company, goals that may change over time. Combining this with the previous characteristic shows that the management of assets should not be considered a stand-alone process carried out in a vacuum. Rather, the

operation and maintenance of assets should continuously be aligned to changes in corporate objectives and the operating environment (Komonen et al., 2012).

The importance of Asset Management with respect to the corporate goals is also shown by the PAS 55 definition of Asset Management: Asset Management consists of “systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan” (Institute of Asset Management and British Standards Institution, 2008, p. 2). This definition shows that Asset Management is inextricably connected to the achievement of the ‘organizational strategic plan’ and therefore the corporate strategy. As assets are necessary means to reach the corporate objectives, the management of these assets is of a strategic concern to a company. For example, the assets used by a chemical company facilitate the chemical processes that create the added value for the company. For a utility company, the infrastructure assets allow the company to deliver electricity, gas or water to its customers. For an airline, the aircraft are indispensable to transport travellers to destinations all over the world. To summarize, as companies are highly dependent on the assets they operate to achieve their corporate objectives, the strategic aspects of maintenance and Asset Management should be emphasized. However, the connection between Asset Management and the corporate strategy is often lacking (Komonen et al., 2012).

Asset Management considers the relevant risks and regimes

Asset Management should take relevant risks and regimes into account. Risks can be failures or safety risks, the type of risks most maintenance methods focus on (e.g. RCM or Condition Based Maintenance (CBM)). However, risks may also be related to topics as diverse as production errors, reputation, sustainability, or cyber security. Asset Management should also consider regimes, which relate to the external developments mentioned earlier: new regulations, changes in the labour market, social pressure to increase sustainability, or a lobby to improve working conditions.

The concept of risks emphasizes the inherent uncertainty in Asset Management. Asset Management should consider the asset’s complete life cycle, but our knowledge of the future is incomplete by definition. Additionally, often only limited information on the asset is available, and – as Asset Management is a multidisciplinary practice – this information may be dispersed over different people, departments, and software systems. Also, the quality of data (e.g. failure data or condition data) may be unreliable (Braaksma, 2012). Nevertheless, decisions have to be made about the assets and the allocation of resources.

Asset Management determines the allocation of resources

Ultimately, Asset Management is all about the allocation of resources. Where should money be invested? Where may a reduction of working hours be achieved? What maintenance tasks are necessary, and which may be postponed? Which activities do we do our-

selves, and which can be carried out by service providers in a more cost effective way? The allocation of resources applies to both the daily operations (e.g. production schedules, spare part availability), as well as the strategic management of the assets (e.g. the budget reserved for an overhaul or the purchase of a new asset). Many methods and tools exist that may be used to effectively allocate resources, especially for operational and tactical planning. The field of maintenance management addresses these topics (for to good reviews of this topic, refer to Frangopol et al. (2012) and Garg and Deshmukh (2006)).

Asset Life Cycle Management (ALCM)

To conclude, Asset Management should be a multidisciplinary practice focusing on the achievement of changeable corporate objectives over the complete life cycle of the asset, taking into account the relevant external developments and risks. Such a strategic, multi-disciplinary, and long-term approach to Asset Management will be termed Asset Life Cycle Management (ALCM) in the remainder of this chapter.

6.3 Lifetime Impacts

Asset Management ultimately focuses on the realization of business value from the use of physical assets over their complete lifetime. For the short-term, maintenance concepts such as Reliability Centred Maintenance (Moubray, 1997; Smith and Hinchcliffe, 2003), Total Productive Maintenance (Wireman, 2004) and many others exist (Waeyenbergh and Pintelon, 2002). These often produce an overview of maintenance tasks to be carried out in a certain time period, tasks that may be repeated over and over again. Additionally, there are many tools available to continuously improve asset performance, such as Pareto analysis or root cause analysis (e.g. Ishikawa diagrams) (for an overview, see Zaal, 2013). Looking at the remainder of the asset's life, many approaches exist that focus on the estimation of the remaining useful life (RUL) of the asset (e.g. Si et al., 2011). These tools aim to estimate the point in time when the asset will cease to perform its function because of technical failures, for example after a specified amount of operation hours.

Maintenance concepts and RUL estimation cover the short-term and the end of the asset's life. However, what is lacking is a method that covers the period in between, a method that assists the asset manager to ensure the asset's value for the company in a changeable context (see Figure 6.3.1). After all, repeating the same maintenance tasks during the asset's lifetime may overlook changes internal or external to the company that may impact the asset. These changes may present opportunities or threats with an impact on the realization of value from the use of the asset. Therefore, these should be taken into account to ensure a maximum contribution of the asset to the business. Additionally, both the maintenance concepts and RUL estimation primarily take a technical perspective on the asset, rather than the multidisciplinary approach that is important in Asset Management.

To fill this gap in the asset's life cycle, the authors have proposed the concept of “lifetime impacts” in earlier publications (Ruitenburt et al., 2014a; Ruitenburt and Braaksma, 2017b). Lifetime impacts can be defined as: “probable (technical and non-technical) events or trends that may have a positive or negative influence on the value creation with the asset in the intermediate or long term” (Ruitenburt and Braaksma, 2017b, p. 56).

Figure 6.3.1 - The gap in Asset Management between maintenance concepts—covering the short-term and sometimes repeated periodically—and the outcome of RUL estimations giving the expected end-of-life of the asset

The concept of lifetime impacts is explained most easily using an analogy of the Titanic. For a moment, imagine yourself as the asset manager responsible for the safe and reliable operation of the Titanic. From a pure maintenance perspective, you might carry out a sophisticated FMEA-analysis to create a maintenance program to keep this massive, valuable ship in optimum condition. Additionally, an RUL-estimation could give an idea of the projected end-of-life moment of the vessel, based on assumptions on operation hours, operation conditions, and knowledge of degradation mechanisms. However, it is well-known that neither the maintenance program nor the RUL-estimations would have prevented the Titanic from sinking. It was an iceberg that had been overlooked that brought this massive, high-tech asset to a premature end, resulting in massive financial and reputational losses, not to mention the human tragedies caused by this event.

One of the many intriguing stories surrounding the Titanic disaster is about the lookout in the crow's nest (Salkeld, 2007). It is told that he did not have the key to open the locker with the binoculars. In the official inquiry, the lookout was asked about the consequences of the lack of binoculars. He stated that, with binoculars, “we could have seen it [the iceberg] a bit sooner.” When asked, “how much sooner,” he replied, “well, enough to get out of the way”.

Figure 6.3.2 - Lifetime impacts¹⁵

¹⁵ The picture of the Titanic is created by Boris Lux, available at Wikipedia (Wikipedia, 2015).

Just as a single iceberg sunk the Titanic, there are many proverbial icebergs that may impact the creation of business value with an asset (see Figure 6.3.2), for example, a large increase in the costs of spare parts, or the ban of a certain toxic substance used in the asset. Only by a timely identification of such icebergs, timely measures can be taken to circumvent them. Knowing the remaining useful lifetime will only become relevant if the asset does not find a premature end-of-life due to the consequences of a lifetime impact. To give an example, a plant in the process industry only produces business value as long as it complies with regulations on safety, emissions, hazardous materials, etcetera. If a change in regulation, which would be a lifetime impact, makes the operation of the plant illegal, the plant may need to be shut down. In such a case, the plant will be worthless to the asset owner, irrespective of its technical condition and remaining useful life.

6.3.1 Five perspectives

As ALCM is a multidisciplinary practice, the lifetime impacts that are relevant for an ALCP should be multidisciplinary as well. Based on an industry project with Dutch asset owners by Rob van Dongen (2011c) and a first application of the concept of lifetime impacts in practice (Ruitenburg and Braaksma, 2017a, 2017b), five different perspectives have been identified. Using the Titanic analogy, there are five different types of binoculars to look into the future in order to identify the relevant opportunities and threats:

1. **Technical perspective:** technical lifetime impacts concern the ability of the asset to comply with the technical specifications set regarding its technical condition and performance. Reliability, availability, production quality, remaining useful lifetimes, and bathtub curves are all related to this perspective;
2. **Economic perspective:** the economic perspective is concerned with the financial aspects of the asset and its operation. Does the asset still deliver financial value to its user or owner? Maintenance costs, operating costs, costs of spare parts, life cycle costing, and total cost of ownership are relevant concepts here;
3. **Compliance perspective:** the compliance perspectives asks if the company is still allowed to operate the asset. This perspective looks at all kinds of regulation (e.g. safety, environmental, worker conditions, or hazardous materials). Additionally, the social acceptance of the asset and its operation is relevant here, as a decreasing acceptance may precede official regulation;
4. **Commercial perspective:** the commercial perspective looks at the extent to which the asset still fulfil the demands of the market. An asset producing discmans or mp3-players may be in great condition from a technical perspective, but it probably no longer fulfils the demands of the market;

5. **Organizational perspective:** finally, the organizational perspective concerns the ability and willingness of the company to operate the asset. There may be a lack of specialized knowledge, limiting the ability of the company to maintain the asset in the desired condition. Or, the organization may aim for an increased standardization of its assets. This may make certain asset types redundant for the company, even though from the other perspectives there may be no reason to decommission these assets.

These five perspectives, abbreviated to TECCO, together give a multidisciplinary insight in the main lifetime impacts regarding the future of the asset. The perspectives are not intended to be mutually exclusive. For example, an incentive towards a more sustainable operation of the assets may come from social pressure (Compliance) or from higher management (Organizational). Or, a certain degradation mechanism (Technical) may result in higher maintenance costs (Economic). Using these five perspectives to look into the future will help the asset manager identify a wide variety of lifetime impacts for the asset.

6.4 Asset Life Cycle Plans

The identification of lifetime impacts is a crucial step to ensure continuous value creation with an asset over its complete lifetime. However, knowing these impacts in itself does not necessarily result in the desired performance of the asset, nor in an alignment of the operation with the asset with the corporate objectives. Therefore, in response to the required “life cycle approach” by ISO 55000, this paper proposes the concept of the Asset Life Cycle Plan (ALCP). In their earlier research, the authors carried out a case study on Asset Life Cycle Management (ALCM) using these ALCPs at a rolling-stock maintenance company (Ruitenburg et al., 2015). In this company, the ALCP was used as a means to align corporate objectives with the management of trains, as well as to communicate the expected performance and the associated costs of the train to the relevant stakeholders (idem). In this way, the ALCP can be a means to assist ALCM practices in a company and to support strategic Asset Management decisions.

Figure 6.4.1 - The structure of the ALCP

Figure 6.4.1 shows the main structure of the ALCP. This structure has been developed based on the means-end analysis (Holmström et al., 2009), the Pyramid Principle for structuring texts (Minto, 2008), and the ALCPs in the case study on ALCM carried out by the authors (Ruitenburg et al., 2015).

The ALCP starts with the strategic objectives the company has for the assets. These are compared with the current and expected performance and costs of the asset. In case the performance does not comply with the objectives, interventions may be needed to bring the performance in accordance with the goals. Lifetime impacts may have an impact on either the strategic objectives (e.g. goals for the reduction of CO2 emissions), or the asset's future performance and costs (e.g. higher costs due to higher spare part prices). In the ALCP the main focus lies on the value realized from the exploitation of the asset. This involves the continuous alignment of the asset's performance with the corporate objectives in a changeable context.

This general structure was translated into the following chapter structure for an ALCP:

0. **Management summary:** states the main message of the ALCP, aiming at higher management. This should answer the question, “what needs to be done to keep the asset (population) valuable to the company on the long term?”
1. **Introduction:** gives a brief introduction to the ALCP, including its purpose, aim, the scope of the ALCP and an outline of the document.
2. **Strategic objectives and function:** lists the main corporate goals relevant for the asset, as well as the main strategic developments and decisions that are relevant, for example, the aim to enter new markets. Additionally, it states how the asset contributes to these goals.
3. **Current situation and performance:** gives an overview of the main characteristics of the asset (population), including its age, main components, replacement value, and a brief summary of the current maintenance policies. It lists the current performance of the asset, related to the strategic objectives and goals relevant for the asset. As ALCM is a multidisciplinary practice, the performance should be measured from different perspectives as well, for example, production output, availability, reliability, maintenance costs and safety.
4. **Lifetime impacts:** this chapter lists the main lifetime impacts that impact the value the asset will have for the company in the future. Lifetime impacts are listed for all five TECCO perspectives. Attention is paid to both positive as well as negative lifetime impacts.
5. **Expected performance and costs:** based on the current performance and the impact of the lifetime impacts identified, the expected performance on the asset ob-

jectives is presented, as well as the costs of the asset. This may be by means of KPIs or other quantitative measures, but can be qualitative descriptions as well.

6. **Life cycle management:** this chapter recommends actions to be taken to keep the asset valuable to the company. This may include additional maintenance, design changes, overhauls, modernization projects, preventive replacement, and actions to collect information needed to manage the asset more effectively in the future.
7. **List of actions:** gives an overview of the main actions resulting from the ALCP, including projected start and end dates and the responsible person or department.

6.5 Writing an ALCP – step by step instructions

Writing an ALCP is not just a matter of writing a number of chapters according to a specific structure. It is not so much the structure that is important, but rather the process of creating an ALCP. One of the main challenges of writing an ALCP is to bring all the relevant knowledge, information, and expertise on the asset together in one document. Many companies are used to organize the disciplines relevant for Asset Management in separate functional silos. Hence information is often scattered over different databases (e.g. failure data vs. maintenance budgets vs. outsourced maintenance), departments (e.g. regulation vs. operations vs. financial vs. purchasing) and documents (e.g. maintenance manuals vs. market trend reports vs. company strategies). Additionally, certain pieces of information may not be available in explicit form, but are rather stored in the heads of people.

Figure 6.5.1 - The twelve steps towards the ALCP, including its relation to the ALCP document. The three deliverables in the process are indicated in bold.

To structure this process, a twelve-step approach has been designed. The twelve steps are based on the Lifetime Impact Identification Analysis (LIIA) method, as presented in an ear-

lier publication by the authors (Ruitenburg et al., 2014a; Ruitenburg and Braaksma, 2017b), as well on the experience of the first author with the writing of ALCPs.

The twelve steps can be used as a guide to develop an ALCP. Some of the steps may be carried out in tandem, but the order of the steps has been designed in such a way that each step produces the preconditions for the next steps (see Figure 6.5.1 for an overview of all twelve steps and their relation with the ALCP).

The description here is aimed primarily at the person responsible for the creation of the ALCP. Oftentimes this will be the asset manager, writing the ALCP for the asset(s) he is responsible for. Not only should the asset manager take the lead over writing the ALCP, he should also act as a director of the execution of the twelve steps that will be presented.

To illustrate the twelve steps, a case is presented from Liander, a Dutch network operator applying ALCPs in their Asset Life Cycle Management practices.

Illustration: ALCPs at Liander

Liander is the largest Dutch network operator, responsible for the safe and reliable distribution of electricity and gas to its 3.1 million customers. As shown earlier, the ageing of assets is a well-known issue in Western Europe. Liander experiences the same problem, as large parts of its networks have been constructed in the 1960s and 1970s. As many of the assets in the network have expected lifetimes between 40 and 60 years, large-scale replacement may be needed in the years to come. The current changes in the production and use of energy—often called the energy transition—offer an additional challenge. Distributed electricity production, for example by means of solar and wind power, is on the rise, while new applications such as electric vehicles may cause a large increase in demand. This results in new demands on the existing electricity grid. To support the strategic decisions Liander has to make, the Asset Management department has decided to start working with ALCPs.

One of the ALCPs that has been written covers the distribution transformers Liander operates. Its main question was, “Is there reason to expect a large increase in the replacement rate of the distribution transformers?” As the population of distribution transformers consists of 28,000 assets with a replacement value of 200 million euros, this clearly is a strategic topic. The twelve steps will be illustrated using both the process of developing this ALCP as well as the structure of the final document. The goal is not to show every detail of the ALCP, but rather to give the reader an idea of the scope and logic of such a document. For reasons of confidentiality, the numbers as well as some of the life-time impacts presented in this example are fictive.

Step 1: Asset selection

The first step is the selection of the asset (population) as the topic of the ALCP. This may seem obvious, but it requires some thought. Depending on the availability of information and the depth of the analysis, the whole process of writing an ALCP may take one fully employed asset manager a couple of weeks of work. Therefore, only those assets should be selected that deserve such an investment of time, for example, assets with questionable performance or assets on the verge of an important life cycle event, like a modernization or overhaul, or maybe assets with a high criticality for the company or those representing a very large financial value. Additionally, a very dynamic environment may increase the desire for an ALCP, to investigate the consequences for the asset.

Additionally, the level of detail of the analysis has to be determined. What are the system boundaries that will limit the analysis? And will the analysis cover the asset as a whole, or will it rather take the main functional components as the object of analysis? When a population of similar assets is taken as the subject, scoping decisions have to be made. What assets are similar enough to be treated as one population, and which are too different? It is important to reason from the function of the asset and the value it produces rather than the technical characteristics. Some assets may be different from a technical point of view, but can be treated as similar in an ALCP as they have the same function and need to fulfil the same objectives. Certainly, when differences between subpopulations are relevant, these should be reported, but only if necessary for the main message of the ALCP.

Step 2: Determination of objectives, target audience and preliminary planning

Now that the topic for the ALCP has been chosen, the main objective of the ALCP has to be determined. What questions does the ALCP have to answer, and what needs need to be satisfied? This clearly relates to the target audience of the document. This may be higher management, or the asset manager for whom the ALCP can be a working document and a way to set the right priorities. Depending on the target audience, a short and preliminary answer to the main question(s) of the target group can be given. This may help the writer(s) of the document set the right focus for the document. Such a core message may be, “on the short-term, the asset performs well, but due to changing market conditions a business case should be made to determine if the life of the asset should be extended.”

Next to the content of the ALCP, the target audience may have special requirements for the presentation of the ALCP, for example, format, lay-out, length, or use of data. These requirements should be made clear at this stage already, to prevent potential rework later in the process. In the remainder of these steps, the target audience and the company at large will not be discussed again. However, this is clearly important to effectively meet the demands of the target audience.

Additionally, this is the moment to set preliminary planning. Many inputs are needed from other departments and people, and these dependencies should be managed to make the process of writing an ALCP as efficient as possible. Depending on the organization and the availability of information within the organization, the collection of information from different departments may take several weeks to months.

Step 3: Data collection

Now that the goal of the ALCP has been set, the time has come to collect all the information that is needed to answer the main question(s) of the target audience. The information should cover at least three different topics:

1. **The corporate objectives relevant for the asset:** what are the business values the asset should contribute to (e.g. safety, reliability, costs, and customer satisfaction)? What strategic decisions have been made that are relevant for the asset? An example would be the decision to enter new markets to increase quality or quantity of production, or maybe to become a front-runner in sustainability. These objectives set the stage for the remainder of the ALCP. The asset is only valuable insofar as it contributes to these objectives. Therefore, it is of crucial importance to align the management of the asset with these goals.
Next, these (often relatively broad and intangible) objectives should be translated to specific goals for the asset. What does the asset have to achieve? This can be done by means of KPIs or other quantitative measures. Alternatively, this can be qualitative descriptions of performance, such as a continuation of the contract with the main customers or a happy workforce. However, it may still be advisable to make these objectives measurable in some way, as this will make it easier to determine if a goal has been reached.
2. **Static asset data:** the asset should be described in a way that gives the target audience a better background on the asset. As the ALCP may be used in departments not directly involved with Asset Management, for example in the strategy department or the purchasing department, some of the most important facts and figures may be needed, at least function, age, (replacement) value, population size, projected date of decommission (if any), and a brief overview of the current maintenance policy.
3. **Dynamic asset performance data:** next to the static data, the current performance of the asset should be reported, related to the objectives relevant for the asset. The performance should be reported in a multidisciplinary way, covering, for example, the five TECCO perspectives. At least the production output of the asset, its reliability/availability, safety, and cost performance should be covered. Ideally, the

performance should be given over a period of time (e.g. the previous five years), to give an indication of the trends visible in the performance. This will also allow a better prognosis of future performance.

It is important to note that this information will probably not be available within one department, hence there is a need to cooperate with the relevant people to bring all the information together. This may very well cross functional boundaries within, and maybe even across, the organization. While this may be a cumbersome and time-consuming process, it is crucial in order to establish a multidisciplinary Asset Management. Additionally, it is a way to bring the relevant stakeholders together and to get them involved in the process of writing an ALCP. As a result, the ALCP can be positioned as a “shared understanding” of the performance of the asset and its future.

Additionally, one should realize that—especially when writing the first ALCP—not all relevant information may be available for the ALCP. This is an excellent opportunity to identify the relevant information gaps (see also Haffejee and Brent, 2008) and to discuss which information may be necessary for an effective management of the assets. Depending on the costs of collecting this information, new information may be collected for a future ALCP.

Step 4: Writing the first chapters of the ALCP (chapters 1-3)

With the work done thus far, the first three chapters of the ALCP can be written. The reason to start writing the ALCP is threefold: 1. It can serve as a first tangible milestone in the process of crafting an ALCP, 2. It allows a first discussion with the stakeholders on this fundamental part of the ALCP, and 3. It is an important input for the next steps, where the main lifetime impacts relevant for the asset will be identified using one or more expert sessions.

Illustration: the first three chapters of the ALCP on distribution transformers

Chapter 1: Introduction

This ALCP describes the future of the population of distribution transformers for the coming 20 years. The main question it will answer is, “Is there reason to expect a large increase in the replacement rate of the distribution transformers?” The scope of this ALCP is limited to the 28,000 distribution transformers in the grid. The large majority of these assets transforms electricity from medium voltage (10 kV) to low voltage (400 V). Figure 6.5.2 shows a picture of a distribution transformer.

Figure 6.5.2 - A distribution transformer. In the interior the medium and low voltage coils are visible.

Chapter 2: Strategic objective and function

Liander aims to create maximum business value from the exploitation of its assets by achieving the required performance (i.e. availability, reliability, safety) at minimum costs, at an acceptable risk. The performance on each of the relevant KPIs should minimally remain constant in the next 5 years of operation.

The main strategic developments relevant to the distribution transformers are energy transition and sustainability. The energy transition may cause temporal reversals of the electricity flow in residential areas with a high number of photovoltaic power cells or wind turbine generators. As this is a new phenomenon, it is yet unknown if this will negatively influence the remaining service life of the asset. The corporate ambitions on sustainability aim for a strong reduction in CO₂ emissions. As distribution transformers cause a significant part of the current CO₂ emissions through the energy losses inherent to the transformation process, the sustainability ambition may have implications for the distribution transformers. Additionally, Liander has decided to apply 20 kV on its medium voltage grids. This transition may take decades, but irrespective of its planning, which is currently unknown, the management of the distribution transformers should be aligned to its implementation, as the 10 kV transformers will be obsolete in a 20 kV grid.

Box continues on the next page.

Chapter 3: Current situation and performance

Figure 6.5.3 shows the age of the distribution transformers of Liander (28,000 in total). The average age is 30 years, compared to an expected life of at least 40 years. Based on the current experience, this may be an underestimation of the life expectancy, experts agree this lies around 60 years. Currently, every year 600 transformers are replaced, based on capacity (quality of the transformers is not yet a reason for preventive replacement). A preventive maintenance policy based on periodic inspections is used.

Figure 6.5.3 - Example of age distribution of distribution transformers (based on fictive numbers).

The current performance of the population is good. The reliability of the transformers is very high (99.98% reliability). Their contribution to the yearly outage per customer is less than 1%. Regarding safety, no incidents have been reported regarding the distribution transformers. From a sustainability point of view, the energy losses of the transformers are substantially higher for older transformers.

Step 5: Preparation for the LIIA expert session¹⁶

As stated before, it is crucial in Asset Management to look ahead and to notice proverbial icebergs in the future. The identification of these lifetime impacts will be done in step 6 by means of an expert session. The current step prepares for this session. The preparation consists of content-related and practical preparation.

Content-related preparation

The main goal of content-related preparation is to collect the relevant information to identify the lifetime impacts. A large part of this information has already been collected in step 3 and has been reported in step 4. But there is some additional information that may be relevant, as the information from step 3 and 4 predominantly describes the current and past situation, while lifetime impacts relate to the future. Therefore, information should be collected regarding the future of the asset. This may be scenarios of market developments, analyses of failure data (e.g. bathtub curves), remaining useful life estimations of components (RUL), cost prognoses, or lists of upcoming changes in regulation. It may be useful to think about the information that may be available within the company on future developments the five TECCO perspectives. The goal is not so much to get a full overview of every bit of information within the company, but to facilitate an efficient and effective expert session. There is a trade-off to be made here: more time spent on the preparation of the expert session will reduce the time needed to be spent in the session.

Practical preparation

Practical preparation mainly concerns the organization of the expert session(s). This starts with the selection of the experts to be invited. It is advisable to invite experts from the five different TECCO perspectives, and to keep the group size limited to between 4 and 8 persons. As many experts have to be able to join the meeting, setting a date for the meeting should be done several weeks in advance. Additionally, the goal of the meeting should be explained as well as the uses of an ALCP. Some of the experts may have already been involved by providing information in step 3; others may be new to the concept of an ALCP. Some may even have little knowledge of the asset (e.g. a financial or regulation expert). Especially for these experts, a level playing field should be created to allow them to join the discussion in the expert session. This can be achieved by distributing the first chapters of the ALCP, as written in step 4. The experts may be asked to prepare themselves for the meeting, for example, by preparing a short statement to kick-start the discussion on the TECCO perspective they represent.

¹⁶ Earlier work of the author (Ruitenbunrg et al., 2014a; Ruitenbunrg and Braaksma, 2017b) has introduced the Lifetime Impact Identification Analysis (LIIA), a method consisting of several steps. The twelve steps as presented in this chapter include and extend the steps of the LIIA.

Other than the experts, it is important to think of two other roles to be fulfilled. The first is the chair or facilitator of the expert session. This person should guide the expert session, keep the discussions focused, keep track of the time, and may need to bring in relevant questions that are overlooked in the session. These may, for example, be topics that were raised in the content-related preparation. It is recommended to prepare a list of topics that need to be discussed for the facilitator. Additionally, the facilitator should make sure that sufficient attention is paid to both positive and negative lifetime impacts. It is not necessary that the facilitator is an expert on the asset, but rather that the facilitator has the right chairman skills to keep the discussion efficient. The second role is the secretary or note-taker, who is not involved in the discussion, but rather records the discussion. Furthermore, the structure of the session should be prepared. This may include a time schedule and a presentation that guides the process and gives the necessary information inputs and a background on ALCM and lifetime impacts.

Step 6: the Lifetime impact identification expert session

The expert session lies at the heart of the process to write an ALCP. In the expert session, experts are brought together to share their knowledge and expertise. This resembles the expert sessions as used in the Failure Mode and Effect Analysis (FMEA) to develop maintenance plans in RCM (Moubray, 1997). Regarding the ALCP, the expert session is the means by which all the information collected in the previous steps is processed, combined, enriched with the tacit knowledge of the experts, and put to use in the identification of lifetime impacts. This section will present the main parts of the expert session. Additionally, two important topics related to the expert session—time and uncertainty—will be discussed at the end of the section.

Introduction

The expert session starts with an introduction. In the introduction, the experts may briefly introduce themselves, as some may be from very different departments. Additionally, the ALCP, lifetime impacts and the different TECCO perspectives are explained, for example using the Titanic analogy.

Evaluation of the current maintenance program

After the introduction, the expert session proceeds with an analysis of the current maintenance program, as some lifetime impacts may be hidden in the current maintenance program. For example, the maintenance program may prescribe certain maintenance actions that are not carried out in practice, or the work quality may be poor. Alternatively, a critical evaluation of the current maintenance policy may reveal opportunities for improvement, for example by adopting new innovative techniques or by lengthening the maintenance intervals. After a critical discussion of the current maintenance program

and its execution, the current maintenance program will be out of scope for the remainder of the expert session.

The identification of lifetime impacts

After this evaluation, the time has come to look into the future and to identify the relevant lifetime impacts. This is done by means of the five TECCO perspectives, which are used as binoculars to look into the future from a certain perspective. Each perspective is discussed separately, to ensure that explicit attention is paid to each of the perspectives. The goal is to identify the main lifetime impacts for each perspective, negative as well as positive. The discussion begins with an introductory statement from the expert representing the relevant TECCO perspective. Then, the other experts may react on this statement, while the facilitator facilitates the discussion in order to get a good overview of all the relevant positive and negative lifetime impacts. The focus should especially be on the likelihood of the impact, its effect, and the certainty of the expert(s) on the impact. The amount of discussion on a lifetime impact may be a useful indicator for the level of certainty: the more disagreement among the experts, the lower the certainty.

Each discussion ends with a brief summary by the facilitator or the note-taker, to verify that the most important impacts have been identified. This may trigger additional discussion, as it may take a moment to realize that something important has not yet been discussed.

If there are specific future scenarios available within the company (e.g. describing different demands from the market), these may be used as well to elicit additional lifetime impacts. In this case, after the discussion of the TECCO perspectives, each scenario is discussed separately. Some scenarios may give rise to additional lifetime impacts, while others may make certain lifetime impacts that were already identified more important while reducing the importance of others. Additionally, one may make use of brainstorm techniques to elicit the lifetime impacts. For example, the expert session may start off with a brainstorm using sticky notes, where each expert can individually write down the lifetime impacts considered relevant.

Closure

At the end of the session—with an advised length of no longer than four hours, including one or two breaks—the session is closed. The closure should at least include an outlook on the remainder of the process. If a second expert session is needed, this can already be told and even planned. Also, the next steps in the process should be explained, including the possibility to give feedback on the Lifetime Impact Report (see step 8).

Two notes on the topics of time and uncertainty

The expert session may raise an important topic: the time horizon used in the identification of lifetime impacts. Are all lifetime impacts relevant, or does one limit the discussion

to impacts within a certain timeframe (e.g. five or ten years)? This highly depends on the needs of the target audience of the ALCP: do they want an overview of the lifetime impacts to expect during the next five years, or rather of all impacts to expect during the assets remaining life? Either way, it may be advisable to pay at least some attention to the complete life cycle of the asset. Some high-impact lifetime impacts may have an influence on interventions that will be taken on the shorter term. For example, in a modification of the asset, future changes in regulation should be taken into account. Additionally, the time horizon may depend on the flexibility of the organization compared to the changeability of its context. If the context is highly changeable while the organization needs much time to adapt the asset or its operation to these new circumstances, there may be a need to look further into the future, and in more detail. If the organization is very flexible and the context is stable, the time horizon for a detailed analysis may be shorter. Irrespective of the time horizon chosen, the facilitator needs to ensure that the discussion does really cover the complete time horizon, rather than just covering the lifetime impacts nearby. Additionally, the topic of uncertainty may require some attention here. Some lifetime impacts are known to happen in the future (e.g. if a supplier has announced to stop the production of spare parts), others are uncertain (e.g. changing regulations). Of some, the effect on the assets performance may be clear; for others, this is entirely unsure. It may be advisable to elicit all reasonably likely lifetime impacts. However, it may not be necessary to think of suitable interventions for all of these, as some may not be worth the effort. Additionally, the interventions may depend on the certainty of the lifetime impact: those that are certain may need direct action, while those that are uncertain may rather need to be monitored or to be studied in more detail.

Step 7: Writing the Lifetime Impact Report (LIR)

A second important deliverable in the process is the Lifetime Impact Report (LIR). The LIR lists all the lifetime impacts identified during the expert session. Additionally, it relates these to the performance of the asset. This gives a first idea of the future performance to be expected from the asset. Some impacts may, for example, only relate to the maintenance costs of the asset (e.g. higher price of spare parts), while others may relate to many performance measures (e.g. technical degradation of a specific component may result in downtime, lower reliability, and safety risks). Additionally, some lifetime impacts may be very hard to directly relate to the performance, but may be very important to register, for example, the realization that it becomes harder to find skilled technicians, which on the long term may reduce the maintenance capacity of the organization.

It is important to list all of these lifetime impacts, including the less likely or seemingly unimportant ones. These may not all find their way into the final ALCP, as the effect of some impacts on the value creation with the asset may be negligible. However, the asset manager may want to monitor these, by revisiting the list periodically, to see if new devel-

opments make one of these more important. In this way, the LIR can be viewed as a priority list for the asset manager: it lists all the potentially important lifetime impacts on the asset. Some may be considered very important, others may seem irrelevant, but depending on the future developments all may require some attention of the asset manager at some point in time.

There are four other uses of the LIR that are worth mentioning. The first function is to get feedback from the experts in the expert session. Second, the LIR may be used as an input when decisions need to be made regarding life cycle events, such as overhauls or modernization. The LIR can then be used as an overview of everything that may be relevant to consider, and ensures that no important issues are overlooked in the decision-making process. Third, the LIR can be used as an input to the expert session for other ALCPs. Some impacts may not be very relevant for one asset, but may have a large impact on others. In this way, the LIR facilitates information sharing. A final use of documenting these insights is that important expertise is made available on paper, which makes the company less vulnerable if knowledgeable employees leave the company.

Illustration: the expert session and the LIR

The expert session

The expert session was attended by 8 experts from the departments of Asset Management, Innovation, Grid Planning, Purchasing, and Maintenance Execution. The session took 4 hours, which was barely enough to discuss the five TEC-CO perspectives at sufficient length. Lifetime impacts were elicited in two ways: first, by means of an individual brainstorm using post-its, which were collected on five large sheets of paper (one per perspective). Second, each perspective was discussed in a plenary discussion. This yielded a total of 124 lifetime impacts. After filtering out double impacts and combining closely related ones, 34 unique lifetime impacts remained. The lifetime impacts filtered-out were retained on a list for safe keeping.

The LIR (input for ALCP chapters 4 and 5)

These 34 lifetime impacts were reported in the Lifetime Impact Report. Table 6.5.1 shows examples of the lifetime impacts reported on in the LIR on the distribution transformers.

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Table 6.5.1 - Examples of lifetime impacts related to the distribution transformers for each of the five TECCO perspectives (positive impacts (+) on the left, negative impacts (-) on the right).

Technical lifetime impacts	
<ul style="list-style-type: none"> + real-time load measurement may yield additional insights in the remaining lifetime of the assets + the limited availability of condition data limits the insight in the remaining useful life of the transformers 	<ul style="list-style-type: none"> - the change towards 20 kV grids will render 10 kV transformers obsolete, the impact depends completely on the speed of this transition - the energy transition may give rise to a need for power management in distribution transformers (on-load tap-changers (OLTC)). As modification of existing transformers is expensive and difficult, replacement may be necessary
Economic lifetime impacts	
<ul style="list-style-type: none"> + the use of aluminium coils may reduce the costs of new transformers (but this will increase the size of the transformers, limiting their suitability for existing stations) 	<ul style="list-style-type: none"> - increasing prices of materials (copper, aluminium) increase the price of transformers
Compliance lifetime impacts	
<ul style="list-style-type: none"> + none 	<ul style="list-style-type: none"> - new regulations on power quality and energy losses in transformers is under development
Commercial lifetime impacts	
<ul style="list-style-type: none"> + none 	<ul style="list-style-type: none"> - the energy transition may give rise to new demands, e.g. power management in distribution transformers - the use of DC (direct current) instead of AC (alternating current) in the grid would make transformers redundant
Organizational lifetime impacts	
<ul style="list-style-type: none"> + the use of bio oil in the transformers may increase their recyclability, fitting the organizational ambitions on sustainability + innovative amorphous transformers may reduce energy losses in new transformers 	<ul style="list-style-type: none"> - the technicians in the transformer workshop will all retire in the coming years, giving rise to potential capacity and knowledge problems - Liander pays increasing attention to sustainability and energy losses, which may lead to the decision to preventively replace a substantial part of the population

Based on the current performance of the transformers and the lifetime impacts identified, the performance is expected to remain on the current levels for the next five years. An increase in the amount of failures is not expected, even

though the population is ageing. However, on the longer term three lifetime impacts may give rise to a need for an increased replacement:

1. The energy transition may lead to new demands on the transformers (e.g. power management, additional monitoring), which may result in the modification or replacement of transformers in areas with a high local production of solar power;
2. The transition to 20 kV grids will make the existing 10 kV transformers obsolete;
3. The corporate ambition to reduce CO2 emissions may lead to a replacement of the oldest transformers (which are still reliable but less energy efficient).

Step 8: Evaluation of the Lifetime Impact Report (LIR)

Now the LIR has been written, summarizing the lifetime impacts identified as well as their impacts on the asset performance, it can be discussed with the experts that were present in the session. One could organize a special evaluation session for this purpose, have short meetings with each of the experts individually, or just send them the LIR and ask for their feedback. Irrespective of how this is done, it is crucial to ask the input of the experts again. They may think of additional impacts, may criticize the summary, or comment on the effects on the asset performance as described in the LIR. Also, they may give different priorities to the lifetime impacts listed.

Additionally, the LIR may be used to involve other experts in the process, for example those that could not be present at the expert meeting or those with a very specific expertise that may shed their light on specific lifetime impacts.

By taking the time for an evaluation, the resulting ALCP will be more reliable. Additionally, the ALCP will become more of a shared understanding of the future of the asset, rather than just a view of the asset manager writing the ALCP.

Step 9: Think of appropriate life cycle management interventions

After rewriting the LIR based on the feedback of the experts, a joint understanding of the main lifetime impacts relevant for the asset has evolved. Based on this understanding, it may be necessary to take actions to prevent negative lifetime impacts from happening (or to reduce their effects), or to grasp the full potential of positive lifetime impacts. In other words, there may be a need for life cycle management interventions. These interventions may range from changes in the maintenance program, starting pilot projects to test out new innovations or the collection of additional information on particular lifetime impacts, to design changes, overhauls, modernization projects, or even the preventive replacement

of particular assets. Additionally, some lifetime impacts may be very uncertain and/or only materialize in the very long run, and monitoring their progress may be sufficient. Whatever the specific solution, it may be important to give a brief indication of the costs of the solution, its benefits, and the moment in time when actions have to be taken. Still, for the asset manager some actions may have a high priority and need to be listed. Important to note here is that the ALCP is not meant to be a decision-making document. Rather, it is a document that gives an overview of the asset, the main future opportunities and threats, and the recommended actions to be taken. In most organizations, a specific decision-making process will be existing, which needs to be followed to take large and high-impact decisions. Nevertheless, just giving an overview will probably not satisfy the needs of the target audience. Hence, it is important to think of the main actions that are necessary to produce maximum business value with the assets on the long term.

Illustration: ALCPs at Liander

Chapter 6: Life Cycle Management

Currently, there is no need for large changes in the current management of the distribution transformers. Innovations such as bio oil, OLTC, and amorphous transformers are being monitored by the innovation department. A business case will be developed to investigate if replacing old transformers for new energy efficient ones may be profitable. If so, this may have an impact on the older transformers in the population. This particularly applies to the transformers built before 1980. According to the fictive age structure given in figure 7 this amounts to a total of 10,800 units.

The strategic decision of Liander to change existing 10 kV grids to 20 kV potentially has a large impact on the existing population. The size of the impact depends on the speed of this transition. To make this transition as cost efficient as possible, the existing population of distribution transformers should be taken into account when planning this transition. Additionally, the new demands on the transformers caused by the energy transition need to be monitored closely, as these may give rise to modifications or replacement in the future.

Step 10: Writing the ALCP

The tenth step is the actual writing of the ALCP. The first three chapters have already been written in step 4. The information for chapter 4 and 5 can be taken from the LIR. The information for the remainder of the ALCP has been collected in step 9. The chapter on life cycle management should list the main actions to be taken and their main consequences. Additionally, it gives an outlook regarding the future of the asset, for example, by means of a description of the situation in 10 or 20 years. In this way, the target audience can be

prepared for decisions that may need to be made in the future, as well as their consequences. In this way, the ALCP is not just a document that gives an overview of the future of the asset. It also becomes a communication device to manage expectations and to create a shared understanding of the future of the asset.

Step 11: Discussion and evaluation with target audience and other relevant stakeholders

The ALCP itself is just a piece of paper, irrespective of the huge amount of effort, time and expertise it has taken to produce. It has to be put to use. This happens by means of a presentation of the ALCP to the target audience and other relevant stakeholders, and a discussion and evaluation of the main results. If the target audience is higher management, they may be especially interested in the financial implications of the ALCP and the main decisions that need to be made. The ALCP may help to create a joint understanding of the future of the asset and facilitate decision-making on strategic issues relevant to the asset.

If the discussion and evaluation of the ALCP give rise to changes in the ALCP, these need to be made. Then the ALCP can be accepted and authorised by the target group and/or the management. This makes the ALCP not only a joint understanding of the asset's future, but the official view of the organization.

Step 12: Determine revision date

It is important to realize that the ALCP is not a one-time exercise, but rather a way of doing as Asset Life Cycle Management. This implies that every ALCP will need to be kept up to date. Depending on the internal and external dynamics relevant to the asset, this may need attention every one to five years. Updating an existing ALCP will of course take less time, as just the changes compared to the previous ALCP have to be processed. However, it is of crucial importance to carry out a new expert session, as new lifetime impacts may appear on the horizon.

The revision date should be set already, to make sure a revision will be carried out in time. Still, it may be necessary to do some updates before the revision date, for example, if a large life cycle event happens or a large decision needs to be made.

This is also the moment to start the execution of the actions listed in the final chapters of the ALCP. Their results can be reported in the next ALCP and their impact on the performance can be evaluated. In this way a loop has been created, from objectives, current and expected performance, the development and execution of lifetime interventions, to the evaluation of the new performance. This loop results in a growing understanding of the asset and a more effective management of the asset.

Illustration: ALCPs at Liander

Evaluation

The ALCP has been evaluated with the asset manager responsible for the distribution transformers. He indicated that the ALCP is a foundation for further improvement. It gives an overview of the main topics relevant for the asset for its complete lifetime. This makes it different from existing maintenance policy documents, which often have a more limited focus, both in time and in perspective. This makes it easier to identify the main priorities in the management of the transformers. Additionally, it is a communication device to share the expected performance of the asset with other stakeholders or departments.

The ALCP was presented to the management of the Asset Management department. It was well-received. Especially the strategic focus of the document and the discussion of the future replacement needs were stated to be strong characteristics.

Discussion

The application at Liander shows the potential value of working with ALCPs. The ALCP on distribution transformers allowed the company to get an integrated understanding of the asset's future from the different TECCO perspectives. Based on such an understanding, well-informed strategic decisions can be made. The experts joining the expert session regarded this session as useful and interesting. They especially valued the fact that experts from different departments were present, allowing an integrated and multidisciplinary view on the transformer's future to emerge.

By means of an ALCP, Asset Management may become proactive rather than reactive. It looks ahead, presents the main challenges and opportunities that lie ahead and comes up with suitable solutions that can be implemented in time. This also implies that the chances are small that new problems will suddenly appear and ask for immediate and often less cost-effective solutions.

6.6 Conclusion

Asset Management should aim to create maximum business value from the use of physical assets. To do so, it is crucial to take a multidisciplinary approach towards Asset Management, to be aligned with the corporate objectives, and to focus on the complete lifetime of the asset. The concept Asset Life Cycle Management (ALCM) has been used to describe this "ideal" way of doing Asset Management.

To assist strategic Asset Management decision-making, an integrated insight in the remaining lifetime of the asset is necessary. This insight can be developed by the use of an Asset Life Cycle Plan (ALCP). Such an ALCP starts from the strategic objectives a company has for the asset in order to let it create business value. The current and expected performance on these objectives is reported to show how the asset delivers business value. Additionally, future impacts and trends on the value creation with the asset are identified, and their effect on the performance is estimated. Finally, the ALCP gives an overview of the Asset Life Cycle Management interventions that may be useful to secure or increase the asset's value for the company.

Current maintenance concepts and tools primarily focus on the short-term of the asset's life and often do not take a multidisciplinary perspective, hence, these tools do not assist in the identification of future impacts and trends with an impact on the asset. To support strategic decision-making in Asset Management, the identification of these "lifetime impacts", as they have been called in this paper, is vital. Therefore, a twelve-step approach has been presented to identify lifetime impacts from a multidisciplinary perspective. Five different perspectives are used for the identification: technical, economic, compliance, commercial, and organizational lifetime impacts result (TECCO). The lifetime impacts ranging from these perspectives are identified by making use of the knowledge and information available within the company, primarily by bringing experts together in an expert session. In such a session, a joint understanding of the asset and its future will develop, and the relevant lifetime impacts can be identified.

By following the practical twelve-step approach presented in this paper, an ALCP can be written. The approach is illustrated with an ALCP written by Liander, the largest Dutch network operator. This illustration shows how an ALCP supports asset managers in taking strategic decisions in a timely and effective manner.

6.7 Discussion and implications

This final section discusses the conclusions from this chapter, as well as its implications for further research and for practitioners. A first topic of discussion concerns the prioritization of lifetime impacts. During the expert session, many lifetime impacts will be identified. The question then asks which of these are the most important and most relevant. In RCM, the failure modes identified in an expert session are prioritized based on likelihood and effect size, resulting in a risk priority number (RPN) (Moubray, 1997). A similar approach may be applicable to lifetime impacts.

Second, further research may also address the question as to how to mitigate negative lifetime impacts, and to exploit the full potential of lifetime impacts. The twelve-step approach presented in this chapter does not offer much guidance on this topic. The identi-

cation of lifetime impacts will only deliver value if the right interventions are made in a response to the lifetime impacts identified.

A third topic to discuss is the generalizability of the ALCP and the steps presented in this chapter. While developing the method, the authors aimed for a general applicability in Asset Management. The focus on the creation of business value allows users to adapt the method to a specific industry. However, thus far the ALCP has only been applied on populations of similar assets in the energy sector.

A last issue concerns the title of this book: “Optimum Decision-Making in Asset Management.” The authors are of the opinion that optimum decisions do not exist in long-term Asset Management. Obviously, some decisions are better than others, and some may be plainly wrong. But as one never knows what the future holds, making optimum decisions on the long term is a myth. Rather than optimal decisions, good and timely decisions are needed. Therefore, this chapter has set out to assist asset managers in the difficult and uncertain decisions they often need to make.

6.8 Implications for practitioners

Apart from the twelve practical steps to develop an ALCP, this chapter has four important implications for practitioners in Asset Management. Firstly, practitioners should focus on the complete lifetime of their asset(s) to produce maximum business value for their companies. As decisions made now may have important implications for the remainder of the lifetime of the asset, only by taking the full lifetime into account can maximum value be created. It is crucial that higher management supports this approach to Asset Management. Particularly, as many of the benefits of the ALCP will only be visible on the long term, the long-term support of management is needed. Such lengthened support will allow the asset manager to keep working with the ALCPs until tangible results can be seen in a higher value created with the use of the asset.

Secondly, this chapter has shown that Asset Management should be a multidisciplinary practice. One may compare the disciplines represented in one’s Asset Management practices with the TECCO perspectives, to see if all important disciplines are covered.

As a third implication, practitioners in Asset Management may ask themselves if their Asset Management practices have closed the loop of objectives, performance, interventions, expected performance, and new performance figures. Closing this loop will facilitate a process of continuous improvement.

Finally, this chapter has stressed the importance of the knowledge of experts. Often, asset managers face limited data availability and/or data of a doubtful quality. Additionally, the future is uncertain by definition. Nevertheless, decisions need to be made. The use of the knowledge of experts, adding to existing information and data, may allow for better decisions to be made.

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Publication history

An earlier version of this chapter, which discussed mainly the prioritization of the lifetime impacts, was presented as a conference paper at the EurOMA conference in 2016. This conference paper was written in collaboration with Tijmen van Diepen, who did his master graduation project on this topic. This final chapter was recently submitted to the *CIRP Journal of Manufacturing Science and Technology*.

Reference to previous publication

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7

Lifetime Impact Centred Asset Management to manage predictable change

The application of the LIIA at Liander showed that a large number of very diverse lifetime impacts were identified using the LIIA. Therefore, a tool was developed to assign priorities to all lifetime impacts resulting from the LIIA. Additionally, a decision support tool was designed to assist asset managers in finding suitable solution strategies for the high priority lifetime impacts. These tools complement the LIIA, and together they have been labelled Lifetime Impact Centred Asset Management (LICAM), as it assists asset managers to identify and manage lifetime impacts, just as Reliability Centred Maintenance (RCM) helps to identify and manage failure modes.

Skippable text

The background on ALCM and the LIIA are summarized in this chapter. Additionally, the Dutch network operator Liander is introduced again, as the LICAM was developed and evaluated in this company.

7

Lifetime Impact Centred Asset Management to manage predictable change

Abstract

Asset life cycle management (ALCM) is the effective management of physical assets over its lifetime (typically decades). During this time, changes in the goals and context of the assets may present a variety of threats and opportunities; lifetime impacts. The availability of resources to manage these lifetime impacts are limited. Therefore, a decision support tool was developed to prioritize lifetime impacts based on likelihood, effect and required management efforts. The tool also assigns suitable solution strategies to high-priority lifetime impacts. This tool was tested by an application in practice. The tool may help asset managers to manage future threats and opportunities in a more effective and efficient way.

Keywords: Asset Management, Asset Life Cycle Management, decision making, lifetime impact, Lifetime Impact Centred Asset Management, Reliability Centred Maintenance, risk management, decision support tool, strategy, design science

7.1 Introduction

Our daily lives are dependent on the correct functioning of physical assets, including the electricity grid, roads and bridges and equipment and machinery in manufacturing. Even minor failures in these assets can have severe consequences, including safety incidences, quality defects, environmental damages and power blackouts. Therefore, it is crucial to effectively maintain and manage these assets.

The discipline of Asset Management focuses on the best ways to manage physical assets. The recent ISO 55.000 standard on Asset Management described (ISO, 2014, p. 16) Asset Management as a “coordinated activity of an organization to realize value from assets.” Additionally, this standard emphasized the importance of considering the complete life cycle of the asset by asking for a life cycle management approach (ISO, 2014).

To create maximum value from asset exploitation over a lengthy lifetime, the assets must adapt to changing goals and a changing context (Ruitenburg and Braaksma, 2017b). For example, imagine a paper factory designed and built 30 years ago, anticipating a stable demand for newsprint (the paper for newspapers). Over the years, several changes required an adaptation of the physical assets in the factory. Rising environmental awareness related to toxic substances and carbon dioxide impacted production processes. The inception of the internet reduced the demand for newsprint, which forced the factory to access new markets and quality requirements. To create maximum value with the factory, such future changes should be considered in a timely manner in Asset Management. As these changes may have an (positive or negative) impact on the remaining lifetime of an asset, these have been named lifetime impacts: “probable (technical and nontechnical) 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” (Ruitenburg and Braaksma, 2017b).

The methods, sometimes called maintenance concepts (Pintelon and Parodi-Herz, 2008), most often used in Asset Management, such as reliability centred maintenance (RCM), total productive maintenance (TPM), risk based maintenance (RBM) and effectiveness centred maintenance (ECM) (Garg and Deshmukh, 2006) do not take such lifetime impacts into account. For example, Moubray (1997, p. 7) described RCM as “[a] process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context.” The focus on the present operating context shows that changes in the operating context exist outside the scope of RCM. While other maintenance concepts consider the operating characteristics, they only relate these to technical failures (i.e. risk based maintenance), which “aims at reducing the overall risk of failure of the operating facilities” (Khan et al., 2004, p. 563). However, technical failures are not the only way in which an asset may cease to deliver value to its owners. Lifetime impacts that make the asset or its production obsolete or too costly to remain profitable also hamper an organization’s ability to realize value from its assets. Other examples include changes in regulations or corporate objectives.

To summarize, the lengthy lifetimes of the assets and a focus on their value realization present asset managers with a multitude of lifetime impacts. These changes demand attention and time to be properly managed or mitigated. However, existing maintenance concepts do not offer guidance to properly manage these changes. This article develops a decision support tool to complement existing maintenance concepts by focusing on lifetime impacts. The decision support tool will assist asset managers in proactively managing changes impacting their asset’s goals and context.

7.1.1 Outline

The article starts with a presentation of the theoretical background on Asset Life Cycle Management (ALCM), which lays the foundation for the development of the decision sup-

port tool (section 7.2). The article uses the four phases of the design science methodology (section 7.3): 1. problem exploration (section 7.4); 2. initial solutions (7.5); 3. solution design (7.6); and 4. evaluation (7.7). These phases structure the remainder of the article. In an analogy with reliability centred maintenance (RCM), the article concludes in section 7.8 that threats and opportunities resulting from changes can be prioritized based on likelihood, effect and effort to manage lifetime impacts. Using these variables, expert knowledge can assess each threat or opportunity. A logic tree is presented to assist the asset manager in developing suitable solution strategies to effectively and efficiently manage high-priority threats or opportunities. The decision support tool test shows that it assists asset managers to effectively use their time and resources. The last two sections of this article present the limitations and implications from this research (7.9 and 7.10). Together with the Lifetime Impact Identification Analysis (LIIA) presented in earlier papers (Ruitenburg and Braaksma, 2017a, 2017b), the tools developed in this article constitute Lifetime Impact Centred Asset Management. This may be regarded to be a long-term strategic complement to RCM because it focuses on change rather than a stable operating environment. This method assists asset managers to identify, prioritize and manage potential future opportunities and threats to the assets, which creates maximum value over their complete lifetime.

7.2 Theoretical background

According to Pudney (2010), definitions commonly note that Asset Management combines several disciplines (e.g. technical, financial and risk management) and aims to fulfil some kind of objective (e.g. a level of service or strategic target). Pudney (2010) noted that some definitions do not consider an asset's complete life cycle, which would require the incorporation of long-term and strategic decision making. Finally, Pudney (2010) noted that all definitions fail to mention the impact of change in Asset Management. This is especially notable as a multidisciplinary and strategic practice that tries to reach certain objectives with physical assets during their complete lifetime – which typically lasts decades – but does not consider change is almost by definition doomed to fail.

To address these deficiencies in existing Asset Management definitions, Pudney (2010, p. 8) proposed the following definition: “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, geopolitical, economic, social, demographic and technological regimes.” Based on this definition, Asset Management has at least five characteristics: 1. a multidisciplinary practice; 2. in which the whole life cycle of a physical asset is considered; 3. with the goal of achieving certain specified objectives; 4. within acceptable limits of risk and relevant regimes; and 5. it

should determine the allocation of resources. In the remainder of this article, Asset Management that fulfils these five requirements will be called asset life cycle management (ALCM). To gain a better understanding of the literature on ALCM, this article discusses two of these requirements in relation to change: the whole life cycle and multidisciplinaryity.

7.2.1 ALCM covers the complete life cycle

The physical assets considered in Asset Management typically have lifetimes of several decades. These lengthy lifetimes make the management of these assets a complex activity, even more so as not just the operation and maintenance of the assets should be taken into account, but also the other life cycle phases, such as design, acquisition and disposal (Schuman and Brent, 2005). Over such lengthy lifetimes, many threats and opportunities may present themselves. These threats and opportunities may result from changes in the context in which the asset operates (Pudney (2010) refers to these contextual factors as 'regimes'), for example technological change, changing regulatory regimes, volatile markets (Al-Turki, 2011; Komonen et al., 2012). Additionally, the performance targets of the asset may change, to stay aligned with changing corporate objectives (Komonen et al., 2012; Velmurugan and Dhingra, 2015). Therefore, ALCM must consider the changes in the context of the asset as well as changes in the objectives for the asset that may happen during its complete lifetime.

7.2.2 ALCM is a multidisciplinary practice

Different disciplines should be involved in Asset Management. As noted by Garg and Deshmukh (2006, p. 219) in their literature review on maintenance management, "... maintenance is increasingly viewed as a multidisciplinary activity." These disciplines include maintenance, engineering, design, financial management (e.g. El-Akruti et al., 2016), human resources (e.g. Kriege and Vlok, 2015), data management (e.g. Braaksma et al., 2011), risk management (Catrinu and Nordgård, 2011), information communication technologies (e.g. Al-Turki, 2011), the environment (Niekamp et al., 2015) and customer relationships (Jooste and Vlok, 2015). The diverse disciplines need to be considered to create maximum asset value. Therefore, it is important to consider potential threats and opportunities from these disciplines over the complete lifetime of the asset.

7.2.3 Coping with change in ALCM using RCM

One of the most important maintenance concepts is reliability centred maintenance (RCM) (Moubray, 1997; Smith and Hinchcliffe, 2003). RCM is often used in Asset Management practice (Braaksma et al., 2013). Due to its importance in practice, this article explores how RCM deals with change. As stated in the introduction, RCM is "[a] process used

to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context” (Moubray, 1997, p. 7). As is clear from this citation, Moubray (1997) considered the operating context of the asset. For Moubray (1997), the operating context included factors internal to the operations of the assets (e.g. redundancy, spare part availability and repair times), as well as external factors (market demand, safety regulation and environmental standards). Moubray explicitly discussed the influences of a different operating context by stating that “great care should be taken to ensure that the operating context is identical before applying an FMEA [which is one of the main outputs of RCM – added] developed in one set of circumstances to an asset which is used in another” (Moubray, 1997, p. 73). Therefore, the asset manager is advised to describe the operating context so that “users can readily identify and reassess tasks which are affected by a change in the operating context of the asset (such as a change in shift arrangements or a change in safety regulations)” (Moubray, 1997, p. 211). However, this is a reactive approach. Rather than offer a way to identify potential changes, RCM helps to adapt maintenance tasks if a change occurs. Although RCM is meant to be a living program that continuously updates maintenance instructions (Moubray, 1997), this does not happen in practice (Braaksma et al., 2013). This hampers the ability of RCM to (reactively) deal with change in practice. RCM has a clear focus on operational issues; strategic changes are not addressed (Coetzee, 1999; Murthy et al., 2002). Finally, RCM aims to identify failure modes. It is not designed to address positive changes, including innovations or cost savings (although these are discussed as part of the operating context).

It is important to note that many varieties of RCM exist¹⁷, building upon the version presented by Moubray (Moubray, 1997). An important version is presented by Smith and Hinchcliffe (2003). This version of RCM does not at all discuss the operating context of the assets. It only briefly discusses two (technical) sources of change that may impact the RCM results: 1. that the plant itself is not a constant; and 2. new technology may be available that offers opportunities to improve the reliability of the assets. Gupta and Mishra (2016) presented a comparison of 19 versions of RCM, including the aforementioned version of Smith and Hinchcliffe (2003). These 19 versions do not address change in the operational context in the steps they prescribe, nor changes from other backgrounds. Interestingly, Gupta and Mishra (2016) did not consider this a weakness in the approach. However, this article does consider this an RCM weakness because change is paramount in the maintenance context, especially due to asset lifetimes and the multidisciplinary nature of their management.

¹⁷ Additionally, RCM can generally be executed in two different ways: the classical vs. the streamlined version (Smith and Hinchcliffe, 2003).

7.2.4 Lifetime Impact Identification Analysis (LIIA)

To facilitate asset managers to deal with change, the authors designed (Ruitenburg and Braaksma, 2017b) and tested (Ruitenburg and Braaksma, 2017a) a method to identify opportunities and threats with a potential impact on the asset. The Lifetime Impact Identification Analysis (LIIA) method is named after the lifetime impacts, which can be defined as “probable (technical and nontechnical) 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” (Ruitenburg and Braaksma, 2017b). Lifetime impacts can be either negative (threats) or positive (opportunities). Examples of negative lifetimes are (new) failure modes, cost increases or obsolescence. Positive lifetime impacts can be innovations, new market opportunities or potential cost savings. To gain a complete and multidisciplinary overview of the changes relevant to the asset, the following five perspectives are considered in the LIIA: 1. technical; 2. economic; 3. compliance; 4. commercial; and 5. organizational (acronym of TECCO).

These changes require time and attention from the asset manager, as well as resources from the organization. For example, changes may identify a need for the asset’s technical modification, adjustments of the operation or maintenance instructions or the preventive replacement of the asset. Regarding positive lifetime impacts, it may identify innovations to be implemented, processes to be changed to exploit potential cost savings and new products or services to be developed to enter new markets. Limited resources are generally available to minimize negative lifetime impacts or to exploit the potential of positive lifetime impacts. Therefore, decisions must be made on the most important lifetime impacts and the appropriate reactions to these high-priority lifetime impacts.

7.2.5 Decision-making in Asset Management

In the maintenance and Asset Management literature, the challenge to get the most out of a limited budget is well known. Many types of decision support are available for maintenance and asset managers. There are many models and tools for a variety of decision problems, as shown by literature review on maintenance cost management (Ansari et al., 2016), opportunistic maintenance (Ab-Samat and Kamaruddin, 2014), condition-based maintenance (Alaswad and Xiang, 2017), maintenance policy selection (Hong et al., 2012), the optimization of maintenance policies (Ding and Kamaruddin, 2015) or for specific applications such as in infrastructure management (Kabir et al., 2014). However, these decision support tools focus on operational or tactical decisions rather than strategic decisions. They do not consider changes in the goals or context of the asset over their complete life cycles.

The authors carried out a literature review to study the availability of decision support tools for strategic Asset Management and their suitability for the purpose of this article¹⁸. The authors analysed papers using various aspects, including the goal of the support tool and the type of asset it concerned, the alternatives considered in the tool and the criteria on which the alternatives are evaluated. Based on the authors' discussion on ALCM and lifetime impacts, they looked at whether decision support tools consider changes in the use or context of the assets, as well as what types of opportunities or threats were considered. Analysis results are presented in Table 7.3.2.

The papers developing these decision support tools all start with the assertion that the most needs to be made of limited budgets and that decision support tools may help to do so. In the words of Selih: "[t]he optimal selection of intervention projects across a broad spectrum of assets is [...] a challenging task and in practice, is often carried out in a subjective manner" (Šelih et al., 2008, p. 300).

Several conclusions can be made based on the analysis of the 11 decision support tools¹⁸ (see Table 7.3.2). First, all decision support tools considered different maintenance actions, with most of these focused on maintenance strategies or rehabilitation options. The underlying reason for action in all but one of these models was the degradation of the asset, which would lead to failure if no action was taken. Niekamp et al. (2015) is a notable exception because this model supported asset managers in decisions among alternatives. Other reasons for Asset Management actions fall outside the scope of these tools. These might include the unavailability of spare parts, increased maintenance costs or new innovations. This omission is also clear from the threats and opportunities considered in these models, in which threats related to the degradation of the assets and opportunities (if any) related to grouping maintenance actions. Second, all except one decision support tool were developed for a specific asset (e.g. pavement or transformers). Lastly, the models generally did not consider changes over the lifetime of the assets. Some papers used different scenarios to account for different futures. However, they did consider opportunities or threats from these changes or scenarios. The only threats considered were failures, which are often the main reason for designing the support tool (as without failures, no maintenance would be needed). Regarding opportunities, no single opportunity from future changes was considered in any of the support tools.

To conclude, the decision support tools in the literature are not suitable for our purpose. They focus on how to deal with degradation of specific types of assets. They do not con-

¹⁸ The authors searched for English journal articles containing combinations of the following terms in either title or keywords to indicate decisions on the long term: "decision, prioritization, or priority" and "life cycle, long term, or strategic." To look for decision support tools, they used "tool, framework, support, or logic." They used "Asset Management" to limit the findings to decision making in the field of Asset Management. This resulted in 18 articles. Seven were excluded because they did not discuss a decision support tool. Instead, they discussed Asset Management decision making at large.

sider opportunities or threats from changes in the goals or context of the assets. As a result, they do not offer ways to identify or handle the most important opportunities and threats. Therefore, the development of a tool to meet these needs will contribute to the Asset Management literature.

7.3 Methodology

This article develops a support tool to assist asset managers in setting ALCM priorities. This tool should be practically relevant, as well as based on rigorous scientific research (Van de Ven and Johnson, 2006). The design science methodology is suited for this purpose. It aims to develop generic solutions to practical problems or opportunities in a structured way, as well as to contribute to scientific knowledge (Hevner et al., 2004; Holmström et al., 2009). For a general introduction of this methodology, see Section 1.5, page 17.

The design science methodology consists of the following components: 1. a descriptive/explanatory component studying the field problem and 2. a design/testing component to produce the design. This article follows all four phases with two phases for each component: 1. problem exploration; 2. initial solutions; 3. solution design; and 4. evaluation & test (this is a slight adaptation of the three phases used by Meyer et al. (2014)). The output of this methodology is a tested design (e.g. a framework or a tool) to address a practical problem in a scientifically rigorous way. It is based on mechanisms grounded in scientific literature. In the remainder of this section, the phases will be discussed (Table 7.3.1 presents a summary).

Table 7.3.1 - summary of the four phases of the Design Science methodology used in this article

Phase	1. Problem Exploration	2. Initial Solutions	3. Solution Design	4. Evaluation & Test
Description	Exploring the problem to thoroughly understand it, as a preparation for the development of a solution	Seeking initial solutions for the problem through the literature on ALCM, decision-making and in practice	Combining initial solutions into a final solution design, a decision support tool to effectively deal with lifetime impacts	Testing the model by means of an application at Liander, evaluating the model and its outcomes with stakeholders
Main Activities	15 semi-structured interviews (1 hour), a document study and participant observation	Literature study, (unstructured) interviews, a document study and attending meetings	Designing the tool, discussions with practitioners and adjustments to the tool (iterative process)	Participation in the implementation of the model and evaluation interviews to assess its effectiveness
Output	Description of three main problems	Initial solution to the problems	Solution design	Evaluation of the model

Problem exploration concerns the study of a theoretically relevant problem in practice. It attempts to understand the underlying reasons for this problem¹⁹. The authors have carried out a case study on the problem of dealing with large numbers of diverse threats and opportunities in the practice of Asset Management (De Vaus, 2001; Yin, 2014). The case study was performed at the Asset Management department of Liander, a Dutch network operator. Liander operates assets (e.g. transformers, switchgear and gas pipelines) with expected lifetimes of 40 years. Operating in a changeable context, it is probable that Liander will deal with many threats and opportunities. Additionally, the LIIA has been developed within this company; it is currently the only known company that applies the LIIA in its Asset Management. Although Liander is the only company using the LIIA, Liander also fulfils the two selection criteria mentioned by van Aken et al. (2016): 1. the problem to be studied is important here and 2. management is willing to cooperate with the researchers. The authors carried out 15 semi-structured interviews of about 1 hour with Asset Management department individuals who were involved in decision making (Appendix A.7 (page 316) presents the interview questions). Company documents were studied and meetings were attended (participant observation). Based on this information, three different problems were identified. The identified problems were discussed with members of the Asset Management department to refine them and establish their accuracy.

The problems will be related to the literature and **initial solutions** will be presented (Denyer et al., 2008). These solutions are the initial, scientifically-valid pieces of the puzzle used to develop a final **solution design**. This decision support tool will assist asset managers on proactively dealing with changes in goals and context that may impact their assets. To allow for continuous feedback and learning, the support tool was developed in an iterative process with the help of Liander's asset managers.

The final phase is the **evaluation & test** of the solution design in practice, in which the main goal is to test the model's usefulness for the problem. It also explores the generative mechanisms underlying the solution design work as anticipated. Due to the iterative and collaborative nature of the design process, the design was also evaluated during its design and adapted accordingly. Additionally, the final tool was tested at Liander.

As van Aken et al. (2016) stated, it is not always possible to evaluate the ultimate outcome of a design. In this case, it is a more effective Asset Management in a changing context. Rather, one should "test for direct outcomes rather than for ultimate ones" (van Aken et al., 2016, p. 6). Therefore, the authors evaluated the decision support tool by asking the asset managers if the tool helped them to deal more effectively with identified opportunities and threats. Additionally, the effectiveness of the tool was assessed by comparing the initial situation (see section 7.4.3) to the situation in which the tool was used.

¹⁹ Important to note is that even though the problem exploration will focus on the lifetime impacts identified using the LIIA, the remainder of this article will apply to any lifetime impact, whether it has been identified using the LIIA, a different method or without a structured method/tool.

Table 7.3.2 - description of decision support tools for strategic decision-making in Asset Management (for the selection criteria, see footnote 18)

Reference	Goal of the Support Tool	Type of Asset	Alternatives	Criteria	Change Considered	Threats Considered	Opportunities Considered
Abdelaty et al. (2016)	Select the lowest cost alternative	Highway infrastructure	Three rehabilitation options	Costs	None	Failures (model-based)	None
Alegre et al. (2016)	Assess and compare alternatives	Water infrastructure	Any maintenance strategy, project or solution	Performance, costs, risk	Scenarios can be used	Failures (model-based)	None
Campelo et al. (2016)	Select the lowest cost alternative	Transformers	Four maintenance policies	Costs	None	Failures (model-based)	None
Grönner et al. (2010)	Optimize long-term maintenance strategies	Gas infrastructure	Any maintenance strategy	Many	None	Failures (model-based)	None
Marlow et al. (2015)	Select the best performing alternative	Water infrastructure	15 pipe rehabilitation techniques	Many	None	Failures (model-based)	None
Niekamp et al. (2015)	Guide decision-makers to consider sustainability aspects in AM	Generic	Alternatives for any Asset Management decision	Any relevant criteria	Scenarios can be used	None	None
Rama and Andrews (2015)	Show the performance of different alternatives	Railway infrastructure (School Buildings)	Four intervention policies	Not clear	None	Failures (model-based)	None
Rashedi and Hegazy (2016)	Analyze the impact of alternatives		Different budget allocation policies and maintenance strategies	Many	Different scenarios	Failures (model-based)	None
Scholten et al. (2014)	Select the best alternative	Water infrastructure	18 strategic rehabilitation strategies	Costs, reliability, intergenerational equity	Different scenarios	Failures (model-based)	None
Selih et al. (2008)	Determine the priority ranking of rehabilitation projects	Highway infrastructure	List of potential rehabilitation projects	Condition, age, costs	None	None	None
Takahashi and Okamoto (2016)	Select the lowest cost alternative	Transformers	Five maintenance strategies	Costs	None	Failures (model-based)	None

7.4 Problem exploration

7.4.1 Introduction of the case company

Liander is one of the three main Dutch network operators responsible for the safe, reliable and affordable distribution of electricity (3.1 million users) and gas (2.5 million) customers (Alliander N.V., 2017). It operates and maintains the electricity and gas grid. This consists of several assets, including 85.000 kilometres of electricity cable, 45.000 distribution transformers and 35.000 kilometres of gas pipeline. The replacement value of the grids has been estimated at 10 billion euros.

Liander's asset managers are responsible for the management of Liander's assets. In 2015, at the start of this research, Liander was coping with two important developments. The first was the ageing of Liander's assets. Large parts of the networks, which were constructed in the 1960s and 1970s, were approaching the end of their expected 40-year lifetime. The second development regarded current changes in energy consumption (e.g. electric vehicles) and production (e.g. distributed production of sustainable electricity). These changes were often referred to as the energy transition (see for example Kern and Smith (2008)). For Liander, the energy transition could result in new failure modes (from changing loads on the assets, e.g. bidirectional loads) or require large investments in the grid. For example, local storage would facilitate large-scale local energy production and additional capacity would facilitate electric vehicles.

7.4.2 Liander's Asset Management: a multitude of lifetime impacts

Having recognized these developments, Liander investigated the impact of these developments on its assets. One way to investigate the impact was via Asset Life Cycle Plans (ALCPs): documents describing current and future performance of an asset population (e.g. cables or distribution transformers) in light of changes in the goals with and the context of the asset (Ruitenburg et al., 2015). The ALCPs attempted to identify the main lifetime impacts over the lifetime of the assets and to develop actions to realize maximum stakeholder value from the assets over their complete life.

To identify lifetime impacts, the LIIA was developed in close cooperation with Liander (Ruitenburg and Braaksma, 2017b). The LIIA brought together diverse experts (e.g. engineering, purchasing, supply chain management, customer relations, regulation and Asset Management strategy) to discuss an asset population. The experts met in workshops to discuss potential trends or events that may positively or negatively impact the asset's performance or remaining lifetime. Lifetime impacts were elicited using an individual brainstorm session and group discussions surrounding five different perspectives on the asset (i.e. technical, economic, compliance, commercial and organizational). After the LIIA, life-

time impacts were used as input when writing the ALCP. This discussed and addressed the most important lifetime impacts.

Selections of the lifetime impacts and appropriate actions were based on the knowledge and experience of the asset managers. They indicated that not only facts and thorough analysis, but also emotions, intuition and first impressions played a role in their decisions. This was considered a problem because it could result in non-optimal decisions. Priorities were assigned based on experience. Therefore, prioritization was not transparent. This limited discussions based on prioritization outcomes. In other words, it was problematic that the selection of lifetime impacts and suitable solution strategies were made in an ad hoc, non-transparent and emotion-based manner. These non-optimal decisions were hard to discuss because it did not follow a structured process. Hence, decision motivation was not explicit.

7.4.3 Three underlying problems

This problem was grounded in three underlying problems. Firstly, the use of the LIIA resulted in several lifetime impacts. This corresponded with the article's statement that many threats and opportunities can present over the lifetime of a physical asset. For example, the LIIA for a specific switchgear resulted in 76 lifetime impacts. These included new failure modes, difficulties in obtaining spare parts (both technical lifetime impacts), new regulations on arc protection (compliance) and a shortage of experienced technicians (organizational). More impacts were found for the complete population of power transformers (130 impacts resulted from the LIIA). However, the resources to address these lifetime impacts were limited.

Identified problem #1: there were many identified lifetime impacts. Yet, no resources were available to execute suitable measures to address all of these.

Within Liander's Asset Management, multiple processes were available to effectively distribute limited resources over potential projects and risks. For example, business cases were made for investment projects and asset-related risks were evaluated based on their likelihood and effects on Liander's company values. However, due to the large variety, these existing processes were unable to deal with lifetime impacts from the LIIA. They ranged from five different perspectives on the asset (i.e. technical, economic, compliance, commercial and organizational), spanned the complete lifetime of the asset and included both positive and negative lifetime impacts. The risk management process in the Asset Management department was more operational and did not consider all perspectives because this process was designed for specific issues (e.g. technical risks or innovation projects).

Identified problem #2: the diversity of these lifetime impacts was very large. Existing decision support systems could not cope with the diversity.

Nonetheless, decisions had to be made on the most important lifetime impacts and the assignment of appropriate actions. Without an existing process, these decisions were left to the asset manager. However, asset managers who wrote the ALCP were involved in several projects and their time for these strategic topics was limited by many operational matters (see Ruitenburg and Braaksma (2017b) for more detail). Therefore, they had limited time to follow up on the identified lifetime impacts. Consequently, there was no time for a thorough analysis of lifetime impacts. A thorough analysis was not possible. Therefore, asset managers settled for knowledge- and experience-based ad hoc decisions.

Identified problem #3: limited time was available to identify and address the most valuable lifetime impacts.

In summary, the identification of lifetime impacts resulted in several diverse lifetime impacts. Limited time and resources were available to develop and execute suitable measures to address these impacts. The absence of a decision support tool caused unclear and emotion-based decisions on lifetime impacts. This may have resulted in poor decisions and limited discussions on the outcomes.

7.5 Initial solutions

This article noted that Liander, as well as current literature, has expressed a need to make the most out of limited resources. As a result, decision support tools for Asset Management have been designed to help managers select the most valuable and effective alternatives. Therefore, a decision support tool may be a solution to **Identified Problem #1**. However, the authors' analysis of existing tools did not yield a suitable tool to deal with the broad range of positive and negative lifetime impacts relevant in Asset Management (consistent with **Identified Problem #2**). A new method or tool needs to be designed based on the tools and mechanisms described in the literature.

This article found that multicriteria decision analysis (MCDA) offers a versatile way to deal with a variety of alternatives and conflicting criteria (Brugha, 2004; Niekamp et al., 2015). Therefore, the authors propose to use MCDA as a solution to **Identified Problem #2**. In addition, MCDA offers a structured and transparent decision-making process (Catrinu and Nordgård, 2011). This allows the decision makers to discuss preferred alternatives resulting from the analysis.

RCM (Moubray, 1997) is a well-known MCDA in the field of Asset Management. It differs from other decision support tools in the literature section because it starts from the iden-

tification of different failure modes (ways in which the asset is unable to deliver the required functionality). The analysis may result in large numbers of potential failure modes. For example, the simplified illustrative case used by Smith and Hinchcliff (2003) already yielded 37 failure modes. Therefore, a prioritization of these failure modes is made before suitable maintenance actions are assigned to the failure modes. This is done using a risk priority number (RPN), which calculates the most important failure modes based on the severity, the probability of occurrence and the likelihood of detecting the failure, each of which is estimated by experts (Dieter and Schmidt, 2008; Braaksma et al., 2013). Afterwards, RCM offers a decision support tool to select a suitable maintenance action for each failure mode (Moubray, 1997; Smith and Hinchcliffe, 2003). This helps the asset manager select the most effective maintenance task for the highest priority failure modes (Smith and Hinchcliffe, 2003).

RCM is an MCDA that offers support to asset managers to decide on and address the most important failure modes. This article uses RCM as an initial solution to **Identified Problem #3**. The use of the logic behind RCM has additional advantages. For example, it allows the use of expert knowledge as advised by Komonen et al. (2012). It is also a method familiar to many asset managers, which makes it easier to implement the tool (Hunt, 1987).

7.6 Solution design

A final solution design has been developed based on the exploration of the problems, RCM as an initial solution to these problems and in consultation with Liander experts. The design of the decision support tool was an iterative process. For the sake of clarity, only the final design will be presented in this article.

The decision support tool consists of three steps. First, lifetime impacts are prepared for analysis by combining similar lifetime impacts and describing remaining lifetime impacts more precisely. Then, the remaining lifetime impacts are prioritized based on effect, likelihood and effort. Finally, a decision tree assesses high-priority impacts and assigns the most effective candidate solutions. This process is shown graphically in Figure 7.6.1.

7.6.1 Step 1: preparation

To prepare for the next steps in the decision support tool, it is necessary to define lifetime impacts and reduce their numbers. To clearly describe lifetime impacts, the 5 Ws of Kepner and Tregoe (1973) are used: 1. *who* (in this case, which asset) is affected by the lifetime impact; 2. *why* is it important; 3. *what* are the symptoms; 4. *when*; and 5. *where* will the lifetime impact occur?

In refining the formulation of lifetime impacts, it may be possible to combine impacts as they cover the same threat or opportunity. It was useful to categorize similar lifetime impacts. This was based on the dominant life cycle phase on which the impact had an effect

(construction, operation & maintenance, disposal) and whether the lifetime impact was an opportunity or a threat. This resulted in six categories. Within each category, the number of impacts was smaller, which simplified the combination of similar lifetime. Based on the authors' experience, care must be paid to the nuances and details of the lifetime impacts that are to be combined: do they really discuss the very same threat or opportunity?

Figure 7.6.1 - the input, steps and output of the prioritization tool (both written and illustrated)

7.6.2 Step 2: prioritization of lifetime impacts

Developing the criteria

In multicriteria decision analyses (MCDA), alternatives are scored on several criteria. The scores are then combined. Criteria have a large impact on the priorities ranging from the MCDA. Therefore, these should be chosen with great care (Brugha, 2004). Furthermore, using a company's existing methods or practices facilitates implementation (Hunt, 1987). Many companies apply risk matrices to assess current and future risks (Cox, 2008; Duijm, 2015). The authors chose to adhere to the criteria typically used in risk matrices: likelihood and effect. These criteria are also used in the established RCM method, which shows their applicability to the maintenance context.

The first criterion is the likelihood of the lifetime impact (e.g. the likelihood of a critical supplier going bankrupt). If different future scenarios are available, each scenario's likelihood can be given to take the future uncertainty into account (Scholten et al. (2014) also uses this approach).

The second criterion is the consequence of the impact (e.g. consequences if spare parts can no longer be purchased from the supplier). The effect should be measured in a multifaceted way. Issues to consider include performance, safety and financial and environ-

mental consequences. Many Asset Management organizations have their own methods to assess effects. Therefore, the authors do not propose a specific method. Instead, they leave this to individual users of the generic design (as proposed by van Aken et al. (2016)). For the application at Liander, the authors operationalized it as the effect on Liander's six business values (e.g. reliability and safety). This is a standard procedure in their asset risk management.

When discussing the use of risk matrices, Cox showed that "priority ranking [based on likelihood and effect - added] does not necessarily support good decisions" (2008, p. 507). With limited budgets and resources, the highest priority risks do not always yield the highest risk reduction for available resources. For example, assume three lifetime impacts are identified (A, B, C). Impact A has a large impact ($I_A = 100$). Impacts B and C both have medium impacts ($I_B = I_C = 60$). Assume the resources needed to deal with impact A are 40, while for impacts B and C only 20 resources are required. For a total of 40 resources, the maximum impact that can be dealt with is 120 ($I_B + I_C$). A singular focus on the largest impact would not result in the most effective impact reduction. Therefore, the authors have decided to use the effort as a third criterion. Effort is to be assessed in terms of resources (e.g. manpower, time, money, capacity to change, etcetera) translated into a monetary value. Effort is different from the effect of the lifetime impact (criterion 2), as the effect measures the potential damage or benefits. The effort measures how much effort is needed to suitably address the lifetime impact.

Scoring the criteria

Each lifetime impact needs to be scored on each criterion. This is done using linguistic variables, which has been found to increase the usability and reliability of decision-making (Torfi et al., 2010). The categories may be different for each organization, depending on their established practices. In our application at Liander, we have used the scoring options given in Table 7.6.1. Numerical values are assigned to each scoring option to allow the calculation of a final priority score, following the recommendations of Duijm (2015).

Table 7.6.1 - overview of the three criteria, their categories and the related numerical scores

Certainty	score	Impact	score	Effort	score
extremely unlikely	1	very low	1	< €500.000,-	1
remote	3	low	3	500.000 – 5 million	3
occasional	6	moderate	6	> 5 million	6
reasonably	10	high	10		
frequent	15	very high	15		

Calculation of the total priority

In RCM, the scores for likelihood, effect and detectability are multiplied to form a final Risk Priority Number (RPN). For lifetime impacts, a multiplication of likelihood, effect and effort would result in assigning highest priority to issues with a large impact and effort. As

discussed, this will not deliver the most efficient use of limited resources. On the other hand, giving priority to lifetime impacts with the highest potential for impact reduction (for negative impacts) or impact creation (for positive impacts) for any given effort could assign low priorities to impacts that are crucial for the company's long-term strategy.

Therefore, this article has developed a scheme with four quadrants to show the impact (likelihood x effect) on one axis and required effort on the other (see Figure 7.6.2). An overview of lifetime impacts is presented by plotting lifetime impacts on the quadrants (based on real values or relative ranking).

This has two main advantages. First, the decision-making process surrounding the most important lifetime impacts is made transparent through the visualization of lifetime impacts. This allows for further discussion among decision makers. This is valuable, as generally, more criteria play a role in decision making than can be incorporated into a decision support tool. For this reason, Niekamp et al. (2015) proposed a tool to include criterion desired by the stakeholders.

Second, each quadrant offers a strategy to deal with lifetime impacts. The different strategies are briefly described in Figure 7.6.2. These are based on the logic that the high-impact lifetime impacts should be acted upon. Dealing with those impacts depends on required efforts. High effort impacts (or strategic priorities) require a thorough preparation due to the number of resources involved. Low effort impacts (or low hanging fruit) should not take too much of the asset manager's (limited) time and attention because there are fewer resources involved and the impact reduction (or creation for positive impacts) is large.

Figure 7.6.2 - the four quadrants with the different lifetime impact management approaches, based on their potential impact size and the effort needed to manage the impacts.

The quadrants are not meant to prescribe whether action is required. This is assigned to the decision maker, who has more information than has been inserted into the decision support tool. Rather, the quadrants present an overview of important characteristics of lifetime impacts (i.e. impact and effort) to support discussion and decision making.

7.6.3 Step 3: assigning solution strategies

The final step is to assign suitable solution strategies to each of the high-priority impacts (see Table 7.6.2). This is facilitated by a decision tree developed for this purpose (see Figure 7.6.3). Due to space constraint, the discussion will be limited to the main principles underlying the decision tree.

First, there is an important difference between positive and negative lifetime impacts. All impacts are uncertain because they exist in the future. This results in an important distinction between positive and negative lifetime impacts. Positive impacts are potentially valuable to the company; efforts should be made to allow these impacts to materialize with the highest likelihood and at the shortest term. The opposite holds for negative impacts. Efforts are wasted if spent on impacts that do not materialize. Thus, the focus should be on postponing actions. Hence, the decision tree first distinguishes between positive and negative impacts. The logic for positive impacts is to efficiently and effectively exploit them. The negative impact goal is to postpone actions as long as possible and to reduce the likelihood and effect of the impacts.

Timing is a second important decision tree feature. Lifetime impacts differ as to when they impact the assets (i.e. short term or long term). Monitoring is an option for impacts in the (far) future. However, this is only an option if the recognition of the future materialization of the lifetime impact leaves sufficient time to prepare measures to address it.

Thirdly, the feasibility and business case of the solution strategies must be considered. Therefore, the decision tree asks to assess these prior to the proposal of a certain solution strategy (indicated by the diamonds in the logic tree). The logic tree is designed to first ask comparatively easy questions related to the theoretical possibility of each solution strategy. Then, it asks the more time consuming questions related to the practical feasibility and business case. Depending on the potential impact of the problem and its potential solution, the level of detail in the answers to these questions may differ.

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Figure 7.6.3 – the lifetime impact decision tree – for an explanation of the different solution strategies, see Table 7.6.2

Table 7.6.2 - Explanation of different solution strategies for positive (top) and negative (bottom) lifetime impacts as presented in the logic tree, including an example

	Solution strategy	Explanation	Example
Positive lifetime impacts	Positive lifetime impact: the introduction of a new technology to allow condition monitoring of electricity cables		
	exploit	Actively exploit the full potential of lifetime impact	Adopt new technology to monitor degradation of electricity cables
	monitor (M)	Actively monitor the availability and value of lifetime impact	Annually visit a technology exhibition where new monitoring technologies are presented
	M + increase effect	Monitor and actively increase positive effects that can be generated from the materialization of this lifetime impact	List high-risk cable segments that would benefit most from monitoring
	M + increase likelihood or speed	Monitor and increase likelihood or speed of the materialization of this lifetime impact	Invest in company developing new monitoring systems for electricity cables
	exploitation plan	Prepare a plan to allow for a fast and efficient exploitation of materialized lifetime impact	Prepare a plan with relevant stakeholders regarding steps needed to implement a new monitoring system (e.g. training or new maintenance policies)
Negative lifetime impacts	Negative lifetime impact: the decreasing availability of (highly) skilled and experienced technicians		
	monitor	Actively monitor progress of materialization of lifetime impact (if possible, look for early warning signals)	Annually check on registration numbers of all relevant vocational studies to monitor future availability of skilled personnel to employ
	evade	Change Asset Management strategy to evade effects from lifetime impact on the organization	Outsource maintenance to several service providers to avoid vulnerability of being unable to employ sufficient skilled technicians in the future
	reduce likelihood	Actively reduce likelihood that lifetime impact will materialize	Invest in close relationships with several schools to attract larger numbers of student interns
	reduce effect	Actively reduce effect on organization when lifetime impact materializes	Employ knowledge and skills of current technicians to develop a tablet app to support less skilled technicians
	contingency plan	Prepare a plan to allow for a fast and efficient management of the consequences of the materialization of this lifetime impact	List potentially suitable service providers that can carry out parts of the maintenance work

Fourthly, the decision tree does not prescribe an ultimate solution strategy to each lifetime impact. Instead, it presents a suitable candidate solution strategy. In this way, the tree acknowledges the skill, expertise and context knowledge of the asset manager using the tool. The most suitable solution can only be found through this contextual infor-

mation. The same applies to the translation of the proposed general solution strategy to a specific solution. The proposed solution strategy is not a final solution to the problem. It directs the development of a specific solution for each lifetime impact. For example, the assigned solution strategy may be to monitor the advance of a negative lifetime impact. However, it does not describe how it should be monitored. This translation is left to the skill, expertise and context knowledge of the asset manager (and the team) using the decision tree. It is crucial to take the specifics of the situation into account.

Finally, as only high-priority lifetime impacts are assessed in the decision tree, the authors assume that no impact can be left without a follow-up. If it is impossible to identify a suitable, feasible or affordable solution strategy, the final resolution is either a contingency plan for negative lifetime impacts or an exploitation plan for positive impacts. These plans should prepare the organization to efficiently deal with the lifetime impact and prevent value loss due to the absence of an appropriate response.

The decision tree assists asset managers in efficiently assigning suitable and feasible solution strategies to high-priority lifetime impacts. Additionally, it is structured to propose solution strategies that effectively and resourcefully create maximum value from the positive lifetime impact. It also reduces negative consequences from negative impacts.

7.7 Evaluation

Development of the final solution design was an iterative process, which was carried out partly in parallel with the problem exploration and initial solution phases of the Design Science research (as recommended by Van Aken et al. (2016)). Therefore, the evaluation and test of the decision support tool (also at Liander) also happened iteratively. This section discusses the main findings of the tests. It focuses on the principles underlying the tool rather than the company's implementation at Liander (e.g. using Liander's company values and risk matrix). The test was carried out for Liander's gas delivery stations. These are assets that safely reduce gas pressure between the transport and distribution grid. For a more detailed report of the test from an earlier version of the model, the authors refer to an earlier conference publication (Ruitenburt et al., 2016b).

7.7.1 Step 1: preparation of the lifetime impacts

The first step in the decision support tool redefines lifetime impacts to facilitate the remainder of the process. Input was formed by the 161 lifetime impacts identified in two expert sessions. Step 1's test was executed by the two asset managers who were responsible for the gas delivery stations. They were guided by written instructions provided by the researcher. Therefore, direct influence of the researcher on the test was minimized.

Due to the large number of impacts in this test, they were first categorized to facilitate easy recombination of similar lifetime impacts. This reduced it to 24 clearly formulated

lifetime impacts (16 threats and 8 opportunities). During the evaluation interview, the asset managers indicated that this reduction was caused by the large number of similar lifetime impacts. The preparation process was experienced as pleasant, transparent and structured. The asset managers also recognized that the process helped them to better understand the problems underlying the lifetime impacts. The need for a clear understanding became apparent after a preliminary test showed that some descriptions of lifetime impacts were unclear. This prevented an easy assessment on the three criteria because experts interpreted the lifetime impacts in different ways. The main confusion was whether the effect only considered the gas delivery stations or the complete gas grid. To solve this, explicit descriptions were given for each impact regarding consequences for the gas delivery stations.

7.7.2 Step 2: prioritization of lifetime impacts

In the second step, four experts individually scored lifetime impacts to test the prioritization on likelihood, effect and effort. For likelihood, the chance in Liander's four future scenarios was scored using 5 categories (see Table 3). For effect, the effect on each of the six company values was assessed using five categories. For effort, scores were based on three categories.

The four experts' scores were similar. The experts' average effect score differed maximally one category for 19 (79%) of the lifetime impacts. For likelihood, this applied to 11 (46%) of the impacts; 20 (83%) were assigned average scores that were maximally two categories apart. For effort, for 17 (71%) impacts the difference across the experts was maximally one category (but only three categories were available). The difference in the experts' score consistency may have depended on their experience with assigning scores. Assigning effect scores was familiar to the experts. Using the recently developed future scenarios to assign likelihood scores was less familiar. Scoring effort had not previously occurred because effort scores were developed for this prioritization step. This may explain the lower agreement among the experts.

Larger differences in the scores indicated disagreement between the experts. Further discussion or a second round of scoring as used in Delphi studies (Linstone and Turoff, 1975) may increase the understanding of lifetime impact. It can also clarify its likelihood, potential impacts and management efforts.

During the evaluation by the experts, it was stated that assigning scores for different company values and future scenarios forced them to carefully think about the score assignments. It made the scores more objective and less dependent on first impressions or emotions. Asset managers concluded that the scoring tool's value is in its structured and transparent approach to prioritizing lifetime impacts. Additionally, they indicated that the process of preparing and prioritizing lifetime impacts is as valuable as its result, because it achieves a deeper understanding of lifetime impacts and fosters discussion.

Lifetime impacts were plotted on the four quadrants based on impact (likelihood x effect) and effort. This resulted in a clear visual representation of lifetime impacts. It revealed the low hanging fruit, as well as the impacts requiring significant attention from the asset manager. The asset managers agreed that this would help them decide on priorities. One manager stated that approximately 70% of his time should be spent on impacts in the strategic priority quadrant; the remaining 20% and 10% should be spent on issues in the low hanging fruit and leftover categories. This distinction between strategic priorities and low hanging fruit may be useful when identifying the management of compulsory lifetime impacts (e.g. a change of regulation). While “doing nothing” is not an option, asset managers can choose to spend more or less time on these types of impacts.

The discussion on quadrants yielded a deeper insight on the effort variable. The asset managers distinguished two types of effort: 1. resources spent on the lifetime impact (e.g. man-hours and expenditures); and 2. organizational efforts to make required adaptations in processes and policies. An example of a negative lifetime impact was the reduction of knowledge available within and outside the organization. Offering additional training to the mechanics would cost man-hours and money. However, currently, the asset managers have no influence on technician training. Realizing organizational change would require huge efforts to get the organization to understand the need for additional training and processes. Therefore, the asset managers proposed to score effort in terms of both resource needs and organizational complexity.

To conclude, prioritization of lifetime impacts helped the asset managers achieve a deeper understanding of the impacts, fostered discussion, clarified the most important impacts and assisted in decisions related to time management. In other words, it put lifetime impacts in the right perspective. In the words of one of the asset managers: *“At first sight, the list of 161 lifetime impacts appeared to indicate a lot of problems with the gas delivery stations. But after using the [prioritization] tool, all lifetime impacts were put into perspective and actually, the situation is not that bad after all.”*

7.7.3 Step 3: assigning suitable solution strategies

In the third step, the decision support tool supports the asset manager in finding a suitable solution strategy for each impact. A logic tree was developed in collaboration with two asset managers of the gas delivery stations and in consultation with two Asset Management scholars. Due to time constraints, only an initial evaluation of the logic tree was carried out with the two asset managers. In the evaluation, the proposed solution strategy from the logic tree was compared with the solution strategy already adopted by Liander.

This test resulted in several observations. First, the proposed solution strategies showed considerable resemblance to the current actions. However, the comparison also showed that the logic tree was not able to deal with the subtleties of lifetime impacts. These can have various effects on different assets within a population. They may also have different

impacts on regions within the grid. Some lifetime impacts require further study to understand the feasibility of the solution strategies. Therefore, some of the current actions aim to gain information (a part of the feasibility and business case boxes of the logic tree). This was not meant to discard the value of the tree. Rather, as one of the asset managers stated, it *“can assist in structuring your thoughts”* and help to identify suitable actions for each lifetime impact.

Secondly, structuring the process may also make implicit decisions explicit, which fosters discussion on the most suitable solution strategies. Asset managers who are new to the concept of lifetime impacts can find guidance and training. While the RCM logic tree is often used implicitly by experienced reliability engineers, it is also very useful for training purposes.

Finally, the evaluation also showed that not all lifetime impacts are within the current mandate of the asset manager. Instead, some fall under another department’s authority. This caused the asset managers to reluctantly use the logic tree because it interfered with the current organizational structure. This shows how organizational context may influence the effectiveness of the tool or hinder its implementation. On the other hand, this also shows the value of the tool. Rather than merely selecting the impacts within the asset manager’s control, it forces the manager to take a broader perspective on the assets and involve other departments to create maximum organizational value.

7.8 Conclusion

Asset Management aims to realize maximum value from the exploitation of physical assets over their complete lifetimes. As a result, future changes in goals and context should be identified to allow for time to prepare appropriate measures. As a multidisciplinary practice, Asset Management may see changes from various backgrounds, including technical, economic, compliance, commercial and organizational. Furthermore, the future holds both threats and opportunities for the asset. Additionally, due to the long lifetimes of assets, the number of threats and opportunities (or lifetime impacts) to consider may be overwhelming.

Existing maintenance concepts (e.g. RCM) and decision support tools do not offer guidance on prioritizing and managing lifetime impacts. This article presents a tool to assist asset managers in the management of lifetime impacts. Following a three-step approach, identified lifetime impacts are prepared, prioritized and assigned suitable solution strategies. In the preparation step, lifetime impacts are clearly defined and similar impacts are combined. Secondly, the remaining lifetime impacts are prioritized based on experts scoring the assessment criteria likelihood, effect and effort. Based on these scores, lifetime impacts are plotted on four quadrants to visualize the most important and promising lifetime impacts. Additionally, the quadrants propose how asset managers can effectively

divide their time over the lifetime impacts. Thirdly, the asset manager uses a logic tree to find suitable solution strategies for the high-priority lifetime impacts. It aims to reap the full potential of positive lifetime impacts while reducing negative consequences from negative impacts. Together with the Lifetime Impact Identification Analysis method (LIIA) (Ruitenburg and Braaksma, 2017b), this decision support tool constitutes Lifetime Impact Centred Asset Management.

The decision support tool presented in this article assists asset managers in efficiently dividing their time and company resources over lifetime impacts. It is also a valuable tool to structure decision making on lifetime impacts and facilitate discussion. The tool makes implicit decisions explicit and open for discussion.

7.9 Limitations

The decision support tool was developed and tested in the same Asset Management organization. Additional testing in different organizations/sectors is needed to assess its generalizability. Additionally, decision support tool test focused on the most direct consequences of the tool (i.e. the support it gave to asset managers to prioritize lifetime impacts and to assign suitable solution strategies). However, the tool's goal is to efficiently address future opportunities and threats and create maximum asset value over their complete lifetime. A longitudinal test may assess if the tool realized this goal. It may also yield insight in the implementation and evolution of the tool's usage over time. Finally, the test was limited because some of its proposed solutions were perceived to exist outside the current span of control of the asset managers. Further research may address suitable organizational structures for strategic Asset Management.

This article assumes that it is possible to identify, analyse and prepare timely measures for lifetime impacts. This also assumes a certain level of predictability. However, management literature abounds with discussions on unpredictable change and strategies to cope with change, including agility (e.g. Gunasekaran, 1999; Sharifi and Zhang, 1999) and resilience (e.g. Hamel and Välikangas, 2003; Bhamra et al., 2011). The solution strategies contingency plan and exploitation plan deal with uncertainty as to when a lifetime impact may materialize. Unknown unknowns (Teece et al., 2016) are outside the scope of the Lifetime Impact Centred Asset Management method. Therefore, companies in volatile contexts are advised to complement their management of lifetime impacts with the level of agility required by the volatility of its environment. This article's parallel research on agility in Asset Management (Ruitenburg et al., 2016a) is a recommended reading.

7.10 Implications

This research has several implications for practitioners. First, it is important to realize that the assessment of lifetime impact is an art rather than a science. It requires the imagination of a future that may or may not materialize. Assessing the impacts demands creativity and rigor. The decision support tool stimulates this creative process as it offers rigor and structure. One should not aim for perfection or ultimate precision when using the decision support tool. Instead, one should use it to structure a thought process and facilitate focused discussion.

Secondly, expert collaboration is key in the management of diverse lifetime impacts. For example, specialists in regulation or customer demands. Lifetime impacts can only be thoroughly assessed through close collaboration with the relevant specialists. experts in regulation or customer demand.

Thirdly, it is important to realize that priority setting is an iterative process. The output of prioritization is input for further discussion. Over the years, the understanding of lifetime impacts may improve. Therefore, it is recommended to regularly repeat the identification and prioritization of lifetime impacts. To evaluate time management, asset managers could regularly inspect lifetime impacts plotted on the four quadrants.

Finally, the logic tree may help asset managers find suitable solution strategies for each lifetime impact. It will create maximum value from the identified opportunities and mitigate negative consequences of the threats.

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8

Developing Asset Life Cycle Management capabilities

This chapter describes the development and evaluation of the LICAM – presented in chapters 4, 5 and 7 – from a different point of view: it focuses on the capabilities that were developed throughout this development process. During the four years of this research project, ten Asset Life Cycle Plans (ALCPs) were developed at Liander. These ALCPs were used as ‘artefacts of change’ to initiate change within an Asset Management organization. Five ALCM capabilities emerged from this change process, which will be presented in this chapter.

Skippable text

This chapter does not focus on the methods and tools used in ALCM (as the review in chapter 2 did), but rather discusses the skills and competences for Asset Management mentioned in the literature. However, minor overlaps exist with earlier chapters, mainly in the introduction, general background on ALCM and the introduction of the Dutch network operator Liander as the case company.

8

Developing Asset Life Cycle Management capabilities

Abstract

Asset Life Cycle Management is a strategic approach to managing physical assets over their complete life cycle. Even though the literature and the recent ISO 55000 standard stress the importance of such a strategic life cycle approach to Asset Management, they do not offer guidance as to how to develop such an approach. This paper aims to address this gap by studying the development of Asset Life Cycle Management capabilities in practice.

In a four year Action Research project, Asset Life Cycle Plans were developed and implemented to develop ALCM capabilities within an Asset Management organization. This change process was studied to study the main capabilities for Asset Life Cycle Management and how these can be developed.

During the development and implementation of the Asset Life Cycle Plans, five main ALCM capabilities emerged: 1. strategic information use; 2. vertical alignment of operations and strategy; 3. horizontal alignment of different disciplines; 4. a dual time perspective on both short and long term matters and 5. exerting influence over the assets throughout the entirety of the organization.

This paper shows practitioners how ALCM capabilities can be developed, which may help them to do the same in their organizations to align asset related activities within their organization to create maximum value from the exploitation of their assets.

Keywords: Asset Management, Asset Life Cycle Management, Asset Management Plan, Action Research, capability, organizational development, ISO 55000, alignment, multidisciplinary

8.1 Introduction

The management of physical assets is a crucial activity in industry, as well as in society at large. Production lines, machinery, chemical plants, but also highways, the electricity grid and trains and planes depend on effective maintenance. Maintenance can be described as

“the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function” (European Committee for Standardization (CEN), 2010).

Over the last decades, industry has witnessed a development in the scope and importance of maintenance, turning it from a ‘necessary evil’ to a strategic ‘cooperative partnership’ (Pintelon and Parodi-Herz, 2008) and a ‘potential profit generating function’ (Maletic et al., 2014). Concurrently, it developed into the broader activity of Asset Management, which “involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organizational objectives” (ISO, 2014, p. 2). Asset Management is not just occupied with the prevention or restoration of technical failures, but involves a far broader scope, including ICT, human resources and sustainability (Pintelon and Parodi-Herz, 2008). In Asset Management, the ultimate goal is to maximize the value realized from the exploitation of physical assets over their complete lifetimes (Ruitenburg and Braaksma, 2017b). The focus on value creation also elevates maintenance from an operational to a strategic function within the company (Murthy et al., 2002; Haarman and Delahay, 2004). As a result, it is important to consider the complete lifetime of assets when making strategic decisions, as is strongly emphasized by the recent ISO 55000 standard asking for a ‘life cycle management approach’ (ISO, 2014) as well as by the literature on Asset Life Cycle Management (ALCM) (see for example Schuman and Brent (2005) or Haffejee and Brent (2008)).

The importance of such a life cycle approach is even aggravated by two recent developments: the ageing of assets and an increasing level of change in the goals and context of the assets. A study issued by the European Union, carried out in 2014, showed that 44% of the industrial assets in Belgium, the Netherlands, France and Germany will reach the end-of-life before 2024 (Haarman and Delahay, 2015). These findings are corroborated by other research, indicating that a large part of the infrastructure and industrial assets in Western-Europe, Northern-America, Japan and Australia are currently approaching their expected end-of-life (Allan, 2005; Jongepier, 2007; Tinga, 2013). Secondly, the literature indicates that asset managers face an increasing amount of change, ranging from new operations management strategies, ever stricter societal expectations, increasing global competition and increasing environmental awareness (Tsang, 2002; Al-Turki, 2011).

Even though the importance of a true life cycle approach to Asset Management is paramount, little guidance is offered as to how to develop such an approach in both the literature and standards such as ISO 55000 (Jooste and Vlok, 2015). What is clear from ISO 55000, is that so-called ‘Asset Management Plans’ are essential to manage assets over their complete life cycle. These Asset Management Plans are defined as “*documented information* that specifies the activities, resources and timescales required for an individual asset, or a grouping of assets, to achieve the *organization’s Asset Management objectives*

[original italics]" (ISO, 2014, p. 14). But again, the ISO standard does not offer guidance as to how such an Asset Management Plan should look like.

Therefore, this paper aims to investigate how a life cycle approach in Asset Management can be established and how Asset Management Plans – called Asset Life Cycle Plans (ALCPs) in the remainder of this paper – can help to do so. The main focus of this paper is to establish what capabilities are necessary in Asset Life Cycle Management (ALCM). With capabilities, we mean “ways of organizing and getting things done which cannot be accomplished merely by using the price system” (Teece et al., 1997, p. 517) and which therefore “typically must be built because they cannot be bought” (p. 518). Therefore, the main research question guiding this paper will be: ‘what are the main capabilities for Asset Life Cycle Management and how can an Asset Management organization develop these ALCM capabilities?’

8.1.1 Outline

To answer this question, first we will discuss ALCM and the literature on the skills and capabilities deemed important for ALCM (section 8.2). This will result in a list of four ALCM principles that distinguish ALCM from general Asset Management: multidisciplinary cooperation, strategic consideration of the complete life cycle, pursuit of strategic objectives throughout the entirety of the organization; and the anticipation and management of change. The change process from Asset Management to ALCM has been studied using the Action Research methodology, which will be introduced in section 8.3. Over a period of four years, the first author was involved in the development of Asset Life Cycle Plans (ALCPs) within the organization and made several interventions based on the four ALCM principles from the literature.

The resulting change process will be described and analysed in section 8.4, resulting in five important ALCM capabilities: 1. strategic use of information; 2. vertical alignment between higher management and operations; 3. horizontal alignment between different disciplines; 4. a dual focus on short term operational issues and long term strategic topics; and 5. exerting influence even outside one’s direct span of control. The strategic use of information and the ability to exert influence outside one’s direct span of control allows asset managers to align asset related activities and decisions horizontally and vertically across the organization, as well as over time. After a discussion of the results in the light of the principles abstracted from the literature (section 8.5), this paper will conclude that these five capabilities are crucial to make the most of the information and expertise available within the company in order to create maximum value from the exploitation of the assets for the organization (section 8.6). Finally, the limitations of this research will be discussed (section 8.7) and a number of implications for practitioners will be presented to assist them to develop these ALCM capabilities in their own organizations (section 8.8).

8.2 Theoretical background on ALCM capabilities

In their discussion of the evolution of maintenance since WWII, Pintelon and Parodi-Herz (2008) note that: “[o]ver the last decennia industrial maintenance has evolved from a non-issue into a strategic concern. Perhaps there are few other management disciplines that underwent so many changes over the last half-century” (p. 21). However, few authors explicitly discuss the capabilities needed to achieve this change. A notable exception are Peppelman and Kramer (2012), who describe the development of an Asset Management organization towards maturity: from reactive to proactive and from fragmented to integrated. A similar process is described by Brunetto, Xerri and Nelson (2014), who stress the importance of organizational culture to accomplish such a change: “[f]or Asset Management organizations to become more proactive and less reactive, more customer-focused and less technically focused, more successful in terms of Asset Management performance and less driven by cost management, a change in organizational culture will be necessary.” (Brunetto et al., 2014, p. 6). Such an organizational change can be brought about by a technical improvement process, such as an improvement of an Asset Management planning process, as the case described by Sutton and Chadwick (2014) proved. We will adopt a similar approach in our Action Research, where we hope to bring about an organizational change by the introduction of Asset Life Cycle Plans.

But before we do so, we will first briefly introduce Asset Life Cycle Management and the capabilities deemed relevant for ALCM in the literature.

8.2.1 Asset Life Cycle Management

Throughout the profound evolution of the field of maintenance, maintenance starts to be called Asset Management, “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” (Pudney, 2010, p. 8). This definition shows the breadth of Asset Management: it combines different (technical and non-technical) disciplines to achieve (corporate) objectives with the assets over their complete life and considers the context in which the asset operates (e.g. governance). In other words: Asset Management involves both the physical assets and the wider organization in order to create maximum value from the exploitation of the assets over their complete lifetimes. In the remainder of this paper, we will use the term Asset Life Cycle Management (ALCM) to refer to approaches to Asset Management that live up to this definition.

8.2.2 Literature on ALCM capabilities

While a large literature exists on Asset Management methods and tools, relatively little is written about the organizational capabilities that are important for ALCM. As in the literature no clear framework exists about ALCM capabilities, we will use the five different characteristics of ALCM following from the definition of Pudney (2010) to structure our discussion: ALCM is 1. a multidisciplinary practice; 2. in which the whole life cycle of a physical asset is taken into account; 3. with the goal of achieving certain specified objectives; 4. within acceptable limits of risk and relevant regimes; and 5. it should determine the allocation of resources. This discussion of the ALCM capabilities mentioned in the literature will lead to a list of four important principles for ALCM, which we will use to guide our Action Research interventions.

1. ALCM is a multidisciplinary practice

The literature is clear about the importance of approaching maintenance as more than a technical matter. Many lists of disciplines exist, but one rather complete list is given by Amadi-Echendu, who argues that creating value with assets throughout their life cycle “requires a higher level integration of the synergies between the traditional disciplines in accounting, economics, engineering, finance, and humanities; as well as logistics, process and information systems technologies” (Amadi-Echendu, 2004, p. 1157). This is especially important as these different disciplines may each pursue their own, sometimes conflicting objectives (Wenzler, 2005). This is also acknowledged by ISO 55000 (2014), which argues that “cross functional integration” is crucial to manage assets in “an integrated manner” (2014, p. 5) to improve asset value. Also Peppelmans and Kramer (2012) acknowledge that working in teams is a way to bridge the ‘natural silos’ of the different disciplines relevant in Asset Management (other authors describe the same challenge in terms of ‘island cultures’ (Zoeteman, 2006) or ‘a silo mentality’ (Amadi-Echendu et al., 2007)). Therefore, the ability to join and lead multidisciplinary teams is considered an important skill (Scott and Yates, 2002).

The collaboration between maintenance and operations gains explicit attention in the literature. Moubray (1996) acknowledges this as one of the ‘paradigm shifts’ underlying the change from ‘maintenance as an ‘unavoidable cost’ to a value creator. This value has been discussed by Iravani and Duenyas (2002), and this topic has been treated in more detail by Garg and Deshmukh (2006) in their discussion of ‘maintenance integration’. However, due to the differences in goals and culture between maintenance and production, this collaboration may turn out to be challenging (Chan et al., 2005).

Also within the maintenance discipline, collaboration and knowledge-exchange is crucial. However, research indicates that the knowledge of operators and technicians is not always used to its full potential (Xerri et al., 2015), which is nicely shown in this quote: “[i]t appears through the interviews that the organisations continue to see the operators and

technicians as skilled hands, rather than also having brains and being very sophisticated sensors” (Lin et al., 2007, p. 123). However, it is this knowledge and experience that is necessary to gain the ‘bigger operational picture’ (Shah et al., 2017) that is important in Asset Management.

To facilitate the use of the (existing) knowledge from different functional silos within the organization, knowledge management is an important capability: “the collection of all important knowledge and expertise that people bring into the organization and its distribution to where it is needed and where it can improve organizational performance” (Kriege and Vlok, 2015, p. 442). Due to the size of many organizations, the translation of tacit knowledge (e.g. in the heads and skills of people) to explicit knowledge (e.g. on paper) is an important step towards effective knowledge management (Longley et al., 2012; Kriege and Vlok, 2015). Another important competence are communicative skills (Ravesteijn et al., 2006; Bish et al., 2014), especially as engineers – as most asset managers are – tend to have a lack of communication skills (Riemer, 2002). Due to the involvement of many non-technical disciplines in Asset Management, especially the ability to communicate technical information to non-technical audiences is important (Asset Management Council, 2009; cited in: Bish et al., 2014).

To summarize, for ALCM to succeed, the integration of multiple disciplines to see the ‘bigger picture’ of the assets is necessary. This can be accomplished by working in multidisciplinary teams, as these will foster information exchange and communication.

2. in ALCM, the whole life cycle of a physical asset is taken into account

Due to the long lifetimes of physical assets, a multidisciplinary approach does not suffice for a complete view on the assets. This is made clear by ISO 55000, which stresses the importance of “[t]he shift from maintenance management to whole life cycle asset management” (Jooste and Vlok, 2015). This asks for an integration of the management of the assets over different life cycle phases (Amadi-Echendu, 2004), for example the use of the knowledge and skills of the OEM (original equipment manufacturer) throughout the complete life of the asset (Henderson et al., 2014). Asset Management should emphasize the complete life cycle of the asset (Amadi-Echendu et al., 2010). Nevertheless, many authors show how Asset Management is predominantly focused on the short term (e.g. Zoeteman, 2006; Amadi-Echendu et al., 2007; Wijnia and Herder, 2010). An important aspect of Asset Management is therefore ‘time generality’, which Amadi-Echendu et al. (2007) describe as follows: “Asset Management extends over time to include short term (e.g. utilisation) and long term (e.g. lifecycle) aspects of physical assets” (Amadi-Echendu et al., 2007, p. 124).

An important competence to do so is ‘life cycle planning’ (ISO, 2014), for example by means of Asset Management Plans (which in this paper are called ALCPs). In other publications ‘strategic planning’ is mentioned as an important competence for asset managers

(Stapelberg, 2006; Hyland et al., 2009; Bish et al., 2014). Jonsson (1999) showed how long term planning contributed to the performance of manufacturing companies.

3. the goal of ALCM is to achieve certain specified objectives

Strategic planning implies the pursuit of a certain objective. Schraven et al. (2011) discuss three challenges related to these objectives in infrastructure Asset Management. The first challenge is to manage multiple actors, as many different stakeholders pursue different and conflicting objectives, which is widely acknowledged in the literature (e.g. Wenzler, 2005; Al-Turki et al., 2014; Shah et al., 2017).

A second challenge is to clearly define objectives, not only to make these measurable, but also to allow performance management (Parida et al., 2015). This also allows continuous improvement of maintenance performance, which is “much talked-about, but more rarely evident as an organizational habit” (Woodhouse, 2012, p. 3).

A final challenge is the alignment of decisions throughout the organization, sometimes also called ‘line of sight’: “a key principle in Asset Management is a line of sight, which means an approach within an organisation that looks to line up the work that is done directly on assets with the objectives of the organisation” (Shah et al., 2017, p. 232). Alignment is not just a translation of organizational objectives to plans and activities (as described by ISO 55000 (2014)), but also considers the organizational culture (Novak et al., 2017). Furthermore, it is not just a top-down translation from objectives to activities, but also involves an understanding of maintenance execution at top-level management (Murthy et al., 2002). It requires that Asset Management takes place in all levels of the organization (Amadi-Echendu et al., 2007) and that all activities throughout the organization levels are aligned.

Schraven et al. (2011) acknowledge that, despite the understanding of the importance of alignment, there is still little understanding about how to reach alignment in practice. This is in line with the statement of Pintelon and Parodi-Herz, who state that one of the most important challenges for maintenance is the “threatening gap between the top management level and the overall maintenance strategy determination and the tactical level on which the maintenance concepts are designed, detailed and implemented” (2008, p. 45).

4. ALCM considers risk and relevant regimes

The focus on corporate objectives makes ALCM strategic, rather than just operational. This also requires that “maintenance must be viewed in the long-term strategic context and must integrate the different technical and commercial [i.e. market, economics and socio-political] issues in an effective manner” (Murthy et al., 2002). These contextual issues (or ‘regimes’, as Pudney (2010) calls them) are relevant, as the scope of maintenance has changed from just “to optimize plant availability at minimum cost”, to “all aspects of business effectiveness and risk – safety, environmental integrity, energy efficiency, product quality and customer service” (Moubray, 1996, p. 3). Schraven et al. (2011) clearly de-

scribe the importance of these regimes: “[t]he effectiveness of Asset Management will depend on the extent to which these contextual changes [i.e. new political orientations, more strict environmental regulations, new construction technology or a changed demand] are anticipated and lead to adjusted decisions” (Schraven et al., 2011, pp. 70–71). Therefore, ALCM should anticipate change in order to be effective (Ruitenburt and Braaksma, 2017b). The continuous adjustment of decisions and actions to a changing context is considered an important Asset Management competence (Asset Management Council, 2009; cited in: Bish et al., 2014). Therefore, it is important that the Asset Management organization is willing and able to change (Xerri et al., 2015), showing the importance of flexibility (Pintelon and Parodi-Herz, 2008) and change management for Asset Management (Kriege and Vlok, 2015).

5. ALCM determines the allocation of resources.

Due to the costs and long lifetimes of physical assets, generally large amounts of money and other resources (e.g. people, knowledge, equipment) are involved in ALCM. Therefore, the literature abounds with studies about the selection of the right maintenance regime (e.g. Hong et al., 2012; Goossens and Basten, 2015) or maintenance optimization (e.g. Ding and Kamaruddin, 2015; Alaswad and Xiang, 2017). As a result, “[t]he maintenance manager needs real management skills, to manage the resources – personnel and materials – in an efficient and effective way” (Pintelon and Parodi-Herz, 2008, p. 44). As Stapelberg (2006) rightly stresses, the asset manager should be able to consider both engineering solutions and management techniques to solve Asset Management problems. However, even though the use of resources in ALCM is important, we do not consider it a distinctive characteristic of ALCM compared to maintenance or general Asset Management. Therefore, we do not consider it explicitly in the remainder of this paper.

8.2.3 Summary: four main ALCM principles

The literature shows how broad and encompassing ALCM is, and gives an idea about the capabilities that may be needed to evolve from Asset Management to ALCM. Based on the many different skills, competences and capabilities discussed in the literature, we present four underlying principles of ALCM, which distinguish it from approaches to Asset Management that do not live up to the definition of Pudney (2010):

1. to gain an overview of the ‘bigger picture’ of the asset, multidisciplinary cooperation is necessary;
2. the complete life cycle of an asset needs to be considered in a strategic way;
3. clear strategic objectives should uniformly be pursued throughout the organization; and
4. (contextual) change should be anticipated and managed.

From the literature, it also became clear that living up to these principles is not easy, but requires profound organizational and cultural change as well as years to accomplish (Brunetto et al., 2014). Additionally, challenges remain, such as bridging the gap between top management and maintenance execution. Finally, even though the literature (and ISO 55000) provide guidelines on the requirements ALCM needs to fulfil, it does not offer guidance as to how to accomplish this. Therefore, we carried out an Action Research project to closely study the change process towards ALCM to find the main capabilities necessary for an Asset Management organization to adopt a strategic life cycle approach, and how these can be developed.

8.3 Methodology

In this section, we will first introduce the Action Research methodology (8.3.1) and the main steps of any Action Research project (8.3.2). Section 8.3.3 reports on the execution of this research of ALCM capabilities. Finally, the relation between the Action Research project and the Design Science methodology adopted to design the Action Research interventions will be discussed (8.3.4).

8.3.1 Action Research

Action Research can be defined as “an emergent inquiry process in which applied behavioural science knowledge is integrated with existing organizational knowledge and applied to solve real, organizational problems. It is simultaneously concerned with bringing about change in organizations, and developing self-help competencies in organizational members and adding to scientific knowledge. Finally, it is an evolving process that is undertaken in a spirit of collaboration and co-inquiry” (Shani and Pasmore, 1985; cited in: Shani et al., 2012, p. 51). This definition shows a number of defining characteristics of Action Research. First, Action Research is about solving real-world problems using both scientific knowledge and an intimate knowledge of the organization. Secondly, the goal is not just a practical goal, but also the contribution to scientific knowledge. The focus on bringing about change is instrumental to make this contribution, as “the best way of learning about an organization is by attempting to change it. The very process of change is likely to reveal factors which would not have been unearthed in a stable environment” (Eden and Huxham, 2006, p. 400). Thirdly, as the consequences of change can never be predicted completely in a social system, Action Research “engages in an unfolding story, where data shift as a consequence of intervention and where it is not possible to predict or to control what takes place” (Shani et al., 2012, p. 51). This may seem a disadvantage of Action Research, but it is rather the opposite: joining in the change process allows the researcher to observe the consequences of the change, including its unexpected or undesired results. This is a type of data that is hard to collect in a different way and allows the researcher to

gain a fine grained understanding of the phenomenon unfolding. Finally, Action Research is done in real time collaboration with practitioners. Their knowledge, experience and ideas do contribute to the research and together with the researcher they discuss and evaluate the change process as it develops.

Quality in Action Research

To contribute to both practice and science while being immersed in the change process, “the challenge for action researchers is to engage in both taking action and contributing to practice, and standing back from the action and reflecting on it as it happens in order to contribute theory to the body of knowledge” (Coughlan and Coghlan, 2009, p. 239). Therefore, it is crucially important to distinguish different researcher roles and activities in the project (see Section 8.3.2).

Quality in Action Research should not be assessed using the requirements of positivist science, but rather on its own quality criteria (Coughlan and Coghlan, 2009). Levin (2003) proposes four criteria, including: participation, joint-meaning construction, real-life problems and workable solutions. **Participation** considers the cooperation between the researcher and the members of the organization. The use of the ideas and in-depth context knowledge of practitioners is one of the distinguishing features of Action Research, allowing it to develop a holistic understanding of the problem and its complexity. Joint-meaning construction also addresses the collaboration with the practitioners, considering if the process of interpretation and generating understanding of the problem and the actions to be taken really was a joint effort of researchers and practitioners. **Real-life problems** asks if the project addressed a problem that was pressing for the organization (Coughlan and Brannick, 2014). Also, it considers the iterative and reflexive nature of the research in reaching a solution for the problem. Finally, the requirement of **workable solutions** relates to the practical significance of the work and the change ranging from the project. Reason (2006) adds that the change should persist even after the end of the research project.

With respect to the data exploration, “a high degree of method and orderliness in reflecting about and holding on to the emerging theoretical content of each episode” (Coughlan and Coghlan, 2009, p. 259) must be demonstrated. Quality in Action Research is ensured by the meticulous execution of the Action Research cycles (see section 8.3.2). To prevent (observer) bias, the researcher is urged to distinguish between data and interpretation (e.g. by keeping these apart in one’s fieldnotes), actively seek disconfirming data and to continuously discuss his findings with others (Coughlan and Coghlan, 2009). Finally, in the reporting the researcher should make its process recoverable and his reasoning explicit, to allow others to assess the value and quality of his work.

8.3.2 Action Research process²⁰

An Action Research project typically follows seven steps, including: 1. designing the Action Research project; 2. context and purpose; 3. diagnosing; 4. planning action; 5. taking action; 6. evaluating action; and 7. meta-learning (Coughlan and Coughlan, 2009). Steps 3 to 6 are called the Action Research cycle, which is to be repeated to allow the evaluation of new insights from earlier cycles.

Designing the Action Research project

The design of an Action Research project includes the framing of the issue, the determination of its scope, gaining access and negotiating a role (Coughlan and Coughlan, 2009). The framing of the issue concerns how the (practical) problem must be understood, for example as a communication problem, a power issue or a technical difficulty. The collaboration with members of the organization is crucial to interpret the problem in the right way. The determination of the problem's scope concerns which aspects of the problem – as well as which actors – will be part of the project. This relates to getting access, which is not just getting access to the organization, but also to the specific organizational members and information needed. A project steering group with members of the organization may help to gain access. Finally, the role of the researcher within the organization must be made clear, to prevent role conflicts and conflicting demands made on the researcher (e.g. by the company and the university). Contracting can be useful to clearly define roles and responsibilities.

Context and purpose

The research starts with gaining an understanding of the context of the project. Two topics need to be addressed, including: the rationale for action and the rationale for research (Coughlan and Coughlan, 2009). The rationale for action addresses the necessity and desirability of the project for the organization. The stakeholders and forces driving the need for action must be understood, and collaborative relationships should be established to address the problem. The rationale for research considers the relevance for science and the expected contribution of the project. A background knowledge on the OM literature is essential for assessing these issues.

Diagnosing

Diagnosing is the first step of the Action Research cycle, which is to be repeated. In the diagnosis phase, the problems are named – even if only provisionally – and lies the theoretical foundation for action (Coughlan and Coughlan, 2009). Diagnosis should be a collaborative and data-driven process. Data can be hard (e.g. sales numbers or KPIs) or soft (e.g. perceptions or expectations). The data can be gathered in many different ways: inter-

²⁰ This section is mainly based on Coughlan and Coughlan (2009).

views, observations, attending meetings, but also in informal conversations or from company documents. Other research methodologies may be applied within the Action Research project, for example a survey research to investigate the size of the problem or a case study to compare multiple organizational units. Additionally, data are generated by the actions of the researcher: his questions, his interpretations and his interventions. The diagnosis must be made in collaboration with the members of the organization, as they know the organization best and are the ones who ultimately need to implement and follow through on the interventions made in the project.

Planning action

Based on the diagnosis, one or multiple interventions must be prepared. These need to be described and their intended consequences need to be made explicit. Depending on the nature of the interventions, the support and agreement of the management or the board may be needed. Timely involvement is crucial to gain their support.

Taking action

In the next step, the interventions are implemented in the organization. The implementation may take weeks or months. The intervention may (first) be implemented only in a part of the organization to establish its effects.

Evaluating action

In the evaluation phase, the consequences of the intervention(s) are assessed, both the intended and unintended consequences. Additionally, the implementation process is reviewed. The main goal is to facilitate learning about the problem and the (effectiveness of the) intervention, in order to use this new knowledge for the next Action Research cycle.

Meta-learning

Meta-learning is the continuous process of reflection about the project. This reflection is what distinguishes Action Research from everyday problem solving. It allows learning about learning: meta-learning. Reflection allows the researcher to step back from the action and experience, and to process his experience. Reflection must consider the content, process and premises of the project. The content concerns what is happening, the process is about how things are done, strategies and procedures. Premises consider the assumptions and perspectives held by the researcher. Additionally, meta-learning considers the theoretical contribution of the research, regarding content (the contribution of the work to theory), process (research strategy) and premises (e.g. the scope of the project and the theory).

8.3.3 Action Research execution

The goal of this research was to study the capabilities needed in an ALCM organization, as Liander – the sponsor of this research – aimed to develop its Asset Management into strategic, long-term Asset Life Cycle Management. This change process offered an opportunity to study the capabilities needed for ALCM. Therefore, the Action Research methodology was adopted and its steps were followed.

Designing the Action Research project

In the end of 2012, the research project was initiated by Liander, a Dutch network operator (see Section 8.4.1 for an introduction of Liander). Liander was (and: is) responsible for the safe and reliable distribution of electricity and gas to 3.1 million Dutch households. Liander faced a dual challenge: on the one hand it had to achieve new goals (e.g. sustainability) in a changing context (as a consequence of a steep growth of localized sustainable electricity generation). On the other hand, it had to do so using old assets which were slowly approaching their end-of-life. In 2013, Liander approached the researchers with the desire to start a joint change project to develop their Asset Life Cycle Management capabilities in order to deal with these challenges in a proactive and strategic way. This desire and willingness to act made Liander an excellent case for this study of ALCM capabilities.

Liander presented an initial framing of the project: the limited understanding of the remaining lifetime of their assets was caused by the lack of reliable data. Their proposed solution was the introduction of Asset Life Cycle Plans (ALCPs): documents that discuss the strategic objectives of the company with the assets, its current performance, future threats and opportunities that may impact the future performance, and the policy measures to make sure the future performance meets the strategic objectives (Ruitenburg et al., 2017). A prerequisite for this solution was the collection and analysis of additional data to fill this new type of documents. Based on this initial problem framing and potential solution, a project proposal was written. In this proposal, the scope of the project was described: the development of ALCPs. The focus on ALCPs helped the researchers to have a clear ‘artefact of change’ in the organization, and the focus on practicable and tangible outputs suited the need for practical solutions by Liander.

A contract was drawn up outlining the role of the researcher and the dual goal of contributing to practice and science. A project steering group was set up, consisting of managers from Liander and two scientific colleagues.

The next step of gaining access to the organization included efforts to gain access, relationships and trust with the relevant members of the organization. The first author joined in a number of projects not directly related to the research project to get involved with the members of the organization and to get to know the organization.

Context and purpose

Efforts were made to get to understand the problem and the context of the project. The topic of Asset Management, data and remaining useful lifetime (RUL) estimations were studied in the literature, to get an understanding of the potential theoretical contribution of the project. The researcher discussed the necessity and desirability of the project with the initiators of the project in numerous meetings. Company documents were studied to get to know the company.

Diagnosing

The first diagnosis of the situation was described in the project proposal. Throughout the project, this initial diagnosis was further developed, based on the data collection. The data collection was carried out from January 2013 to April 2017. During this period, the first author of this paper was present at Liander for one day a week on average. He collected a large amount of data about the development process of the ALCPs, as well as about the Asset Management process and organization in general. Data were collected by working together on the ALCPs, attending meetings, semi-structured interviews (see Appendix A.3, page 309), discussions with managers, informal conversations²¹ and reading company documents and the Asset Management related discussions on the intranet. The use of these different information sources allowed triangulation (Silverman, 2006). Additionally, the project steering group met three times a year to track the progress of the project and to reflect on the developments. Finally, after each ALCP was finished, it was evaluated with the responsible asset managers in a semi-structured interview (see Appendix A.4 (page 310) for the interview questions), and using an evaluation form (Appendix A.5, page 312). After each day at the company, fieldnotes were written to capture what happened that day, and in a separate section the author reflected on his experiences, as advised by Coghlan and Brannick (2014).

Planning action

Based on the data collected, interventions were designed. The asset managers of Liander were actively involved in the development of these actions, for example by raising a concern, bringing forward an idea or, the discussion and refinement of the proposed action. All actions were related to the development of the ALCPs within Liander. Some directly (e.g. the development of a document structure) and others indirectly (e.g. the design of a method to collect information for the ALCP). For each intervention, a motivation and anticipated result was written down (presented in Table 8.4.1). The interventions were based on the literature on ALCM, as indicated in Table 8.4.1 (between square brackets).

²¹ Special attention was paid to having conversations with people not supporting the development of the ALCPs (Coghlan and Brannick, 2014).

Here, the authors have made a deliberate connection with the Design Science methodology. Section 8.3.4 discusses this topic in more detail.

Taking action

The planned actions were executed. Some by the researcher, some by the members of the organization. The ALCPs were all written by the asset managers, the researcher had the role of advisor (based on the literature and his experience with other ALCPs). Typically, the interventions were first implemented in the ALCPs being written at that moment.

Evaluating action

Each ALCP was evaluated with the asset manager(s) who wrote the ALCP, using semi-structured interviews (see Appendix A.4 (page 310) for the interview questions), and an evaluation form (Appendix A.5, page 312). Additionally, the TECCO expert sessions were evaluated by all participants, also using an evaluation form (Appendix A.6, page 314). In his fieldnotes, special attention was paid to reflections on the observed data. The progress of the research project was discussed regularly in the project steering group. Based on all these data, the consequences of each intervention were described and compared with their anticipated results (see Table 8.4.1).

The evaluations yielded the information for new Action Research cycles. Challenges in the development of an ALCP, learned during the development process or in the evaluation, were used to improve the support for new ALCPs. Learnings from the TECCO expert sessions were used in the preparation of the next sessions. The interventions made early in the research persisted²², and their weaknesses were addressed in later interventions.

However, as Action Research takes place in real life, a focus on interventions is not sufficient. Rather, it is also important to be receptive to the consequences of unforeseen events and external developments (Coghlan and Brannick, 2014). Therefore, these are discussed explicitly in the results section of this paper.

Meta-learning

After each day at Liander, the first author wrote fieldnotes to reflect on the observed data. This habit allowed him to distance himself from the daily work at the company. Additionally, he did not spend more than one day on average in the company to maintain a critical and objective stance towards the project. Furthermore, the literature was used to continually reflect on the change process at the company.

On multiple occasions, the first author discussed his ideas and preliminary findings with the project steering group, members of the organization (mainly his direct manager), practitioners from other companies (active in other sectors, e.g. fleet and process industry)

²² With one exception: the expert session was introduced twice, as discussed in the results section.

and fellow scientists. These discussions allowed him to validate and refine his ideas and conclusions, resulting in the emergence of a midrange theory on ALCM capabilities. To maintain a critical and objective stance towards the project, the author did not spend more than one day on average in the company. Also, special attention was paid to having conversations with people not supporting the development of the ALCPs (Coghlan and Brannick, 2014). Additionally, the literature used to continually reflect on the change process at the company and on a regular basis the authors discussed their observations. Furthermore, the authors shared and discussed their observations with practitioners from companies active in other sectors (e.g. fleet and process industry) to maintain a professional distance from Liander and to discuss the applicability of their findings in other contexts.

8.3.4 Action Research and Design Science

The interventions made in this Action Research project were guided by the Design Science methodology (Peffer et al., 2007; Holmström et al., 2009; van Aken et al., 2016), a methodology aiming to create practically relevant and scientifically rigorous design artefacts. The iterative approach to the design process in Design Science fits with the focus on intervention cycles in Action Research (Holmström et al. (2009) also note this parallel). Therefore, this research can be regarded as the Action Research complement to the Design Science studies carried out at Liander (see chapter 4, 5 and 7). The Design Science studies focused on the development of design artefacts²³, whereas the Action Research project focused on the change in the organization brought about by these artefacts. In that sense, this Action Research follows the ALCPs as ‘artefacts of change’ within Liander.

This combination between Action Research and Design Science is visible in the description of the interventions carried out during the project, which are grounded in the four (design) principles (Meyer et al., 2014) which follow from the Asset Management literature. This connection to literature by means of design principles addresses two of the main criticisms of certain applications of the Action Research methodology: that it creates strictly contextual knowledge which has no value outside this context (Eden and Huxham, 2006), and secondly that it is unrelated to existing theory (Blichfeldt and Andersen, 2006; Eden and Huxham, 2006).

²³ Despite the focus on the ALCP as the designed artefact, the authors acknowledge, in line with Introna (1997) and Meredith and Francis (2000), that it is not the plans per se that are valuable, but rather the planning process and the competences that underlie it. Therefore, this research focuses on the ALCM capabilities underlying these plans.

8.4 Results

8.4.1 Introduction to Liander

Liander is one of the three main Dutch network operators, responsible for the safe, reliable and affordable distribution of electricity to 3.1 million and gas to 2.5 million customers (Alliander N.V., 2017). Liander operates and maintains the transportation and distribution networks for gas (8 bar to 0,04 bar) and electricity (150 kV to 230 V) in a number of regions in the Netherlands, and is in public hands, contrary to the energy producers that use Liander's grids to transport their energy to their customers. The grids operated by Liander together represent a historical purchasing cost value of around 12 billion (milliard) euros (Alliander N.V., 2017). The reliability of these grids is comparable with the grids of other Dutch network operators (ACM, 2016), whereas the Dutch electricity grid is among the most reliable in Europe (Wolse et al., 2017).

Within Liander, the Asset Management (AM) department is responsible for the purchasing, construction and maintenance of the assets in the grids. This department is governed by the management team AM (MT AM), consisting of the managers of the different divisions within the AM department. One of these divisions is the Policy & Standardization (P&S) division, responsible for setting the rules and guidelines for the design, purchase, construction, operation, maintenance and disposal of the assets of Liander. The P&S division approached the researchers for this project, and hence this project was mainly carried out within P&S. P&S is managed by a management team (MT P&S), consisting of a general manager, the managers of the electricity and gas sub divisions and two senior advisors.

Other divisions within the AM department are for example innovation, strategy and realization. The last division forms the connection between the AM department and the other (internal and external) service providers carrying out the work prescribed by the AM department.

8.4.2 Project initiation

All of this research project started off with an accidental meeting between the Asset Management director of the Netherlands Railways and an employee of Liander. During this conversation, Liander learned that the Netherlands Railways use Asset Life Cycle Plans for their long term Asset Management. Due to the large number of different train series (about twelve), each with their different maintenance needs and remaining lifetime, in combination with the long lead times for refurbishment of trains (2-3 years) and the production of new trains (4-6 years), the Netherlands Railways needed an overview of the main Asset Management priorities for the next years. Therefore, they designed ALCPs,

that offer this insight and track the performance of the trains over time (Ruitenburg et al., 2015).

At that moment, Liander was investigating how to deal with two complex challenges about the future of their assets. On the one hand, many assets were approaching the end of their designed lifetimes and many questions arose about the remaining lifetime of these assets. As large parts of the grids were constructed in the 1960s and 1970s, Liander was afraid of a 'replacement wave': a sudden and large increase in the need to replace existing assets, which it at that moment did not have the operational capacity to facilitate. The ageing of the grids is a widely recognized problem regarding infrastructure assets in Western Europe and the USA (Brown and Humphrey, 2005; Jongepier, 2007). On the other hand, Liander saw the first consequences of the so-called 'energy transition' (see for example Kern and Smith (2008)): the transition from centralized (fossil fuel based) energy production to localized energy generation from sustainable sources (mainly wind and solar power) and the introduction of new applications of energy (e.g. electric vehicles, ground source heat pumps). This may have profound consequences for the grids operated by Liander. For the electricity grid, local energy production may reduce the capacity needed to transport electricity or may even reverse the direction of the transportation of energy (from the households to the grid instead of vice versa). However, it may also greatly increase the demand for energy, especially in cold winters when electricity would be used for additional heating or hot summers when air conditioners work at full power, but also after the rush hours when people charge their electric vehicles. Additionally, production of energy from renewable sources – especially solar and wind power – is much harder to manage than the production from traditional sources (International Energy Agency, 2011; Morales et al., 2014), due to their unpredictability and the fact that many of these sources deliver their energy to the low and medium voltage grids. Hence a need arises for new ways to manage the grid, for example by means of storage facilities (e.g. Carbajales-Dale et al., 2014) or flexible pricing (Finn and Fitzpatrick, 2014), but also by using different planning techniques. For the gas grid, the transition to using other sources for heating houses (e.g. district heating, ground source heat pumps) would make the gas grid redundant. However, the grid might be usable for the transportation of bio-based gasses or even nitrogen (if the technology to convert electricity into hydrogen would become a feasible and economically viable alternative for batteries for storage).

These challenges should be seen in light of the particularities of these grids: the assets in the grids have designed lifetimes of 40 years, so any large scale replacements would cause a forced write-off of large financial investments. Additionally, Liander aims to use the public money it depends on as efficiently as possible, and thus tries to use its assets as long as possible. As the assets currently still perform as required, only a small fraction of the total number of assets is replaced every year. A sudden increase in work volume due to ageing or the energy transition would require a far larger operational capacity than Liander cur-

rently has. Therefore, a tool such as the ALCPs, which could help Liander to better understand the future of its assets and the main Asset Management priorities resulting from this, seemed promising to Liander. Therefore, a pilot research project was initiated together with the researchers, to assess the added value of Asset Life Cycle Management using ALCPs for Liander's Asset Management.

8.4.3 Initial situation

The project started off with an exploration of the initial solution, to thoroughly understand the problem context and the needs of the organization. After a number of discussion sessions with the management team of the Policy & Standardization division (MT P&S), it was concluded that the main problem could be summarized as follows: "there currently is a limited and dispersed insight in the remaining useful lifetime of the assets (on the medium and long term) and an integral view does not exist" [July 2014]. Underlying this problem statement lay a number of causes.

First, as Liander's Asset Management was (and still is) based on condition based replacements (rather than age based), the (increasing) age of its grids was not a reason for replacements per se. However, a limited number of failures and the limited availability and reliability of data hampered their efforts to assess the current and expected condition of the assets in the grid, and thus the efforts to estimate the remaining useful lifetime (RUL) of the assets. Additionally, it was realized that the energy transition could significantly change the use of the assets, resulting in new failure mechanisms and hence very different RUL estimations.

Second, the policy documents written by P&S addressed different kind of issues on different levels of aggregation (e.g. from a specific type of switchgear from a particular production year to changes in the structure of the complete grid), having different target groups (ranging from the technicians carrying out the maintenance to strategic visions for higher management) and pursuing different goals (e.g. business case based decisions or descriptions of the impact of the energy transition). Additionally, the number of policy documents lay around 180 at the inception of the project, and was steadily increasing. Due to the large variability and numbers of documents, these did not facilitate an integral understanding of the RUL of the assets.

Third, most asset managers working within P&S had a technical education and a long history within the company. Many of them started their career in the operational departments (e.g. as team leader for maintenance technicians). This technical and operational background was reflected in the policy documents they wrote and the requests for assistance they received, which were largely focused on the technical and operational aspects of the maintenance and management of the assets. As a result, other topics (e.g. financial or sustainability) received less attention, which also limited the integral overview of the assets.

This technical and operational background also relates to a fourth factor, the fact that different divisions and departments were dealing with different aspects of the assets. Due to the separation of these departments, data were collected in different systems based on different classifications, knowledge was not always shared throughout the organization and goals were not always fully aligned. This limited the integral overview of the assets, and resulted in a potential misalignment between departments. Additionally, this disconnect was not only found between different divisions and departments (on a horizontal level in Liander's organizational chart), it was also found between the maintenance execution (by external contractors and internal service providers) and Liander's general strategy (vertical in the organizational chart). The general strategy of Liander, as described in the latest Strategic Asset Management Plan (SAMP), was not explicitly translated to the different asset types the grids consisted of in this SAMP, nor did other documents explicitly make this translation.

Finally, the asset managers of P&S indicated that a large part of their time was consumed by all kinds of operational questions and short term priorities. In a brainstorm session on their hopes for the future of the P&S division, one of them sketched the picture of a watchtower: instead of acting reactively, he hoped that P&S would develop into a watchtower, where the asset managers would be on the lookout for future challenges and able to proactively address these. This imagery was recognized by many others in the department. The occupation with short term issues and reactive responses limited their ability to develop an integral overview of the remaining useful lifetime of Liander's assets.

The consequence of not having an integral overview of the future of the assets was also felt by the P&S MT. In the discussion of the problem statement, their main concern resulting from this limitation was aired: "(therefore) it is difficult to answer the (strategic) questions from the management team in a fast and unambiguous way". Examples of these strategic questions were related to the energy transition, the possible 'replacement wave' and strategic priorities or large-scale investments for the near future. As a consequence, there were concerns in the MT AM whether or not P&S was 'in control' with their assets. Was P&S able to identify all relevant risks and threats and capable of managing these, or could the management team suddenly be surprised with large problems (e.g. large scale replacements)?

To address this issue, P&S decided that it needed to become proactive rather than reactive towards operational issues, as well as that a more strategic approach was needed in their approach towards Asset Management. Therefore, the main question for this Action Research project was defined as: "integral overview of the remaining useful life of our assets and the extent to which our assets are future-proof and how can we manage [our assets] in such a way to be 'in control' with our assets?" [July 2014]. The preliminary answer to this question was to start using Asset Life Cycle Plans (ALCPs), following the example of the Netherlands Railways.

8.4.4 Interventions

The main activity in the Action Research project was the development of ALCPs for Liander, where the ALCPs were used as an ‘artefact of change’ to develop ALCM capabilities within the organization. Figure 8.4.1 presents a timeline of the Action Research, showing the ALCPs created in the project, the main interventions carried out by the research team and the external developments having an impact on the change process. In this section, the change process will be discussed, focusing on the main interventions (indicated by the corresponding letter between <angle brackets>) and the ALCPs (indicated by the corresponding number between (parentheses)). A complete list of all interventions and external developments (indicated by [square brackets]) is presented in Table 8.4.1. In this table, for each intervention a description is given of the motivation for the intervention (including the relevant underlying ALCM principle(s)), the intervention itself and its anticipated and realized results.

The very first ALCP concerned a population of medium voltage switchgear from a specific make (1). This population was selected by Liander as due to the low age of the asset and some recent technical problems, much information was available about the asset. The main goal was to establish the RUL for this population of assets, based on quantitative information. However, it was soon discovered that even for this asset the quantitative data did not suffice for a data-based RUL estimation. Additionally, to gain an integral overview of the future of the assets it was decided that a multidisciplinary approach was necessary, following ALCM principle 1. Therefore, a focus on technical, economic, compliance and commercial (acronym: TECC) aspects of the assets was introduced , as proposed by Rob van Dongen (2011c). Also, it was decided to focus the data collection on the identification of (contextual) changes with an impact on the RUL or the performance of the assets <c>, rather than on the estimation of the RUL per se. After all, knowing the RUL is only relevant if it can be reached, in other words: if other impacts (e.g. changes in regulation (compliance) or in customer demand (commercial)) do not make it obsolete before the technically feasible RUL is reached. Therefore, it was decided to focus at those issues having a potential impact at the lifetime of the assets, which were called ‘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’. To identify these lifetime impacts and to deal with the deficiencies in the available data, next to the data-driven approach two expert sessions were organized with experts from different backgrounds and disciplines <d>. Also technicians and team managers from Liander’s service providers were invited, to include their operational knowledge and expertise. Together with the available data, the inputs from these expert sessions were the inputs for the ALCP. The data problems were reflected in the management summary of this ALCP: “The main issue for the population lies in the incorrect and incomplete data, analyses and information” [ALCP 1, p.6].

Figure 8.4.1 - timeline of the Action Research project, listing the ALCPs (blue, 1-10) as well as the main interventions (orange, a-o) and external developments (pink, A-E). See Table 8.4.1 for a more elaborate description of the interventions and external developments

In the evaluation of this first ALCP, it was argued that its level of detail was too high, and that the ALCP should be limited to 10 pages of main text to suit the time the MT AM has available for such a document. Also, the document was mainly a description of the current situation, *“giving information that should be there, but not in the ALCP”* [member MT P&S, May 2014], as the ALCP was expected to use this knowledge to create insights valuable for the MT AM, rather than just to present all information available. To make the ALCP more relevant for the MT AM and to reduce its level of detail, it was decided to focus future ALCPs on a complete population of assets (e.g. all medium voltage switchgear or all power transformers) <e>. Another reason for this choice was to limit the number of future ALCPs and the corresponding effort required to write and regularly update these ALCPs. Following the change of focus of the ALCPs, two sessions were held with the MT P&S to discuss the desired scope and goal of the ALCP <h>, as it was found that very different views of the ALCP existed (also in the MT P&S), resulting in a lengthy and detailed ALCP as it had to fulfil all these different demands. To help the asset managers to change their view of the ALCP accordingly, a number of learning sessions was organized with asset managers from the Netherlands Railways who had years of experience in working with ALCPs <j>.

Based on this discussion on the scope and goal of the ALCP, a document structure for the ALCP was developed <i>, to make clear what information should be presented in the ALCP (and also: what not!) and to streamline the writing process of the ALCPs. This structure also addressed a need from the asset managers, who continuously asked for clear guidance regarding both the desired contents of the ALCP and its structure. The developed structure was highly appreciated by the asset managers: “the structure was a great help” [writer of ALCP (4) – July 2014]. Nevertheless, most ALCPs (except (7) and (9)) required extensive rewriting by members of the MT P&S <k> in order to make the structure and tone of voice suitable for the MT AM.

While writing the ALCP on distribution transformers (3), the O for Organizational lifetime impacts was added to TECC, resulting in TECCO <g>. This perspective was added to address the problems in the quality of maintenance execution resulting from reductions in knowledge and skills among technicians, especially relevant for a small number of non-standard assets that required specialist knowledge. Additionally, the limited capacity of the service providers to carry out construction and maintenance activities, in the face of the energy transition or a replacement wave, was an important reason for the inclusion of this perspective. The organizational perspective was to address all opportunities and threats for the assets resulting from the ability and willingness of the organization to maintain and manage the assets. During the remainder of the project, these five perspectives were found to cover all relevant lifetime impacts for the assets of Liander.

Table 8.4.1 - description of the main interventions (a-o) and external developments (A-E) during the Action Research project. For each intervention, a motivation is given, the related underlying ALCM principle(s) (if relevant), as well as a description of what was done and the anticipated and realized results (continued on next page).

	intervention	motivation [ALCM principle]	description
a	involvement in creating the ALCPs	to assist Liander's asset managers in the collection of information and writing the ALCP (and to study this process) [-]	the first author was intimately involved in the creation of all ALCPs (at least 5 meetings for each ALCP), mainly in the role of advisor (on process and contents) and reviewer.
b	introduction of TECC	to introduce a multidisciplinary approach to ageing in the ALCPs [1]	Rob van Dongen (2011) proposes four different types of ageing (technical, economic, compliance and commercial) of physical assets
c	introduction of lifetime impacts	the RUL estimation was hindered by data deficiencies, the uncertainty of the future and the often very long lifetimes of the assets [2,4]	it was decided to focus the ALCPs on (the identification of) positive and negative lifetime impacts based on TECC, rather than the estimation of the RUL.
d	introduction of expert sessions	the information about the assets was found to be dispersed throughout the organization [1]	to gain an integral and multidisciplinary overview of the assets, experts from different disciplines were brought together in expert sessions (workshops) to identify all relevant lifetime impacts
e	ALCP on complete population	the first ALCP was considered too detailed and operational rather than strategic [-]	it was decided to focus all future ALCPs on a complete asset, contrary to the first ALCP, which focused on a subpopulation of only 6% of all MV switchgear
f	ALCP-presentation to MT AM	to introduce the ALCPs to the MT AM and to gain its support for the Action Research project [3]	the director of the maintenance organization of the NR (also involved in this project) presented the role and use of the ALCPs at the NR
g	addition of the O to TECCO	to address an important issue for Liander: the reduction of skills and knowledge within the organization and its operational capacity [1,3]	the O for Organizational lifetime impacts was added to TECCO to identify lifetime impacts ranging from the organization, e.g. regarding skills and knowledge
h	determination of what an ALCP is	many different views on the ALCPs evolved within P&S, which did not all correspond to the goals of the project. [3]	two sessions were held to discuss the characteristics of the ALCP and the goal(s) it needed to pursue, to communicate a clear and consistent view
i	introducing a generic ALCP structure	the asset managers asked for guidance about the contents (incl. information needs) and structure of the ALCP [-]	a generic structure was developed in analogy to the structure of the ALCPs of the NR and in consultation with the asset managers and the MT P&S
j	learning sessions on NR ALCPs	to make Liander's asset managers acquainted with the ALCPs of the NR and to learn from their experience [-]	four different 'learning sessions' were organized with 3 asset managers from the NR and 4-6 asset managers from Liander
k	rewriting the ALCPs	the P&S managers considered the ALCPs too detailed to address the needs of the MT AM [3]	to make the ALCPs better suited for the MT AM regarding level of detail and strategic concerns, the P&S managers assisted in rewriting the ALCPs
l	writing in pairs	the writing was often interrupted by other tasks, structuring detailed knowledge was difficult for the writers [-]	it was decided to start working in pairs: the asset manager for the contents and details, the other for writing, structuring and keeping the process uninterrupted
m	involvement of stakeholders	getting ALCP (5) approved was difficult as other divisions held a different view on the future of these assets [1,3]	the involvement of the main stakeholders (mainly from other AM divisions) in the information gathering and reviewing phase to gain their support before starting to write the ALCP
n	introduction prioritization tool	the large number of diverse lifetime impacts resulted in a non-transparent and emotion-based prioritization [4]	a prioritization tool was developed to support the asset managers to assign priorities to the lifetime impacts in a structured and transparent way
o	discussions on ALCP actions	the integral and strategic nature of the ALCPs resulted in new actions, outside P&S's span of control [3]	discussions with managers of P&S showed they considered it the task of the asset managers to follow up on these actions even outside their span of control
A	energy transition	none (not an intentional change)	the energy transition makes new demands on Liander, forcing the organization to adapt its Asset Management to these new circumstances
B	rethinking P&S	the asset managers of P&S did not always feel 'successful and appreciated' in the AM organization	to make P&S 'successful and appreciated', its role, its added value, the ideal for the future and the next steps were discussed in a number of sessions
C	restructuring the policy documents	the large number of policy documents of P&S (180 and growing) limited an integral overview	an external consultancy firm assisted P&S to restructure their policy documents in three main types, with the ALCP as the strategic document
D	writing course	the MT AM considered the documents written within AM to be too lengthy and containing too much detail	a writing course, taken by all asset managers of P&S, taught them to structure a document based on its main message and to involve stakeholders when developing this message
E	the new AM vision	the energy transition raised many questions about the AM department's role and strategy	in a number of workshops with the different AM divisions, the MT AM translated the new corporate strategy to a new AM vision

Table continued from previous page.

	intervention	anticipated result	evaluation of the intervention
a	involvement in creating the ALCPs	the creation of ALCPs fulfilling the requirements from the literature and the desires of the MT P&S	the supporting and advisory role was appreciated by all asset managers in the evaluation interviews
b	introduction of TECC	a multidisciplinary focus on ageing in the ALCPs	the focus on the four TECC types of ageing assisted the asset managers not to solely focus the ALCPs on technical ageing
c	introduction of lifetime impacts	a focus on the lifetime impacts in the ALCPs, to address these lifetime impacts with timely measures	the heart of each ALCP is the identification of lifetime impacts using TECC
d	introduction of expert sessions	a joint, integral and multidisciplinary overview of the assets to use in the ALCP	the expert sessions resulted in a deep understanding of the relevant lifetime impacts, but also created support for the ALCP from the experts involved
e	ALCP on complete population	a more strategic and less detail-rich ALCP, which would take less time to write	all remaining ALCPs covered a complete asset population, as this was found to be both more valuable and more workable
f	ALCP-presentation to MT AM	the Action Research project gained the support of the MT AM	the MT AM received a basic understanding of the ALCPs at the NR, and decided to support the project
g	addition of the O to TECCO	a full overview of the lifetime impacts relevant for Liander, and for Asset Management in general	in the remainder of the project, no further additions to TECCO were made.
h	determination of what an ALCP is	a clear and consistent communication about the ALCP to the asset managers from the MT P&S	the discussions resulted in a clear description of the ALCP and a growing understanding among the asset managers
i	introducing a generic ALCP structure	a clear structure for the writers of the ALCP, consistency in the structure across the ALCPs	the structure was highly appreciated by the ALCP writers and facilitated further discussion on the contents of the ALCP
j	learning sessions on NR ALCPs	enthusiasm to develop ALCPs at Liander and knowledge and advice about how to do so	the learning sessions were appreciated by the asset managers of NR and Liander and offered valuable insights to both
k	rewriting the ALCPs	ALCPs that suited the needs of the MT AM and were as a result appreciated and easily approved	addressing the divergent needs of the MT AM turned out to be difficult, which made getting approval a lengthy process
l	writing in pairs	a shorter lead time for the ALCPs and a smoother ALCP writing process	shorter lead times were reached in most instances, but still the time and availability of the asset manager remained crucial
m	involvement of stakeholders	a shorter approval lead time and a larger support for the ALCP contents within the organization	the final ALCPs encountered less discussion, but lead times remained the same due to time constraints of the MT AM
n	introduction prioritization tool	a structured and streamlined process of prioritizing lifetime impacts	the tool facilitated a transparent prioritization, but also increased the understanding of the lifetime impacts
o	discussions on ALCP actions	clarity about the tasks of the asset managers and support for how to deal with these actions	a clear idea about the tasks of the asset managers and a discussion on how to involve other stakeholders in these actions
A	energy transition	none (not an intentional change)	the energy transition forced the AM organization to change (see also [E])
B	rethinking P&S	a better understanding of the value of P&S and a plan to improve its value for the MT AM	it was found that P&S needed to become more proactive and needed to give strategic advice on the future of Liander's grids
C	restructuring the policy documents	a lower number of policy documents better suiting the needs of their target groups	the target groups of the different policy document types felt better served with the new documents
D	writing course	shorter and more readable documents for the MT AM, and less rework in the writing process	the ALCPs were structured by their main storyline, the existing structure <i> remained underlying these 'storyline-based' ALCP
E	the new AM vision	a clear understanding of the role of AM and a new strategy for the AM organisation	the ALCP nicely fits in the new vision, mainly in the priority 'smarter exploitation of assets'

In the evaluation of the second ALCP (2), it was found that the lead time of writing this ALCP was quite long. That was partly caused by the changes in the goal <h> and desired structure <i> of the ALCP, but also because the asset manager was often occupied with all sorts of operational questions and demands. And if these come, “than we work on them, that’s also part of our job description, so I understand the need, but then we as a group [P&S] must also realize that [giving other tasks a higher priority than the ALCP] has consequences for the lead time [of the ALCP]” [writer of ALCP (1), (2) and (8) – November 2015]. To prevent the ALCP writing process being interrupted from all these emerging tasks, it was decided to start working in couples <l>. In the later ALCPs, the asset manager writing the asset, having all required knowledge, expertise and connections, was assisted by a person with good skills in writing and structuring. In this way, the impact of interruptions was reduced but also the asset managers were assisted in structuring the large amount of details they knew about the assets.

Another reason for long lead times lay in the decision making process to get the ALCPs approved. The best example is presented by the ALCP on gas transportation pipelines (5). This ALCP was discussed in the MT AM in January 2015, but due to the large number of comments, questions and proposed revisions, and the lack of motivation resulting from this, the ALCP was only approved in March 2016. One of the members of the MT AM stated “I think it is a mediocre, if not insufficient, document. The goal is to present a frame of mind, but a vision is missing and I see too many short term details” [January 2015]. As a follow-up, meetings with all MT AM members were scheduled to discuss their concerns and to explain the goal and contents of this ALCP. It turned out that misunderstandings and a lack of information exchange between the writer of the ALCP and these divisions (also caused because no expert sessions were held for this ALCP) was the main reason for the rejection of the ALCP. Therefore, it was decided that the later ALCPs should put effort into the timely involvement of stakeholders and decision-makers in the writing of the ALCP <m> in order to increase the speed of the approval process and develop a broadly supported and shared view on the future of the assets.

This involvement of stakeholders was also stressed in the writing course [D] organized by the MT P&S. The goal was to improve the writing skills of the employees of AM to make their documents better suited for the MT P&S and ultimately the MT AM, as well as to reduce the amount of rework needed before the documents were considered fit for the MT AM. This course was based on the pyramid principle as introduced by Minto (2008), which states that every piece of text should be structured to bring its main message across in the most efficient way. Additionally, it was advised to first discuss the main message of a document with the main stakeholders (fitting nicely with <m>) and only then to start writing the final document, to prevent rewriting complete texts. These lessons were also followed up in the later ALCPs. As a result, the ALCPs were no longer structured according to the developed structure <i>, but based on their main storyline. The structure remained

fundamental to the data collection of the ALCP, but the results were largely used to back-up the main storyline of the ALCP and were only presented in full in their appendices. Over time, the expert sessions were developed further, and now included not only a discussion of each TECCO perspective but also an individual brainstorm using forms especially designed for this purpose. This resulted in a very large number of very different lifetime impacts. As a result, the writers of the ALCPs selected the lifetime impacts they considered most important for their ALCPs, but they admitted this was a non transparent and sometimes emotion-based process. Therefore, a lifetime impact prioritization tool was developed <n>. This tool was found to bring structure and transparency to the prioritization of the lifetime impacts, and by also involving experts from other divisions the prioritization was no longer a consequence of the individual views or preferences of the writer of the ALCP, but a combined priority of different experts throughout the AM department (consistent with <m>). The outputs of the tool were also used for further discussion to further increase the understanding of the lifetime impacts and their potential consequences. As the ALCPs matured and became more strategic in nature, questions arose regarding the actions resulting from the ALCPs. The asset managers found that the actions they wanted to propose in the ALCP resulted in discussions in the MT P&S, a reason why one ALCP (5) was even sent for approval to the MT AM without any actions listed. This issue was discussed repeatedly with several ALCP authors and members of the MT P&S <o>. The discussions showed that, as the ALCPs became more strategic and integral over time, also the actions ranging from the ALCPs changed in this direction. As a result, actions to address lifetime impacts identified in the ALCPs not always lay within the direct span of control of the asset manager, but were considered to be the task of other divisions. This issue was discussed and analysed at length <o>, and resulted in the conclusion of the MT P&S that the asset managers should follow up on these lifetime impacts, as their role was considered to be not just an advisory one, but also to include a responsibility for the performance and future value of the assets for the organization at large.

8.4.5 Asset Life Cycle Plans

Table 8.4.2 presents an overview of the 10 ALCPs written during this Action Research project and gives their most important characteristics. From these characteristics, a number of developments emerge. First, the level of detail of the ALCPs diminished over time. Where the first ALCP (1) described 2500 assets worth about 50 million euros in 17 pages of text, ALCP (4) covered 86,000 km of cable with a replacement value of about 6,000 million euros (including 4,500 million of construction costs) in only 10 pages. While the number of pages of the main text decreases over time, the number of pages in the appendices increases, showing that less detail was regarded necessary for the main text of the ALCP (also as a consequence of the writing course [D]).

Table 8.4.2 - overview of the main characteristics of the ALCPs written

#	Name	Asset	# of as-sets	replac-ment value	# of wri-ters	Start date	End date	Writing lead time	Approval	Approval lead time	Struc-ture	Expert session	Pages main text	Pages appen-dix
1	ALCP type X	type of medium voltage switchgear	2,500	50M	3	May 2013	Jan 2014	9	-	1	format-based	2	17	9
2	ALCP MV switchgear	medium voltage switchgear	43,000	1000M	1	Feb 2014	Apr 2015	15	May 2015	2	format-based	-	28	11
3	ALCP DB trans-formers	distribution trans-formers	34,000	220M	1	March 2014	Aug 2014	5	Sept 2014	2	format-based	-	13	5
4	ALCP cables	cables	86,000 km	6000M	1	July 2014	Jan 2016	19	Feb 2016	2	story-based	-	10	22
5	ALCP gas trans-portion	main pipelines	35,000 km	3500M	1	July 2014	Dec 2015	18	March 2016	4	story-based	-	7	42
6	ALCP power transformers	power transform-ers	600	260M	2	March 2015	Nov 2015	9	Dec 2015	2	story-based	1	9	35
7	ALCP gas deliv-ery stations	gas delivery sta-tions	15,000	300M	2	May 2015	Dec 2015	7	Feb 2016	2	story-based	2	11	13
8	ALCP HV switchgear	high voltage switchgear	8,000	650M	2	Oct 2015	-	19+	-	-	-	1	-	-
9	ALCP gas distri-bution	service pipelines	2,000,000	1600M	2	Jan 2016	Aug 2016	8	Jan 2017	5	story-based	2	16	17
10	ALCP electricity connections	household connec-tions (electricity)	3,100,000	3000M	2	Jan 2017	-	4+	-	-	-	-	-	-

Second, for the first ALCP (1), two expert sessions were held to involve experts from other backgrounds and divisions. However, the next few ALCPs did not make use of expert sessions, irrespective of the first author proposing to do so (as a part of his constant involvement in the ALCPs <a>). It turned out that the asset managers suspected their knowledge was sufficient for writing an ALCP without asking for external input (except to answer specific questions). However, in the evaluation of their ALCPs, these asset managers acknowledged an expert session might have helped, to get a broader information input but also to be exposed to the ideas and questions of other experts. For example, the asset manager who wrote ALCPs (3) (without expert session) and (6) (with an expert session) stated as his main advice for a next ALCP to “start with a TECCO workshop [i.e. expert session]” [Nov 2016]. The later ALCPs did all use an expert session, (7) and (9) did even two: one with the technical and operational specialists from Liander’s (maintenance) service providers, another with the colleagues from the AM department. This made the ALCP a rendition of their shared understanding of the future of the asset and thus increased the support for the ALCPs. It also clearly shows the two different foci in the ALCP: a foundation in the technical assets, its operation and its maintenance regime, and based on that a more strategic analysis of the assets future. Both were found to be critical for the success of the ALCP: without the operational grounding a strategic analysis may lack the connection with the everyday practice, without the strategic analysis the operational description does not create any added value for the MT AM (as was the conclusion about ALCP (1)). To make sure that the ALCPs were all grounded in an effective and comprehensive maintenance regime, each expert session started with an evaluation of the current maintenance practices of the assets.

A third important development that presents itself from the data given in Table 8.4.2 is how the ALCPs changed from a description of the performance of a subpopulation of assets, to a more prescriptive document regarding the Asset Management strategy for a complete population of assets, which also better suited the needs of the MT AM. This progress can be illustrated with three ALCPs, each adding an extra layer of analysis and strategy to the previous ALCP. The very first ALCP (1) mainly described the current performance and maintenance policies of a population of a specific type of medium voltage switchgear, giving as its main conclusion that, based on the data available when writing the ALCP, the current maintenance policy did not need to be changed. Next to the description of the population performance (which was placed in the appendix), ALCP (6) proposed a change in the maintenance strategy for the power transformers to cope with the ageing of the population and the limited operational capacity to quickly repair or replace transformers after a failure: from corrective maintenance to a preventive replacement strategy. The last ALCP that was finished (9) went a step further still: not only did it propose a new Asset Management strategy for the gas distribution pipelines, but it also presented a strategic vision for the future of the gas grid in the energy transition [A]. The MT

AM even proposed to split the document into two, as an acknowledgement of these two important aspects of the ALCP, but this did not happen as the authors regarded the strategic vision to be an integral part of the ALCP.

8.4.6 The role of the ALCP in the organization

With the changes of the ALCP as a document, also its role within the organization changed. In the evaluation of the ALCPs with the asset managers and their managers, a number of merits of the ALCPs stood out.

First, the ALCP offers an integral overview of a population of assets. This integrality has two different aspects. First, it is a multidisciplinary overview of the asset, based on the five perspectives of TECCO, which also “leads to new insights” [writer of ALCP (5) – December 2016]. Second, it is a joint understanding of the asset’s future, shared by experts from different divisions of the organization, ranging from operational to strategic and covering different aspects of the asset (e.g. in the last ALCP (10) even the customer department (outside AM) is involved). As a result of this integrality, the goals and activities of the different divisions are aligned and the risk of sub optimization (when different divisions pursue different and contradicting goals) is reduced.

Second, the identification and analysis of future opportunities and threats using TECCO allows the asset managers of Liander to become proactive. Rather than being confronted with urgencies that need their immediate response, it helps them to identify these issues in time to manage these in a proactive way. As discussed earlier, the initial situation was described by the MT P&S as “it is difficult to answer the (strategic) questions from the [AM] management team in a fast and unambiguous way” [July 2014]. During this project, this changed considerably, which can be illustrated by a blog message of the chair of the MT AM. In this blog post [Feb 2017], the MT AM chair stated: “Recently I was surprised by P&S with a policy document, in which they expounded how we should deal with the developments regarding natural gas [due to the energy transition [A]]. I was surprised, because I was about to ask P&S if they would be willing to start working on this topic, but then it was already there. Great!”

This also indicates that progress was made to achieve the first goal: to show the MT AM that P&S was ‘in control’ with its current maintenance and Asset Management. Maybe even some progress was already made on the next step: taking control of the future of the assets. In other words, its Asset Management became strategic and proactive, rather than operational and reactive. The ALCPs helped to make this development, as it intended to address the needs of the MT AM, which are strategic in nature, a third merit of the ALCPs.

Fourth, the ALCP also helped the asset managers to make their priorities clear. In the evaluation interview with one of the authors of the ALCP gas delivery stations (7), it was stated that the ALCP helps to become more proactive in the management of the assets and creates a clear roadmap of the main priorities for the future. In this way, an overview

is created of what is important to work at (and what is not). The asset managers expected that this would also reduce the need for fire-fighting in the future.

Finally, the Action Research methodology also asks that the results of the Action Research project persist within the organization after the project was ended (Reason, 2006). It may be expected that the ALCP will remain important within the Liander Asset Management organization, for at least three reasons. First, the ALCP has become a central document within the new document structure of the P&S division [C]. Second, on multiple occasions members of the MT P&S have stated that the ALCP would be one of the main inputs for the next Strategic Asset Management Plan (SAMP), one of the main documents on long term Asset Management at Liander. And third, when the first author asked the MT P&S about their needs regarding the transfer of his knowledge and skills to the members of the organization, its members responded they did not expect any difficulties with writing the next ALCPs without the support of the first author, as many asset managers were intimately involved in the change process and the development of the ALCPs.

This development also reflects the changing role of the first author in the organization: at the start of the project he was actively involved in the collection of information and the writing of the ALCP. For later ALCPs, especially after the document structure had been established <i>, his role changed into a more advisory role. Additionally, as he was the only person involved in the creation of all the ALCPs, he started to be seen as the main ALCP expert in the organization. This position also allowed him to observe more generic problems in the developments of the individual ALCPs, such as the difficulties with the ALCP actions <o>, and to initiate and discuss further improvements of the ALCPs with the other asset managers.

8.4.7 ALCM capabilities

The change process at Liander also offers us the opportunity to learn about the capabilities needed for strategic and proactive Asset Life Cycle Management. In this final part of the results section of this paper, the discussion will focus on the need for new and additional ALCM competences that emerged during this change process. Five different capabilities will be discussed: 1. using information in a strategic way; 2. relating with both higher management and the operations (vertical alignment); 3. creating a joint understanding on the asset using the expertise from different disciplines (horizontal alignment); 4. focusing on both short term operational issues as well as long term strategic topics (dual time perspective); and 5. exerting control over the assets even outside the official span of control of the asset manager.

1. using information in a strategic way

A first notable competence is the ability to deal with imperfect data. At the inception of the project, the asset managers felt greatly limited by the availability and quality of the

data they needed, as according to them the imperfection of the data made it impossible to use the data at all. But over time, this changed. Getting the right data remained a challenge, but the asset managers no longer felt obstructed because of the lack of data. Rather, they learned that for the purpose of the ALCP, very accurate and precise estimations (e.g. of the RUL) were not necessary. Instead, the ALCP should globally sketch the future of the asset, and also limited data are often able to create such a picture. In the words of one of the asset managers: “because back in the days we did not register everything accurately, one has to deal with a level of uncertainty. That is not a problem [for the purposes of the ALCP], but if it [the uncertainty] is too large it does become a problem” [writer of ALCPs (1), (2) and (8) – November 2015]. The writing course [D], initiated by the MT P&S, complemented this transition by teaching the asset managers to write their documents in a more strategic and less detailed way.

Simultaneously to this new way of dealing with quantitative data, the asset managers realized that their knowledge and experience (as well as those of other experts) was a valuable complement to the data and thus should be used accordingly. An interesting case was presented by the ALCP gas transportation (5), where the analyses of the data predicted a stark increase in the amount of replacements needed in the near future, while the asset manager did not see this based on his experience and contacts within the organization. A few months later a further analysis of the data proved his intuition right, as certain assumptions within the model did turn out not to be true.

However, this does not mean to imply that intuition is more important than the data itself. Rather, another important use of data was found to be to deal with rumours and emotions within the organization. Some assets have the reputation of being unsafe or unreliable, and data – especially when written down in the ALCP – can be used to counter these images if they misrepresent the objective facts. This relates to what the chair of the MT P&S also stated when talking about the ALCP, that “it objectifies information” [Dec 2014]. By taking away reputations and emotions, the ALCP allows to objectively discuss the performance of different assets and to compare these.

To summarize, a first capability for ALCM is *the ability to abstract the main trends out of imperfect data and to complement these with knowledge and experience*.

2. relating with both higher management and the operations (vertical alignment)

This different way of interpreting data relates to a second important competence: the ability to relate with the concerns of the higher management, based on a clear understanding of the assets and the operations. The ALCP started with concerns from the MT AM regarding the future of the grids in the face of the ageing of the assets and energy transition, as well as the concern whether or not P&S was ‘in control’ with the assets. By starting the ALCP with the strategic objectives with the assets and involving experts from the operations in the expert sessions, alignment was created between these two levels

within the organization. In the words of one of the asset managers: “we are often occupied with very individual asset risks, for small groups of assets. And that limits one’s attentiveness towards strategic developments. By making an ALCP one moves to the tactical and strategic level, that’s what the ALCP is about” [writer of ALCPs (3) and (6), Oct 2014]. This was corroborated by the writer of ALCP (4), who stated that the added value of the ALCP was that “it provides direction to the organization” [March 2016].

However, this alignment was not limited to the consideration of strategic objectives in the more operational aspects of Asset Management, it also worked in the opposite direction. The evaluation of the current maintenance policy at the start of each expert session provides an example: here the feedback from the maintenance technicians was collected to improve the maintenance instructions and planning. This feedback even led to changes in the Asset Management strategy, as shown by ALCP (6) where due to a limited operational capacity to repair or replace power transformers a preventive replacement strategy was initiated.

3. creating a joint, multidisciplinary understanding on the asset (horizontal alignment)

This vertical alignment – ranging from the strategic concerns of the higher management to the operations – needs to be complemented by a ‘horizontal alignment’ over different departments and disciplines. The asset manager should have the skills to bring all information relevant for the assets together. In that sense, the asset manager should be like a spider in a web for all information and plans regarding the assets. The asset manager does not have to be a specialist on all topics, but should be able to bring it all together. In the words of one of the asset managers: “you need to have a specific type of person who does it [writes the ALCP]. You are not looking for a specialist [literally: a person with a great eye for details], because they immediately go into great detail, but you do [emphasis] need someone who has the technical understanding of everything that is going on” [writer of ALCPs (3) and (6), Oct 2014]. This also relates to the communicative skills of the asset manager. Some asset managers first tried to finish the ALCP and only then started to involve stakeholders by convincing them of the contents of the ALCP. This resulted in long and detailed discussions and lengthy decision-making processes. The later ALCPs actively involved stakeholders early in the process, which resulted in a broadly supported ALCP. These ALCPs were no longer regarded as policy documents from the P&S division, but rather: “of the complete Asset Management department” [writer of ALCP (7), Feb 2016]. Therefore, the third capability can be described as *the ability to connect with the experts from different disciplines relevant for the asset and to jointly create an understanding of the future of the assets.*

4. focusing on both short term operational issues as well as long term strategic topics

Being a spider in the web as an asset manager also results in a lot of demands being made, questions being asked and issues to be dealt with. However, this daily stream of requests does not fit with the long term and strategic focus of the ALCP. This was acknowledged by the writers of the ALCP, who wrote down as his main advice for future ALCPs to “structurally reserve time [...] for working on the ALCP in order not to let one be driven by the day-to-day hustle and bustle” [writer of ALCP (1), (2) and (8), Nov 2016]. This points at a dual time perspective needed in Asset Management: on the one hand on the daily (operational) affairs and problems, on the other hand the future (strategic) directions and outlook, as the same asset manager stated in an earlier interview: “you are pulled out of the day-to-day hustle and bustle [by the ALCP] and have to put more thoughts into the future. That adds an extra dimension to us as asset managers” [writer of ALCP (1), (2) and (8), Nov 2015]. These two time perspectives need to be combined, but it turned out that it is hard to do so by a single person. Therefore working in teams was proposed for the ALCPs, and – as this was also acknowledged by the manager of the P&S electricity group – within P&S different asset managers now have a main focus on only one of these two time perspectives. The asset managers also admitted that the ALCP helped them to step away from the daily hustle and bustle and to change their focus to the long term and strategic side of Asset Management. This helped them to gain control over the assets and to set their priorities accordingly: “[b]ecause *now* [emphasis] [with the ALCP] I can start thinking like ‘alright, our knowledge is diminishing, we need to take specific action’, [...] so for me it’s easier now to decide which projects I need to join and which not” [writer of ALCP (7), Feb 2016]. To summarize, this fourth capability can be described as *the ability to simultaneously focus on short term operational issues and long term strategic topics*.

5. exerting control over the assets even outside one’s official span of control

A final competence developed further during the Action Research project was *the ability to take control over the (performance of) the assets even outside their direct span of control*. When the research started, the main activity of the asset managers was to develop maintenance and design instructions and to develop policy solutions to mitigate operational risks (e.g. potential safety hazards). As described in the section on the ALCPs, the first ALCP (1) was mainly a description of the performance of a subpopulation of assets. Over time, the ALCP developed into a more prescriptive document regarding the Asset Management strategy for a complete population of assets. This was felt by the asset managers as a way to exert influence in the Asset Management organization. “We are working on a project ‘ageing assets’ with [an OEM], but we cannot get it into motion, and by making an ALCP you are able to make the MT [AM] aware of what needs to happen, to use them as a lever to get these trajectories into motion” [writer of ALCP (1), (2) and (8), Nov

2016]. Also, the ALCPs identified lifetime impacts that did not fall within the span of control of their normal tasks and job description. For example, a threat identified in most ALCPs was the reduction of skills and expertise among the technicians doing construction and maintenance work, resulting in a lower quality of the assets. However, the asset managers of P&S only prescribe what needs to be done and according to what rules, but did not have any influence on the skill levels of the people executing these jobs (sometimes employed by service providers rather than by Liander). As a result, the ALCP created a tension between the intended actions of the asset managers and their official role and mandate. This issue was discussed at length as a part of intervention <0>, and resulted in the conclusion of the MT P&S that the asset managers should follow up on these lifetime impacts, as their role is not just an advisory one, but also holds a responsibility for the performance and future value of the assets for the organization at large.

8.5 Discussion

From our study of the change project carried out at Liander, five ALCM capabilities emerged. When we compare these with the four ALCM principles abstracted from the literature, four remarks can be made.

First, the literature largely overlooks the problems of using information for strategic purposes, the first ALCM capability emerging from our research. The literature considers the problems of insufficient and unreliable data in maintenance (e.g. Si et al., 2011; Jongen, 2012; Braaksma et al., 2013), and also adds that expert knowledge may be used to resolve these data problems (e.g. Garg and Deshmukh, 2006; Si et al., 2011). However, dealing with information in a different, more strategic way seems to be a new and important ALCM capability ranging from this research.

Secondly, our second and third ALCM capability considered horizontal (multidisciplinary) and vertical (strategic to operational) alignment within the organization. These capabilities are in line with what we found in the literature (compare ALCM principles 1 and 3). However, what we add to the literature is how multidisciplinary expert sessions and the resulting ALCPs may help to create this alignment. As described in the literature, this allows to gain a 'bigger picture' of the asset. However, just having this picture is not enough, as our research showed. It is equally important to develop this picture in collaboration (e.g. in expert sessions), to create a 'joint bigger picture' on the assets.

Third, the fourth ALCM capability covers the joint consideration of the short and long term, which we may even call 'time alignment'. Just a focus on the short term issues is not enough, nor is a singular focus on long term, strategic issues and the anticipation of future change sufficient. Only by combining these two time perspectives, the assets can be managed effectively. The existing literature is clear about the importance of these two separate perspectives, but does not offer much guidance as to how to combine these two (ex-

ceptions are more specific fields such as Life Cycle Costing (e.g. Woodward, 1997; El-Akruti et al., 2016) or design for maintenance (e.g. Mulder, 2016). This paper may yield additional insights on this topic, which seems a promising area for further research.

Finally, the fifth ALCM capability discusses how asset managers may need to step outside their direct span of control to effectively manage their assets. This relates to horizontal alignment and bridging functional silos (Peppelman and Kramer, 2012). However, it also requires a sense of responsibility and ownership over the assets and its performance, and the willingness and skill to exert influence outside one's span of control. This does not just ask for management skills, but also for communicative and networking skills. This may be an important capability, especially in the brink of contextual change the organization(al structure) is not prepared for. This asks for ownership (Chan et al., 2005; Longley et al., 2012; Sutton and Chadwick, 2014; Jooste and Vlok, 2015), but also appropriate management support (Phelps, 2011).

8.6 Conclusion

Asset Life Cycle Management (ALCM) requires a strategic focus on the complete life cycle of physical assets, from a multidisciplinary perspective. However, even though the goal to reach is clear, the process to get there is far from self-evident. The literature and practitioner standards such as ISO 55000 do not offer any guidance regarding this change process. Therefore, this paper set out to study the change process towards ALCM, to shed light upon the capabilities that are needed to do Asset Management in a strategic and proactive way.

This was studied during a four year Action Research in an Asset Management organization. Asset Life Cycle Plans were introduced and a number of interventions were made, based on the literature, to assist the organization in their development towards ALCM. Important to note is that, while the ALCP was a new document, the majority of their contents was knowledge and information already available within the organization. However, due to how the Asset Management organization was structured and how the asset managers operated, the full potential of this information remained unutilized. By developing the ALCPs in cooperation with the asset managers, five ALCM capabilities emerged that allowed the organization to make the most of the information available.

First, it turned out that for strategic Asset Management, it is important to be able to interpret data in a more strategic way, focusing on the main trends than on the imperfections of the data. Additionally, asset managers could use their knowledge and experience to complement the quantitative data. Second, an important capability is to be able to relate both with the concerns of higher management as well as with the operations and the characteristics of the physical assets. A third ability lies in establishing the connection with experts from different disciplines relevant for the assets and to create a joint understand-

ing of the future of the assets among the experts. Not only does a strategic approach to Asset Management require an alignment between different levels and disciplines within the organization, but also a combination of two different time perspectives: on the one hand on short term operational issues, on the other hand on long term and strategic matters – the fourth capability. It may be difficult to combine these two time perspectives within the same person, which is why assigning different people to the short and long term may be considered. Finally, as a result of all the (organizational and time) boundaries crossed in strategic Asset Management, the final competence required is the ability of the asset manager to take control over the (performance of) the assets even outside his direct span of control. Only by exerting influence also outside his direct mandate, alignment can be created and the maximum value of the assets can be realized.

8.7 Limitations

The conclusions ranging from this study have a number of limitations. A first limitation is inseparable from the Action Research methodology, namely that only one case company and one change process have been studied. This results in a deep understanding of this unique situation that could not have been reached in any other way, but also raises the question which of the findings are context dependent, and which are more generic. During the research, this question has been addressed by confronting our emerging findings with the literature as well as with the experience of asset managers in other organizations. Therefore, we are confident that the capabilities discussed in this paper bear scientific relevance also outside the unique situation of the change process studied. This limitation regarding the generalizability of the findings may be addressed by a replication study in a different Asset Management organization. However, the change process will be different there by definition, as every (initial) situation is unique, for example in the skills and data available and the organizational structure. On the other hand, if an organization is found to be able to do strategic Asset Management without at least one of the capabilities described in this paper, the results of this paper can be refuted. Such a validation study could also take the form of a survey study to test the generalizability of the results presented in this paper.

8.8 Implications

A number of implications flows from the findings of this paper. First, it is important to realize the importance of aligning Asset Management to the strategic concerns of higher management and even the board of directors. Even though they are often not aware of the operational and technical details of the assets the company depends on, according to LaRiviere et al. (2016), “[e]xecutives in asset-intensive industries often regard unexpected

failures of their physical assets as the primary operational risk to their business". Explicitly addressing such concerns is likely to increase the importance of Asset Management for the executives.

However, doing so requires a set of capabilities that is likely not fully developed in an Asset Management organization. This paper discusses the five main capabilities that are crucial to do strategic Asset Management, a second important implication of this paper.

Thirdly, it is important to realize that developing these capabilities will take time, as new people may need to be hired or the current asset managers need to develop these skills, some of which are counterintuitive to the technical specialists that are often found in Asset Management departments.

Fourth, this paper describes such a change process, which took over four years, and this description may be an important guide for practitioners also desiring to become proactive and strategic in their Asset Management. However, it is important to realize that every initial situation is unique and therefore each change process will be unique as well. Rather than using this description as a blueprint for such a change process, it is meant as a narrative about a unique process from which generic findings emerge. It is these generic findings that are useful for practitioners going through the same change process in their unique situation.

Finally, in this paper strategic Asset Life Cycle Plans (ALCPs) were developed as a vehicle to bring about change in the organization. This paper showed how such ALCPs may be developed, which may help practitioners to develop the Asset Management Plans ISO 55000 (2014) asks for in their own organization. Working with such plans offers the practitioner a unique opportunity to change their organization, as this research showed. Namely, using such a tangible 'artefact of change' was an important success factor in this project, as it made the idea of 'strategic and proactive Asset Management' concrete, the ALCPs were part of the work packages of the asset managers and the plans showed their value to the higher management, gaining and nurturing their support. Practitioners willing to go through the same development may benefit from such an approach.

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Agility enabled by physical assets: a multiple case study

Throughout this research, it became clear that unpredictable change needs to be managed in a different way than predictable change is managed. Therefore, a research was carried out to investigate how Asset Management organizations cope with unpredictable change. The literature on agility – which largely overlooks physical assets as a source of agility – was combined with the ALCM literature to develop a theoretical framework on agility in Asset Management. A multiple case study was carried out using this framework. Three enablers of agility ranging from the use of physical assets were found, which offers a valuable complement to the existing agility literature.

Skippable text

This chapter started from the agility literature, rather than from the literature on Asset Management. Therefore, the overlap with earlier chapters is minimal.

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Agility enabled by physical assets: a multiple case study

Abstract

Businesses are increasingly confronted with change from diverse causes, including customer preference, regulations, climate change or technological breakthroughs. Agility is mentioned to cope with such changes. However, little attention has been paid to the agility offered by companies' physical assets. These assets are various types of machinery designed to operate for decades in a stable context. This paper explores how physical assets offer agility to organizations dependent on physical assets.

Based on agility literature, this paper presents a theoretical framework of agility in the context of Asset Management. A theory elaborating multiple case study of three Asset Management organizations has identified three new agility enablers, ranging from the physical assets: asset resilience, asset adaptability and agile deployment. These are complemented by four organizational agility enablers known from the agility literature (agile people, linkages, data & processes and strategy). For practitioners, this paper shows how physical assets may offer an additional source of agility, and helps practitioners to become aware of this potential and how to realize this potential in practice.

Keywords: Agility, Asset Management, Asset Life Cycle Management, Flexibility, Engineering, Case study, Asset resilience, Asset adaptability, Population agility

9.1 Introduction

With increasing global competition and ever faster changing customer demands, agility is an important concept (Santos Bernardes and Hanna, 2009). In the words of Yusuf *et al.*, "[t]he main driving force behind agility is change" (1999, p. 34). Change requires adaptation of the organization and its operations. According to literature, agility is the only way for companies to keep a competitive advantage in the current globalized, competitive, and consumer-focused markets (Vázquez-Bustelo *et al.*, 2007).

Even though the concept of agility was coined in 1991 (Yusuf et al., 1999), only recently a broadly accepted definition emerged. Agility can be defined as “the ready ability to fundamentally change states to accommodate unforeseen circumstances in a timely manner” (Santos Bernardes and Hanna, 2009, p. 42). Agility is a broader concept than flexibility, which relates to the property of a system to change within certain (designed) limits (van Oosterhout et al., 2005), for example flexibility as a consequence of holding a stock. Flexibility can be defined as “an enabling ability to change status within the current configuration (a pre-established and limited scope and achievability)” (Santos Bernardes and Hanna, 2009, p. 41). Agility also considers changes of configuration.

Agility is most often related to manufacturing and operations (Sharifi and Zhang, 2001; Narasimhan et al., 2006). However, little attention is paid to the physical assets (e.g. machinery) used in the manufacturing process. In agility literature, references to physical assets are scarce. Some authors refer to agile technologies (e.g. Vázquez-Bustelo et al., 2007; Bottani, 2010) or flexible assets and systems (Meredith and Francis, 2000). However, they focus on the manufacturing practices rather than on how assets are agile (see Aravind Raj *et al.*, (2013)). Also in the literature on flexible manufacturing systems, the focus is on the performance characteristics of the system or its manufacturing practices rather than its physical attributes (Koste et al., 2004; Jain et al., 2013; Dubey and Gunasekaran, 2014).

Physical assets are the primary focus of the Asset Management literature. Asset Management is “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” (Pudney, 2010, p. 8). However, also in the Asset Management literature the concept of agility is ill-studied (Harris and Carapiet, 2006 is a notable exception). Nevertheless, many authors have stated that assets and their managers have faced increasing change, which they somehow have coped with (Tsang, 2002; Al-Turki, 2011).

The singularity of these assets in the agility paradigm is their inherent inflexibility. Most of these assets are designed to last for several decades. Hence, the assets see a lot of change in their functional lives and must be adapted accordingly, even if they were designed for decades of stable operation. This results in an agility paradox in which organizations adapt to changes in their environment while they are dependent on assets that have been designed for stability. This article aims to contribute to the theory on agility by exploring how companies cope with this agility paradox (Handfield and Melnyk, 1998). The article attempts to answer how organizations cope with change if they are highly dependent on physical assets.

9.1.1 Outline

The article first looks at the theory on agility in section 9.2. It describes how different types of change drive the need for agility, that agility can result from different enablers and that companies are agile if they are able to adapt to changes in a timely manner. The article adds to the agility literature by describing how physical assets enable agility through their ability to deal with circumstances more severe than their original design (asset resilience), the possibility to change the asset (asset adaptability), and the means of flexibility offered by the availability of multiple assets to fulfil the same function (agile deployment). The resulting theoretical framework on agile Asset Management will guide and structure the multiple case study of three Asset Management organizations that are used to deal with change. Section 9.3 presents the case study methodology used in this research, and the case study results are presented in section 9.4 and discussed in the next section (9.5). The article concludes that Asset Management agility ranges from three sources of agility (agile assets, agile deployment of assets and an agile organization) and seven different enablers (section 9.6). This shows that agility is broader concept than generally presented in the literature. Therefore, companies are advised to not only consider organizational agility, but also the agility that physical assets may offer (section 9.7).

9.2 Theoretical framework

To investigate agility in Asset Management, the main elements of agility must be studied using the distinction between agility drivers, enablers and performance (Vázquez-Bustelo et al., 2007). The need for agility is driven by agility drivers and agility is enabled by certain enablers. This may lead to agility performance. There is an amount of change that cannot be dealt with if the agility performance insufficiently copes with the change ranging from the agility drivers. This is the agility gap. Figure 9.2.1 illustrates the relationship between these concepts.

9.2.1 Agility drivers

As stated in the introduction, “[t]he main driving force behind agility is change” (Yusuf et al., 1999, p. 34). In the field of Asset Management, the anticipation of change secures the value creation potential of the assets. Ruitenbunrg and Braaksma (Ruitenbunrg and Braaksma, 2017a, 2017b) listed five categories of change relevant to Asset Management: 1. technical; 2. economic; 3. compliance; 4. commercial; and 5. organizational (or TECCO) (Ruitenbunrg et al., 2015; Ruitenbunrg and Braaksma, 2017b). Sets of change categories can be found in the agility literature. Sharifi and Zhang (2001) mentioned technology, social factors, marketplace, competition, and customer requirements. van Oosterhout et al. (2005) used technology, social/legal, business network, competitive environment, customer needs and internal drivers (i.e. within the organization). Except for the economic

category, these sets of agility drivers resemble the TECCO categories. As the five TECCO categories fit the Asset Management context, these will be used to operationalize change. Predictability of change is an important notion related to change as a driver of agility. As discussed in the introduction, flexibility is mainly concerned with a system's ability to cope with expected change. Agility is also about coping with unexpected change. The additional value of agility compared with flexibility lies in dealing with unanticipated change. The more dynamic and unpredictable the change (ranging from any of the five drivers discussed), the higher the need for agility. On the contrary, if all change is predictable, flexibility may be sufficient.

Figure 9.2.1 - theoretical framework of agile Asset Management

9.2.2 Agility enablers

The higher the amount of change, the higher the need for agility. Knowing this, the next question focuses on how to increase the agility of the organization. Yusuf *et al.* (1999) were among the first authors to address this question by mentioning four concepts of agility: 1. virtual enterprise; 2. core competence management; 3. knowledge-driven enterprise; and 4. capability for reconfiguration. Since then, a large number of publications have discussed the characteristics of agile (manufacturing) companies (Yusuf *et al.*, 1999; Meredith and Francis, 2000; Sharifi and Zhang, 2001; Brown and Bessant, 2003; van Oosterhout *et al.*, 2005; Vázquez-Bustelo *et al.*, 2007; Bottani, 2010). These characteristics ranged from teambuilding, human resources management, concurrent engineering, partnerships and information communication technologies. It also included performance-related descriptions, including responsiveness, speed and aptitude to learn.

Notable is that none of these authors explicitly mentions agility of assets, equipment or machinery. While some authors refer to agile technologies (e.g. Vázquez-Bustelo *et al.*, 2007; Bottani, 2010), these refer to advanced design and manufacturing technologies and

advanced information systems. Bottoni's (2010) flexible production technology is the only one to include agile assets. Meredith and Francis (2000) are a notable exception in their use of flexible assets and systems to describe one of the four characteristics of agile processes. To remedy this deficiency, this article investigates agility ranging from the following three sources: 1. the physical asset; 2. the deployment of the asset; and 3. the organization (see Table 9.2.1).

Table 9.2.1 - overview and description of the seven agility enablers, ranging from three different sources

Agility Enabler	Description
Asset agility	Agility offered by the physical asset
Asset resilience	The (passive) ability of the asset to change its use or load within certain (designed) limits
Asset adaptability	The capacity of the asset to be (actively) adapted to deliver additional functions in both quality and quantity (e.g. speed or production volume)
Population agility	Agility offered by the population of (similar) assets
Agile deployment	The possibility to influence the use of the assets (including the demand for the services delivered by the assets)
Organizational agility	Agility offered by the Asset Management organization
Agile people	The ability of the workforce to carry out other tasks than their regular work both in quantity (e.g. additional workers) and quality (e.g. skills and training)
Agile linkages	The ability to gain knowledge or other resources from partners outside the Asset Management organization both internal (e.g. the production department) and external (e.g. suppliers)
Agile information & processes	The ability to decide on, plan, and execute actions in a fast and accurate manner, as well as the ability to collect and organise information in such a way that it supports these processes
Agile strategy	The ability to identify and make sense of the changes in the environment and to adapt the Asset Management strategy accordingly, as well as the importance given to agility in the organization

Agile assets

In the engineering literature, only a few authors have touched upon agile assets. Schapiro and Henry (2012) start their paper with the assertion that assets “are faced with an evolutionary operational deployment environment in which the problems the initial [design] sets out to address often evolve to areas that the [...] design falls short of addressing, or misses altogether” (p.1). Changing operating conditions, one kind of change an asset may cope with during its life, give rise to a need for agile assets.

Based on the definition of agility and its relation to flexibility, asset agility may range from the inherent flexibility of the system to change within certain (designed) limits and the possibility to adapt the asset to fulfil functions not anticipated in the initial design. This article will term the first enabler **asset resilience** and the latter **asset adaptability**. Asset resilience may, for example, follow robust designs (Park et al., 2006), which allows the asset to thrive under conditions more severe than anticipated. It may also range from an

excess capacity built within the asset (Kogut, 1985), which allows the asset to be used more intensively.

Asset resilience is a passive capability of the asset; no external action is needed to exploit this agility potential. This is different from asset adaptability, which requires an active intervention. Asset adaptability may follow from the modularity of the asset (Ulrich, 1995), especially when the modules that are most likely to be impacted by changes can be easily replaced (e.g. by more innovative or more robust modules). Additionally, easy modification of the asset improves its adaptability (Schapiro and Henry, 2012). In the context of the adaptability of buildings, six different adaptability strategies have been discerned: 1. adjustable; 2. versatile; 3. refitable; 4. scalable; 5. convertible; and 6. movable (Schmidt III et al., 2014).

Population agility

Not only the individual asset may be a source of agility. When the company uses a larger number of assets, their deployment may offer another source of agility agile deployment. Examples include redundancy (Wenzler, 2005), reserves, and the planning of asset usage (Celen and Djurdjanovic, 2012). It may also be possible to influence the demand for the asset (van der Burg et al., 2015). Examples include raising electricity prices at peak hours (Triki and Violi, 2007) or congestion taxes in city centres (Santos and Fraser, 2006). In other words, agile deployment is the agility offered by exerting influence on the demand for and use of the assets.

Agile organization

Next to the agility offered by physical assets and their deployment, the organization may be a source of agility. As this is an exploratory study, the authors have chosen the simple categorization of agility enablers used by Meredith and Francis (2000) and Brown and Besant (2003): 1. agile people; 2. agile linkages; 3. agile processes & information; and 4. agile strategy. Table 9.2.2 presents an overview of the relevant aspects of each enabler described in the literature.

The **people** working in an organization are the first source of agility in Asset Management. This agility may range from the quantity of people. As with the number of assets, the number of people creates overcapacity and gives a certain level of flexibility. The quality of the people employed may also be a source of flexibility. A wider set of skills allows existing employees to carry out a more diverse set of activities.

Agile linkages concern collaborations within and outside the organization. Within the organization, collaboration with other departments improves knowledge sharing and decision making. Outside the organization, close collaboration with customers and suppliers is considered an attribute of agile manufacturing. In Asset Management, collaboration with the asset user (e.g. the operations department) is important. This can be considered an Asset Management substitute for the customer regarding agile linkages.

Table 9.2.2 - description of the four organizational agility enablers

Organizational Agility Enabler	Relevant Aspects
Agile People	Aspects found in the literature include job rotation (Vázquez-Bustelo et al., 2007), cross-training (Bauer, 2015), education (Bottani, 2010), organizational culture (van Oosterhout et al., 2005), knowledge management and learning (Vázquez-Bustelo et al., 2007; Alavi et al., 2014) and empowerment (Sharifi and Zhang, 2001).
Agile Linkages	For collaboration within the organization, the literature mentions team building (Yusuf et al., 1999) and cross-functional team sharing (Gehani, 1995). Outside the organization, close collaboration with customers (e.g. Bottani, 2010) and suppliers (e.g. Meredith and Francis, 2000) is mentioned. The agility of complete supply chains is also considered (Purvis et al., 2014; Brusset, 2016).
Agile Processes & Information	Agile processes and information contribute to the agility of an organization. Flexible (manufacturing) processes supported by rich data allow for rapid decision making and fast adaptations of the operations. The literature mentions aspects such as manufacturing processes (e.g. assembly cells and robots) (Brown and Bessant, 2003), information communication technology systems and applications (van Oosterhout et al., 2005; Bottani, 2010), decision-making processes (Meredith and Francis, 2000) and rich information systems (Vázquez-Bustelo et al., 2007).
Agile Strategy	Brown and Bessant (2003) described an agile strategy as one of the attributes of agility by stating that it involves “the processes for understanding the firm’s situation within its sector, committing to agile strategy, aligning it to a fast-moving market, and communicating and deploying it effectively.” The authors take this to describe an organization’s efforts to identify changes in its environment (agility drivers) and translate these into appropriate responses. This fits with the four aspects of the agile strategy listed by Meredith and Francis (2000): 1. wide-deep scanning of the environment; 2. strategic commitment of higher management to agility; 3. full deployment (i.e. organization-wide implementation) of agile practices; and 4. the incorporation of agility in the performance management system by means of an agile scoreboard.

Agile processes & information concern the manufacturing process and underlying processes and information needed to produce a variety of products in the same plant or on the same production line. In Asset Management, the main output of the organization is the execution of maintenance tasks. This includes modifications and design changes. To support these activities, decision making, planning, and execution should happen in a fast, accurate, and flexible way.

Finally, the literature does not often mention the concept of an **agile strategy** as an attribute of agility. It describes the importance given to agility within the company, as well as the alignment between the company’s strategy, operations, and the market. For agile Asset Management, this means the appreciation of agility as an important aspect in Asset Management, the use of structured processes to identify changes that require agility, and the development of suitable measures for these changes.

9.2.3 Agile performance

The final aspect of agility concerns the performance of the Asset Management organization. To investigate the organization’s agility, the authors use the agility gap by van

Oosterhout et al. (2005): "... [i]f businesses find it difficult to cope with major changes, which go beyond their normal level of flexibility, they are faced with an *agility gap* [*italics in original*]" (p.278). Hence, a company is (sufficiently) agile if it can cope with changes in a timely manner. A similar notion is used by Ben-Menahem et al. (2013), who talk about the need to align external change (agility drivers) and internal change (changes in the strategy).

Agility performance may change over time, as both the impact of the agility drivers and the potential of the agility enablers change. Related to the latter, the authors assume that organizational agility is costly as it requires investments in excess resources (e.g. knowledge or manpower), as indicated by Narasimhan et al. (2006) and Teece et al. (2016). Therefore, organizational agility may decline if a company does not consider agility an important investment.

Agility is an organization's capability rather than an outcome (Santos Bernardes and Hanna, 2009). In other words: while an organization may be able to reach a certain target (agile), it may not be willing to do so (nonresponsive).

9.3 Methodology

The study of how Asset Management organizations deal with change was carried out using the case study methodology. Section 9.3.1 introduces this methodology and presents its general characteristics. The main steps of the methodology are presented in section 9.3.2. Finally, section 9.3.3 presents how these steps were executed in this study of agile Asset Management.

9.3.1 Case study research

"Case studies are rich, empirical descriptions of particular instances of a phenomenon that are typically based on a variety of data sources" (Yin, 1994; cited in: Eisenhardt and Graebner, 2007, p. 25). This description is a useful starting point to introduce the Case Study methodology, as it points at a number of distinctive characteristics. First, case study research studies a phenomenon in a particular context: the case. The nature of the phenomena to be studied using case studies is diverse: a practice (e.g. Lean manufacturing), a social construct (e.g. power relations), an organization, a relation (e.g. buyer-supplier relationships), etcetera.

Secondly, case studies result in rich, empirical descriptions of the phenomenon. As case study research is "[u]nconstrained by the rigid limits of questionnaires and models, it can lead to new and creative insights" (Voss, 2009, p. 163). The researcher is present in the case, the context where the phenomenon exists. This allows him to get a deep understanding of the phenomenon in its context. Additionally, it allows him to use his creativity by asking new questions or following new threads based on the data collected up to that

point. Furthermore, the case study allows the researcher to “cover both a particular *phenomenon* and the *context* within which the phenomenon is occurring either because (a) the context is hypothesized to contain important exploratory information about the phenomenon or (b) the boundaries between phenomenon and context are not clearly evident [*italics in original*]” (Yin, 1994; cited in: De Vaus, 2001, p. 233). All of this results in rich descriptions of the phenomenon in its context.

Thirdly, case studies typically use multiple data sources, for example interviews, field observations and company documents. Different data collection methods allow the researcher to catch different aspects of the phenomenon. Again, this results in a rich, empirical picture. Additionally, the use of multiple sources of data allows (data) triangulation: the comparison of multiple types of data about the phenomenon (e.g. observations of and interviews about job interviews) (’t Hart et al., 2005). Data triangulation is a way to increase the internal validity of the research (Croom, 2009): the conclusions of the research, especially regarding explanations of the phenomenon studied and cause and effect relations.

Types of case study research and the role of theory

Different types of case study research exist (Voss, 2009), including: exploratory, theory building, theory testing and theory extension/refinement case studies. **Exploratory case studies** aim to explore a particular phenomenon, often as a basis for further research. **Theory building case studies** describe a phenomenon in terms of a domain, variables, a set of relationships between the variables and specific predictions about the variables. As case studies allow a deep understanding and rich description of a phenomenon, they are a good source for building theories. Case studies can be used to **test theories**, often but this is rarely done and often in conjunction with survey research. Finally, case studies can be used to **extend or refine existing theories**, (Ketokivi and Choi (2014) name this category ‘theory elaboration’) as their rich empirical nature allows the researcher to observe subtleties easily overlooked using survey research.

These types of case study already point at the importance of theory in case study research. As De Vaus states, “the task of the case study researcher is fundamentally theoretical” (2001, p. 221). There are multiple reasons for that. First, the goal is to develop, test or refine theory. Secondly, theory is to be used to guide the data collection of the researcher, as it is impossible to observe every single element of a case (e.g. from asset component level to the influence of European regulation). Therefore, decisions have to be made regarding the concepts and phenomena of interest. Only by making these choices explicit and relating them to theory, the case study will yield reliable results (De Vaus, 2001; Diefenbach, 2009). Thirdly, the generalization (external validity) of case study research cannot be based on statistical generalization, as typically the sample of case study research is too small and non-random. Therefore, theoretical generalization is to be

adopted. Theoretical generalization (Eisenhart, 2008) (also known as analytic generalization (Yin, 2014)) extends the findings of a specific case and context to other, similar cases through the logic of the theory developed. For example, if power relations between the management and the operators play a role in following safety regulations, this may be (theoretically) expected to play a role in other change projects as well.

9.3.2 The Case Study research process

A case study research typically follows six steps, including: 1. developing the research framework; 2. case selection; 3. developing research instruments and protocols; 4. conducting the field research; 5. data documentation and coding; and 6. data analysis (Voss, 2009).

The **research framework** includes a description of the concepts to be studied, as well as the presumed relationships amongst them. This is called a conceptual framework (Kumar, 2011). It directs the researcher in the questions to ask and the data to collect. Additionally, it relates the study to the existing literature. Based on the conceptual framework, the initial research question for the study can be formulated. This is likely to be a how or a why question, types of questions case study research is particularly good at addressing (Yin, 2014). Finally, the main concepts in the research question and conceptual model need to be defined and operationalized.

A next step is the **case selection**. Choosing (a) case(s) to study is an important decision, as generally only a few cases can be studied. Therefore, case selection should adopt theoretical sampling. This means that “cases are selected because they are particularly suitable for illuminating and extending relationships and logic among constructs”. As a result, cases are “sampled for theoretical reasons, such as revelation of an unusual phenomenon, replication of findings from other cases, contrary replication, elimination of alternative explanations, and elaboration of the emergent theory” (Eisenhardt and Graebner, 2007, p. 27).

One may choose for a single case study, which allows a deep understanding of the case but reduces the generalizability of the findings. Single cases are selected because “they are unusually revelatory, extreme exemplars or opportunity for unusual research access” (Yin, 1994; cited in: Eisenhardt and Graebner, 2007, p. 27). Additionally, multiple cases may be selected, which allow comparison between cases, increase generalizability and reduce observer bias (Voss et al., 2002). When selecting multiple cases, either similar or contrasting cases can be selected.

Thirdly, the **research instrument and protocols** must be developed. This includes a description of the type of data to be collected as well as the procedures to collect these. The core of the protocol is the set of interview questions. Triangulation needs to be considered when developing the protocol.

Then, the **field research** can be conducted. This starts with gaining access to the case, for example by getting permission of an organization to do interviews and make observations.

The goal of the study needs to be communicated, as well as the rewards for the respondent (e.g. getting the report). Also, confidentiality needs to be discussed with the participants (Kumar, 2011). The collected data is to be recorded, e.g. by recording interviews and making fieldnotes. Fieldnotes should contain both (descriptions of) observations and analysis, preferably separate from one another (Eisenhardt, 1989). Also, the data need to be checked by the organization or respondents (Voss, 2009).

In the **data documentation and coding** phase the collected data are written up. This may include the transcription of interviews. Based on the data, a case narrative can be written, which may be discussed with the (key) informants to increase its accuracy (Voss, 2009). Additionally, the data collected need to be reduced into categories. This may be done using coding. Different types of coding exist, including top-down coding and bottom-up coding (Silverman, 2006). Bottom-up coding starts from the data and assigns categories to the data based on the data itself. Top-down coding starts from the theoretical framework and assigns codes to the data based on the theory.

Finally, in the **data analysis** phase the collected data are used to explore a phenomenon or build a theory. First, in the within-case analysis the patterns are displayed, for example using networks, event lists or critical incident charts. Based on the display, the researcher should look for explanations and causality in the data. Negative evidence and rival explanations must be looked for to prevent reaching wrong conclusions. Secondly, in case of multiple cases, the cross-case analysis compares the cases for cross-case patterns. Any deviations need to be explained to further refine the theory (e.g. contingencies) (Silverman, 2006). In theory developing case studies, hypotheses may be developed based on the findings. Additionally, the findings need to be related to the enfolded literature, which increases the quality and validity of the findings (Voss, 2009). In theory testing case studies, conclusions can be drawn about the theories to be tested.

9.3.3 Case Study execution

To elaborate on the agility theory from the perspective of Asset Management, the authors carried out a case study (Yin, 2014). A case study allowed the authors to gain a deeper understanding of agility in an Asset Management organization. A multiple case study approach was adopted, to allow the authors to recognize similarities and differences between organizations. As this article aims to gain a better understanding of an existing theory (i.e. agility) in a new context, the authors used the theory refining case study approach, also known as theory elaboration (Ketokivi and Choi, 2014). In this approach, the existing theory and the empirical reality contribute equally to the outcomes of the study. It is not an inductive exercise to let a new theory emerge from the empirical data. In addition, it is not a deductive study testing propositions deduced from an existing theory. Rather, the aim is to “modify [...] the logic of the general theory in order to reconcile it with contextual idiosyncrasies” (Ketokivi and Choi, 2014, p. 236). In other words, the authors

study the concept of agility in the context of Asset Management to see how organizations can be agile while using assets designed for stability.

Research framework

To elaborate on the agility theory, the case study started with a study of the agility literature as well as the ALCM literature. A conceptual model resulted, as presented in Figure 9.2.1. The main concepts in this model were defined (see Table 9.2.1). A research question was formulated: how do Asset Management organizations with change if they are highly dependent on physical assets?

Case selection

This study selected three cases. The selection criteria were the high dependence of the organizations on their assets, the long lifetimes of these assets and the high dynamism in their operating environment. Additionally, the authors selected cases that were different in the source of dynamism in their environment and with different types of assets (infrastructure vs. fleet). This allowed for comparisons between the cases with respect to these differences. Finally, the authors looked for cases with easy access to the organization. Table 9.3.1 presents the main characteristics of these three cases.

Research instrument and protocols

The main data source for the case study were semi-structured interviews. An interview guide was developed, based on the conceptual framework (see Appendix A.8, page 317). The interview data were triangulated with data from earlier research (see Chapter 3 for earlier research at the Netherlands Railways, and all other previous chapters for research at Liander). Additionally, some company documents and newspaper articles were used for background information.

Field research

The field research was carried out from February to May 2016. Access was gained using contacts from previous research (NR and Liander) and from personal contacts (DMO). Key informants in each case company were used to find knowledgeable respondents for the interviews. A total of 10 one hour interviews was carried out, with 11 respondents in total (see Table 9.3.1). The interviews were recorded. Additionally, fieldnotes were written about the observations and thoughts of the researcher.

Data documentation and coding

The interviews were transcribed. The transcriptions were coded, using the conceptual model (top-down coding). A data extraction form was used to code the transcripts (see Appendix A.9, page 321). For each case an extraction form was filled out, using a separate column for each interview. Each cell summarized the statements of the interviewee on a particular topic and direct quotes were copied from the transcripts. Based on these large

tables, a single case summary was written for each case. This was sent to the interviewees for validation.

Table 9.3.1 - main characteristics of the three cases

Company Name	Defence Materiel Organization (DMO)	Netherlands Railways (NR)	Liander
Description	DMO of the Royal Netherlands Defence ensures that military personnel have modern, robust, and safe equipment for military and humanitarian operations.	NR is the largest train operator in the Netherlands. It offers easy, fast, safe, and affordable travel in comfortable trains for 1 million travellers each day.	Liander is responsible for the construction, maintenance, and operation of electricity and gas grids. It ensures safe and reliable energy distribution (transportation is done by national network operators).
Type of Assets Studied	Four populations of land-based wheeled vehicles (both combat and transportation, 75- >500 per population)	Rolling stock (for transport of passengers), with a total of 3,000 cars	Electricity grid (from high to low voltage), including all assets (e.g. 45,000 distribution transformers)
Scope	Maintenance of these assets, DMO has no influence on their operational use or deployment	Maintenance and deployment of trains	Maintenance, operation, and deployment of assets in the grid
Expected Lifetime	10 to 30 years but often, at the end of these lifetimes, life extension is decided (life extension is also expected for the majority of vehicles within this case)	15 to 30 years (after 15 years a midlife update [MLU] extends the life to 30 years), subcomponents (e.g. air conditioning) may be replaced at the MLU	For most of the primary assets, 40 to 60 years (until 25 years ago, all were designed for 25 years [now 40], but they last significantly longer), secondary components (e.g. electronics) have shorter lifetimes
Maintenance Practices	Maintenance is partly carried out by the Royal Netherlands Defence (either by units or specialized maintenance organization) and partly outsourced to original equipment manufacturers (OEM)	NR has a specialized maintenance organization to carry out the majority of planned and unplanned maintenance and the MLUs	As Liander assets contain few moving parts (most of which are barely used in normal operations), maintenance needs are limited. Maintenance is prescribed by the Asset Management department and carried out by service providers.
Reason for Selection	The Army never knows where their next mission will be, funding is highly dependent on (changeable) politics	Customer demands change rapidly, political decisions have significant impacts and the introduction of new trains requires flexibility	Due to aging assets and the energy transition (changes in production and consumption of energy) (Kern and Smith, 2008), its stable operating conditions may change rapidly
# of Interviews	4	3 (4 interviewees)	3
Description of Interviewees (code of interviewee, randomly assigned)	Three asset managers of specific vehicles, general manager asset life cycle management ground-based systems (DMO_1-4)	One head of Asset Management (AM), one head of fleet management, one current and one former manager of the AM project department (NR_1-4)	One current and one former manager of the Asset Management strategy department, one senior Asset Management policy advisor (LI_1-3)

Data analysis

The data extraction forms were used for the within-case analysis. Similarities and differences between the interviews, and the specifics of the assets managed by the respondents, were inspected. After the within-case analysis, the authors employed a cross-case analysis to compare the three cases. Special attention was paid to differences between the respondents (within-case) and the cases (cross-case). The authors tried to explain the deviant cases using the data (Silverman, 2006). From the cross-case analysis, patterns emerged. The similarities showed how Asset Management organizations may be agile, while the differences showed contingencies and context dependencies. Finally, the findings were discussed in light of the enfolding literature to increase their quality and validity.

9.4 Results

The three case companies experienced change and a need for agility. They also found ways to accommodate changes by using different agility enablers. The following section presents the within- and cross-case analysis results. It is structured by the main elements of the theoretical framework: agility drivers, agility enablers and agile performance.

9.4.1 Agility drivers

The three Asset Management organizations operated in a changeable context. As expected during the case selection, these changes profoundly impacted daily operations and occupied the asset managers. When comparing the cases, all five types of changes were mentioned in all the cases. However, the relative importance of the agility drivers differed over the three cases (see Table 9.4.1). For example, the technical agility driver was especially important to Liander. Compliance was a main agility driver for Netherlands Railways (NR). The only agility driver important to all three companies was the commercial driver. Additionally, most respondents indicated that they expected the amount of change to increase in the future. This also increased the need for agility, as one interviewee from the NR stated: “... *in that sense, I think our flexibility will only be tested further*” [NR_3].

When taking this comparison one step further, two important observations can be made. Firstly, all changes were mentioned during the interviews, while explicit questions for other types of change did not deliver additional categories. Asset Management is often considered a predominantly technical and financial discipline. Yet, the most important agility drivers do not range from these backgrounds. Changes in customer demands and organizational decisions are the main agility drivers.

Secondly, few positive changes were mentioned. Naturally, some changes offered new opportunities. However, technical innovations or market changes with cost savings were not mentioned. This may be caused by the type of questions asked (changes that have an impact on the organization may be perceived as negative because they require adapta-

tions of the organization). It may also be that asset managers are prone to identify risks rather than opportunities, as it clearly is a risk-averse profession (see for example Moubray (1997)).

Table 9.4.1 - Overview of the main drivers of agility (shaded cells indicate the main agility drivers)

Agility Drivers	Defence Materiel Organization (DMO)	Netherlands Railways (NR)	Liander
Technical	Obsolescence of parts (mainly electronic components), short lifetimes of electronics	Introduction of trains, obsolescence of parts (mainly electronic)	Ageing assets with unknown remaining lifetimes, new failure modes due to the energy transition, short lifetimes of electronics
Economic	Budget cuts (issued by the government), budget allocation dependent on large projects (which may be delayed)	Corporate strategy changed from financially-driven to a broader strategy	Available budget (regulated by government), rising costs of using public space, financial consequences of the energy transition
Compliance	No important changes	Stricter regulations (e.g. safety, noise, and environment), obligatory changes (e.g. new braking system), government decisions (e.g. free public transportation for 90,000 additional students, or the obligation to install toilets in all stopping trains)	Regulation (e.g. safety and related to consequences of the energy transition for Liander's role and finances), decreasing social acceptance of noise and visibility of assets (causing demands from local residents or municipalities to adapt the assets)
Commercial	User demands change due to different mission characteristics (climate, environmental conditions, exposure to specific dangers) (e.g. direct fire vs. improvised explosive devices)	Number of travellers (includes winning contracts to operate lines), which asks for a higher train frequency, additional services required by the travellers (e.g. air conditioning, wi-fi)	Quantity of demand for electricity and gas (may grow or decline), need for new functionalities (related to energy transition)
Organizational	Deployment on missions, tasks assigned to units (reconnaissance vs. battle), decisions to extend lifetime of vehicles, the need to implement new technologies (e.g. communication, which may also require changes of power supply)	No important changes directly from the organizational perspective. However, changes sketched above have far-reaching impact on the organization (e.g. challenge to accommodate many new trains in the [maintenance] processes and need for new maintenance facilities)	Discussion on future of the gas grid, new Asset Management strategy, reduction of skill and expertise of technicians, hard to find sufficient technicians, increased importance of sustainability
Expected Future Development of Change	Increasing (slightly)	Increasing	Internally debated, compared with 10 years ago it is increasing (but not compared with 50 years ago)

9.4.2 Agility enablers

The three case studies yielded several ways in which Asset Management organizations were agile (see Table 9.4.2). The agility enablers anticipated from the literature were found. Additional sources of agility did not come up during the interviews or data analysis. This shows the suitability of the authors' theoretical framework to study agility in the con-

text of Asset Management. However, the findings did allow for refinements in the authors' understanding of enablers.

Asset resilience

Asset resilience concerns the asset's inherent properties allowing it to function under different circumstances than anticipated. These range from the initial design of the assets. All three case companies used resilient assets. However, their resilience was not in all cases intentional. Out of the three cases, asset resilience was the most important at Liander. When Liander installed new assets, the expected increase in size and predictability of the power consumption in the next decades (which used to be highly predictable) was taken into account. Furthermore, the case companies benefited from the skills and expertise of their suppliers in making robust assets. An example is presented by the vehicles of the Defence: *"mechanically it really is an extremely solid vehicle, really a superior car"* [DMO_4]. However, interviewees from all three companies indicated that assets bought today are expected to be less robust than assets produced several decades ago. This is due to more sophisticated design tools and electronic components. Interestingly, many assets in this case study are not designed for life extension although all three companies carry out life extensions on their assets.

Asset resilience is an important source of agility, especially when changes are predictable (e.g. growth of energy consumption) or adaptations of the asset are costly (e.g. replacing cables). In these cases, investing in asset resilience may be worthwhile. Important to note is that new assets are suspected to have less resilience than older ones. This implies that previously unintentional resilience may reduce in new assets and may require explicit attention.

Asset adaptability

Regarding the adaptability of the assets, the picture is mixed. At DMO and the NR, most assets receive a midlife update (MLU) to extend the life of the assets and add new functionalities (e.g. at NR air conditioning has been retrofitted into all older trains). While the MLU is more or less standard for their assets, the large majority of assets are not designed for easy adaptability during these MLUs, as one respondent clearly stated: *"in the basic design, I'd never believe that they took that [i.e. asset adaptability] into account"* [DMO_1].

At Liander we see a different picture. While the adaptability of individual assets is limited due to their geographic dispersion, large numbers and design, the adaptability of the electricity grid as a whole is reasonably high. Local adaptations, such as adding new functionalities to the grid, are easily made. Liander recently increased its standard medium voltage rate from 10 kV to 20 kV. New grids are constructed with cables fit for 20 kV, whereas the overground assets in some cases continue to use 10kV. Overground assets are easier to replace, hence the decision to use 20 kV cables improves the adaptability of the grid. This

solution “is, given the effort required now, a very advantageous one” [LI_1], because it adds capacity and adaptability to the grid at a low cost.

Asset adaptability appears to be a promising agility enabler for Asset Management organizations, especially for less predictable change. Most assets covered in this case are not intentionally designed to easily adapt. However, MLUs offer an opportunity to make many adaptations anyway. DMO and NR consider more use of MLUs as an (organizational) means to increase the adaptability of the assets. Making adaptability an intentional part of the asset design is currently considered by NR and exploited by Liander. From these cases, it seems that asset adaptability is an agility enabler with the potential to further increase the agility of these organizations.

Agile development

The second source of Asset Management agility can be found within the (deployment of the) asset population. The best example is offered by the strategic reserve of the NR. Currently, this reserve is depleted because all trains are in service, “but I was extremely [emphasis] happy that we had [emphasis] it in the meantime” [NR_4]. Liander uses a different approach because its assets are immobile. Therefore, it is collecting data and developing processes to make better use of the grid’s existing overcapacity. In this way, investments in extensions of the grid can be postponed or prevented. Due to the uncertainty of the future, it is important “to postpone [decisions] as much as possible and to keep all options open” [LI_3]. Additionally, Liander tries to exert influence on the use of energy by their customers, in terms of when it is used (e.g. when people charge their electrical vehicles) and on the type of energy. In this way, Liander aims to make sure the energy transition is facilitated in a cost efficient manner.

The cases clearly show that the possibilities of agile deployment depend on the span of control of the Asset Management organization. At the DMO, the population does not offer agility to asset managers because the population (and its agility) is assigned to the units. At NR, the asset user and manager share agility by jointly deciding on the deployment of the assets in the fleet management process. At Liander, the span of control is even greater. Liander tries to efficiently exploit the existing overcapacity, as well as investigates its capability to influence the electricity demand of its household and industrial customers. Span of control offers an interesting topic for further research, as well as a promising agility enabler to asset managers in practice. Joint decisions or assigning population agility to the asset manager may offer new ways to cope with unexpected change.

Organizational agility

The final source of Asset Management agility is the agility of the organization. Organizational agility is important to the three case companies. Liander and NR are paying explicit attention to organizational ways to deal with the increasing amounts of change. In the words of one of the respondents from Liander: “*We could perfectly solve it [the challenges*

presented by the energy transition] in the old way [by means of constructing with sufficient overcapacity], but that is very expensive” [LI_3].

Table 9.4.2 - Overview of main agility enablers (shaded cells indicate the main agility enablers and a trellis shaded cell indicates current efforts)

Agility Enablers	Defence Materiel Organization (DMO)	Netherlands Railways (NR)	Liander
Asset Resilience	Some vehicles have intentional excess capacity (e.g. trucks anticipating heavier weapon systems) or are robustly designed. Life extension is not considered in asset design.	Trains are designed for 30-year lifetimes. Their expected service life (and depreciation period) is 20 years. This allows for life extension. Trains are designed to add an extra car for new functionalities.	The electricity grid is constructed to facilitate growth (which used to be average 2% per year). Assets were bought with a designed lifetime of 25 years. Yet, they last 40 years due to robust design.
Asset Adaptability	One of the assets (articulated truck) can exchange functional modules. Other assets are adaptable, but this possibility is not intentionally designed into the asset. Most assets receive a scheduled MLU halfway through their expected life.	The only train designed for easy adaptability is the most recent train, which is a modular system. Some older trains are based on a modular platform, but after production the design is 'fixed'. Adaptations are limited to the largescale overhaul and life-extension halfway through the service life of the trains.	Adaptation is difficult due to location (distributed, underground) and numbers. Overground assets can be adapted. However, replacement is often financially more attractive. When considering the electricity grid as an asset, its adaptability is higher (especially in medium voltage) but limited by location and numbers.
Population Agility	Assets are assigned to units. Therefore, DMO has no agility from the size of the populations (the units do). Mission reserves are available for some vehicles (taken from other units).	Fleet size and variety offers agility. The strategic reserve (several end-of-life trains that can be put into service in a short period of time) allows it to facilitate sudden demand growth. Additionally, most trains are fit for both stopping and express train services. An additional order is anticipated in procurements.	There is redundancy in the grid as some assets have a strategic reserve (e.g. for power transformers). Liander is exploring new technologies and analytics to allow for better use of existing overcapacity (e.g. improved usage profiles and influence on energy consumption).
Organizational Agility	This ranges from the people (skills, knowledge, training, job-rotation and “make it happen” mentality), collaborations (internally with the user, maintainer and norm-setter, externally mainly with OEMs and other armies using the same vehicles) and strategy mainly focused on the development and adoption (in the vehicles) of new technologies. During missions, faster and more flexible (decision-making) processes are applied.	Sources of organizational agility are mentioned. Most importantly, there is the strategic fleet planning process, which forecasts the future demand and availability of trains and allows NR to identify potential shortages in time. Internal (with its maintenance organization) and external (with suppliers and engineering consultants) collaborations and the knowledge of its personnel also yield agility.	The organization is in transition from a stable to a volatile context. In the stable situation, agility was offered by knowledgeable experts, external collaborations and strategic grid development plans. In the future, the company aims to build agility by using people with new competences, working in teams, flexible processes, new collaborations, increased insight from data, a system focus (vs. primarily the individual assets) and a scenario-based strategy. Collaborations aim to gain knowledge and influence decisions or behaviours of stakeholders. It aims to influence the government for suitable regulation to facilitate the energy transition.

While all four organizational agility enablers were mentioned during the interviews, the agility in information and processes was less pronounced than from people, linkages and strategy (see Table 9.4.2). This article will discuss differences and similarities between the three cases using the four organizational agility enablers. As these enablers are well-known from the agility literature, this discussion will be more brief than the asset related agility enablers.

Agile people are important for all three case companies. All companies stress the importance of skilled and experienced technicians to solve problems. At the DMO in particular, this is an important part of the “make it happen” culture. As one interviewee said, “I do not think that that [the source of flexibility] is the vehicle itself. I rather think it is the people around the vehicle that can easily cope with it [the changes]” [DMO_ 1]. Notably, all three companies stressed that the flexibility offered by their people is decreasing as knowledge disappears due to retirements and layoffs. Therefore, new competences are needed. Liander and NR have put effort in measures to counter this development.

Agile linkages show the importance of internal and external collaborations. Many ways of collaboration are formalized within the organizations. An important difference between the cases is the mandate and span of control of the Asset Management organizations (see agile deployment). External collaborations are primarily with partners that have complementary knowledge on the assets (e.g. suppliers) or carry out parts of the maintenance work. However, Liander also has close collaborations with (local) governments and institutions to gain a better understanding of the future developments in the energy transition, as well as to try to influence its development. Interestingly, the DMO and Liander collaborate with other organizations that use the same assets. This is achieved through sharing knowledge, tools or spare parts. NR does not implement this collaboration. This can be explained by the fact that NR uses assets that are not used by other train operators, as in neighbouring countries other regulations and rail infrastructures force them to use other rolling stock. Using assets that are used by other organizations may offer more agility from agile linkages.

Agile information and processes allow organizations to quickly identify and respond to change. NR’s fleet planning process is an excellent example. This process predicts future train demand and, in consultation between user and asset manager, the most viable ways to realise this demand are developed. Liander has a comparable process for regional grids. The DMO does not have this type of process in place. This may be explained by the predictability of future asset demands. Compared to transportation or electricity demands, new warzones or missions may be harder to predict because past data cannot be used. This relates to what a Liander respondent argued, who stated that data may predict the

near future and postpone investments, but that the far future is too uncertain to make useful predictions. Nevertheless, data may be used to identify changes. Therefore, Liander is investing in data analytics competences.

Finally, the case companies used different types of **agile strategy** as enablers of agility. The DMO focused on changes in technology that are needed to keep their vehicles future proof. NR and Liander focused on market developments. NR used this for future transportation demands and the development of future trains. Both NR and Liander acknowledged that scenario-based thinking was a difficult skill, especially when developments do not fit within the “business-as-usual”. Additionally, all three case companies stressed the difficulty to uphold a dual focus on tasks at hand and future strategy. One respondent noted that “a challenge we are occupied with is to try to anchor the simultaneity of the everyday hustle and bustle and the steady state towards the future in what we are doing” [NR_1]. Especially with the introduction of a large number of new trains, both running and expanding the business at the same time is a challenge requiring adaptation and investments in the organization, processes and equipment.

Clearly, the four organizational agility enablers offered a large agility potential to Asset Management organizations. On the one hand, this shows that the agility enablers in the agility literature are applicable to Asset Management organizations. On the other hand, it shows that Asset Management organizations with a singular focus on the asset and asset population overlook a large and powerful agility potential. The case studies showed that asset managers were increasingly aware of this potential. In the words of one respondent regarding the potential of agile people, “... knowing how hard it is to invest in additional infrastructure or trains, maybe we can solve it by throwing in zillions of people, maybe that will even pay off. So there [...] lay optimization opportunities we are only starting to acknowledge” [NR_4].

Overall comparison on the agility enablers

Patterns occur when comparing the different agility enablers. The three companies perceived a large and growing need to be agile. However, they each approached this need differently (see the shaded cells in Table 9.4.2 for the most important agility enablers for each case company). DMO seems to depend on the agility of its people and its agile linkages and considers carrying out MLUs more often (asset adaptability). On the contrary, NR relies on agile deployment and agile processes & information (the fleet management process). Finally, Liander may be argued to have two approaches to agility: 1. an old approach (suitable for the stable energy world Liander was used to) and 2. a new approach under development (suitable for the changes resulting from the energy transition). The first depends on asset resilience (overcapacity), as well as the information and processes to calcu-

late the necessary overcapacity. The latter largely depends on the organizational agility drivers to deal with an uncertain future and expected local differences in energy demands. It only depends on asset resilience for underground assets.

Interestingly, these approaches appear to be (at least partly) explained by the history and context of the companies. For example, the DMO, which operates in a military environment, trains for unexpected situations. Individuals within the DMO are aware of the importance of equipping “our men on the missions with the right equipment, even if it is only using a band-aid solution” [DMO_3]. This is reflected in the DMO agility profile as it leans on the agility of its people. For NR, the large numbers of highly mobile and interchangeable assets allow them to use a strategic reserve of rolling stock. Long lead times for new rolling stock force them to have this reserve. An important difference with Liander is its immobility of assets, which forces Liander to depend on the asset agility rather than deployment.

Discussion on different types of Asset Management agility does not imply limited archetypes to describe ways in which an Asset Management organization can be agile. Rather, it is an illustration of the fact that agility is highly context-dependent or contingent on context. Companies in different contexts can (and maybe even should) find unique ways to be sufficiently agile. Rather than prescribing how a company should be agile, this article shows a variety of ways in which a company can be agile. It offers an overview on the different agility enablers that may be used for this purpose.

9.4.3 Agile performance

To better understand agility performance in each of the case companies, the authors asked the respondents if their current agility level was sufficient. All three companies considered their current agility sufficient (see Table 9.4.3). NR was barely sufficient as it was awaiting the delivery of new trains in a few months. “We are currently tight on rolling stock and actually do not have any options left to improve this” [NR_3].

Regarding the future, the three case companies realized that agility offered by the seven enablers would slowly decline if additional efforts were not made. Changes on agility drivers would simultaneously increase. One reason mentioned across all cases was the reduction of technical knowledge. This was aggravated by the increasing complexity of assets due to the addition of electronic and software components. NR and Liander admitted the need for a new approach (Liander noted a trend reversal caused by the energy transition and NR noted limits of the rail infrastructure system). In the words of a respondent from NR, there is “a need to be able to adapt [*literally: switch*] quicker, both qualitatively as well as quantitatively. And honestly, we do not yet have the answer to that” [NR_4].

All three case companies discussed ongoing projects to increase the agility of their organizations. This included through carrying out more MLUs, investing in knowledge management, or increasing flexible processes. Additionally, they all made efforts to strengthen the

long-term and strategic perspectives in their Asset Management. They were all aware of the importance of agility.

Table 9.4.3 - overview of the agile performance of the different case companies

Agility Performance	Defence Materiel Organization (DMO)	Netherlands Railways (NR)	Liander
Current Agility	Sufficient	Sufficient (barely), new rolling stock will be available in a few months	Sufficient
Development	Declining	Declining	Declining
Caused by	Reduction of personnel due to budget cuts, more complex systems	Reduction of knowledge available within the company, increasingly complex systems, higher dependency on suppliers, increasingly strict regulations, limits imposed by infrastructure	Organization equipped for a stable context (ta changing context asks for new processes and competences), reduction of available technical knowledge
Current Efforts to Improve Agility	Efforts have been made to create awareness surrounding the importance to consider the complete life cycle of the assets in Asset Management. A pilot project is performing more frequent MLUs during the lifetime (e.g. every five years). Plans are set up regarding an operational reserve for missions (vs. taking them from the units).	Knowledge management is receiving more attention. There is process optimization, data processes, more collaboration with suppliers (e.g. design, spares and knowledge), ideas on planning multiple smaller overhauls during the asset's lifetime and hopes for a modular future train.	Development of scenarios and competences (e.g. working with scenarios and data analysis). Changing processes to deal with a variety of demands and pilot studies to investigate the impact of the energy transition. Identifying possible solutions. Collaborating with other network operators to influence legislation.

9.5 Discussion

Three themes that merit further discussion have emerged from the cross-case analysis. These include differences between predictable and unpredictable change, cost of agility and the impact of insufficient agility.

Agility accommodates both predictable and unpredictable change. The cases show that predictable change (e.g. growth of electricity demand, probable life extension) is often reflected in asset resilience. Unpredictable change is reflected in asset adaptability (e.g. modular trains). In many instances, change was not considered in the design of the assets (including its software). Therefore, this may be a promising topic for further research. Additional research should review sustainability, resource scarcity and the demand for a more efficient use of resources (for example, the circular economy approach; (Ellen MacArthur Foundation, 2012; Korse et al., 2016).

All three cases acknowledged declining levels of agility. Agility, which is a consequence of overcapacity (either the asset or organization), is costly (see Teece et al. (2016)). A decline of agility should be expected if companies do not consider it an important investment

(note the importance of agile strategy). This requires an additional effort by asset managers to substantiate the need to invest in agility. This was done by all companies using the analogy of an insurance policy (i.e. a small amount is regularly paid to prevent an uncertain large cost in the future).

The concept of agile performance merits further discussion. What are the consequences if a company is not sufficiently agile? For example, regarding NR, this would be overcrowded trains during rush hours and unsatisfied customers. Considering these consequences and accepting negative results of insufficient agility may paradoxically offer additional agility. The distinction between hygiene factors (or dissatisfiers) and satisfiers (Herzberg et al., 1959; Johnston, 1995) may also be useful. Satisfiers, which please a customer, offer (temporal) agility. Dissatisfiers, which make the customer change to a different producer, do not.

9.6 Conclusion

Agility is an organization's ability to cope with change. The agility literature focuses on the organization. However, in this study, the authors focused on assets used by an organization. These assets see many changes throughout their lengthy lives. Therefore, the article explored the concept of agility within Asset Management organizations.

This study showed that change—the driver of agility—originates from different backgrounds. The three case companies faced significant changes. This is also expected to remain in the future. The article found that Asset Management agility ranges from three sources: 1. agile assets; 2. agile deployment of the assets; and 3. agile organization. In the case study, assets were found to be agile because of their inherent asset resilience (e.g. overcapacity) rather than their design for adaptability. A larger population of similar assets yields agile deployment, which is an additional agility enabler. In the Asset Management organization, knowledgeable and motivated people, collaborations with capable partners, future-anticipating strategies and insightful information and fast processes are the main enablers of agility.

The three case companies studied are sufficiently agile. However, their agility levels are decreasing due to fewer knowledgeable people, more complex systems and stricter regulations. The need for agility is expected to remain the same or increase. Therefore, efforts surrounding Asset Management agility must increase. This article offers an overview how asset managers may increase the agility in their organization and discussed how agility may be highly context dependent. Additionally, it has increased the understanding of agility by adding the perspective of agile assets to the concept of agility.

9.7 Limitations and Implications

This study's conclusions are limited by the number of cases studied. Additional cases are needed to increase the generalizability of the findings of this exploratory study. When selecting new cases, the span of control of the Asset Management organizations may be an important factor to consider. Additionally, selecting cases in highly competitive environments may yield further insights, as the three selected case companies can be argued to have monopolistic traits). An implication for new studies on agility is that these may need to consider the additions and refinements regarding agility from physical assets presented in this article.

This study has three implications for practitioners. First, it is important to use the five agility drivers to assess Asset Management agility. Based on the resulting need for agility, the framework may offer guidance on increasing the agility of the organization using the seven agility enablers presented in this article. A singular focus on either the asset or the organization to enable agility overlooks important and promising sources of agility. Software, information systems or other non-asset solutions may be considered to accommodate change. Additionally, broadening the scope of the Asset Management organization (e.g. include the deployment of assets and demand for the use of the assets or even the strategy) may offer agility. Second, the organization's agility level may decrease without proper investments and constant attention. Finally, designers and purchasing managers must look for improvements in the designed adaptability of assets. This was found to be low in most assets owned by the three case companies. Software may play an important role here, as software tends to be more easily adapted than hardware.

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10

Conclusions

This final chapter presents the main conclusions from this dissertation. It answers the main research question, addresses the differences between planning for predictable change and preparing for unpredictable change, and discusses how physical assets can safely and effectively be manoeuvred into the future.

10.1 Introduction

This research set out to investigate how Asset Management organizations ‘manoeuvre physical assets into the future’, and to develop methods and tools to plan for predictable and prepare for unpredictable change. This dissertation has presented a rendering of the scientific journey towards an answer to this question. This journey has now come to an end, and in this final chapter, the main research question underlying this research will be answered (section 10.2):

How can a company, based on the knowledge and information available, effectively deal with change in its strategic Asset Life Cycle Management to create sustained stakeholder value with its assets over their complete lifetime?

In the next section (10.3), the six limitations of the Asset Management literature will be revisited. Has this research properly addressed each of these deficiencies, and does the method developed in this research – Lifetime Impact Centred Asset Management (LICAM) – live up to the five requirements of Asset Life Cycle Management (ALCM)? Additionally, the practical challenges discussed in the introduction – the availability of information and the limitations of quantitative approaches – will be come back to. Does the LICAM method also overcome these challenges, or is it rather a theoretical construct that will never overcome the complexity of practice?

Section 10.4 will discuss the limitations of the conclusions of this dissertation, to assess their value and relevance for the scientific community. This will show that this research is neither perfect nor complete, as holds for all research, and hence that care should be taken when using the outcomes of this research. Also, this will give rise to topics for further research, which will be presented in section 10.5, together with the implications for practitioners: what are the main ‘take home messages’ from this research?

10.2 Conclusion

Change is omnipresent, also in the world of Asset Management. Therefore, it is notable that the literature does not pay explicit attention to how to deal with change. Even more so because the long lifetimes, high financial values and limited adaptability of physical assets complicate the ability of Asset Management organizations to cope with (the consequences of) change. The first part of the answer to the research question is therefore the acknowledgement of the importance of change in Asset Management. To stress the importance and relevance of change, this dissertation has introduced a new term: ‘lifetime impacts’. Lifetime impacts have been defined as ‘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’. These lifetime impacts are the first building block of the answer to the main research question.

To further answer the research question, a distinction needs to be made between two types of change: predictable and unpredictable change. First, the answer regarding predictable change will be presented, and then the differences in dealing with unpredictable change will be addressed.

10.2.1 How to deal with predictable change in ALCM?

The distinctive characteristic of predictable change is that, before the change actually materializes, certain early warning signals can be picked up. However, the fact that these signals are ‘out there’, does not mean that they are actually picked up, let alone that the signals lead to a preparation for the upcoming change.

To effectively deal with change, the first step is to identify potential future changes – lifetime impacts – in time, based on the available early warning signals. This research showed that a large number of lifetime impacts can be identified using the knowledge and information available within the company, by bringing people from different disciplines and different layers within the organization together in structured expert sessions. In these sessions, the future of the assets is discussed from five different perspectives: technical, economic, compliance, commercial and organizational, summarized in the acronym TEC-CO. Together, these five perspectives render a complete and multidisciplinary overview of the lifetime impacts relevant for (the future of) the assets.

After the identification of the lifetime impacts, an effective dealing with change requires that the limited resources available (both in terms of time of the asset manager and resources of the organization) need to be used in the most effective way. Therefore, the lifetime impacts are prioritized, based on their likelihood, potential effect and the effort required to appropriately manage each lifetime impact. A four quadrant scheme was developed to assist asset managers in deciding how to use their precious time: predominantly on the lifetime impacts having a large potential impact (effect times likelihood), and

with a different strategy for lifetime impacts requiring a large effort than the quick-wins that require little effort. The high priority impacts, selected using the four quadrant scheme, can then be assigned suitable solution strategies using a logic tree. This logic tree has been designed to propose the most effective solution strategy for each lifetime impact, while minimizing the effort of the asset manager to find this solution. The main distinction made in the logic tree is between positive and negative lifetime impacts. For the positive lifetime impacts, which are potentially valuable to the stakeholders, efforts should be made to let these materialize with the highest likelihood and at the shortest term possible. The opposite holds for negative impacts: any effort spend on impacts that do not materialize are wasted, thus the focus should lie on postponing any actions as much as possible.

The method for the identification of lifetime impacts, their prioritization and the assignment of suitable solution strategies to each of the high priority lifetime impacts has been called 'Lifetime Impact Centred Asset Management'. This method can be regarded as the long-term, strategic and change-oriented complement to Reliability Centred Maintenance (RCM), which is rather short-term, operational and stability-oriented.

Where RCM assists its users to develop a suitable maintenance policy for its assets, the LICAM can be used to develop Asset Life Cycle Plans (ALCPs) to strategically manage its assets effectively. However, for effective management, more is required than just the identification of lifetime impacts and the assignment (and execution) of suitable solution strategies. To be precise, there are five necessary requirements for effective ALCM control: 1. a model of the asset; 2. a clear performance goal; 3. information on the asset's current and future performance and its future operating context (i.e. the relevant lifetime impacts); 4. sufficient control measures to keep the performance of the asset on target; and 5. sufficient capacity to process all the required information. Based on these five requirements, the ALCP has been designed.

However, it is not so much the ALCP that is important, but rather the processes that underlie the creation of the ALCP and the capabilities required to manage assets in a strategic way. From the process of developing the ALCPs, five important ALCM capabilities emerged. The first is the ability to use the available Asset Management information for a new goal, namely to address strategic questions (capability 1). To do so, the information needs to be collected and combined from different disciplines and departments, aligning asset related knowledge both vertically (capability 2) and horizontally (capability 3) within the organization. Additionally, this requires a mutual focus of the asset managers: both on the short term operational issues as well as on long term strategic topics (capability 4). The last capability (capability 5) concerns exerting influence over these issues, even if these do not lie within the formal job description of the asset manager. These capabilities were found to be foundational to an effective long term and strategic ALCM.

To summarize: it is not just the LICAM method that is sufficient to effectively deal with predictable change in its Asset Life Cycle Management. It is only by the combination of the LICAM method and the development of ALCM capabilities that a company can effectively manage its assets in the face of change, to create sustained stakeholder value with its assets over their complete lifetime

10.2.2 How to deal with unpredictable change in ALCM?

However, during this research it became clear that not all lifetime impacts can be identified in time to prepare measures. This concerns unpredictable changes, but also those lifetime impacts where any preparatory measures would be too costly or require too much preparation time to be effective. Nevertheless, also those changes that cannot be identified beforehand or where any preparations would be ineffective need to be coped with somehow. A multiple case study of agility in Asset Management showed three different sources of agility relevant for Asset Management: the asset itself, the population of assets and the Asset Management organization. Within the asset category, two different agility enablers exist: asset resilience and asset adaptability. The first concerns the inherent (passive) resilience of the asset may allow the asset to cope with more severe circumstances than anticipated (e.g. overcapacity). Asset adaptability concerns the possibility to (actively) adapt the asset to new circumstances, for example by a modular design. The second source of Asset Management agility is the population of assets. This category consists of only one agility enabler: agile deployment. If an Asset Management organization has multiple assets at its disposal to perform the same function (e.g. when having a strategic reserve of assets), this offers additional agility. The third source of agility is the organization, from which four agility enablers well-known from the existing agility literature flow: agile people, agile linkages, agile strategy and agile information & processes.

It is these seven agility enablers that allow an Asset Management organization to cope with change that cannot be anticipated. However, by thoughtfully investing in these agility enablers, such unpredictable change can be prepared for. The required level of agility of the organization depends on the changeability of the context in which the assets need to perform. If the right balance is struck, the seven agility enablers allow an Asset Management organization to effectively deal with unpredictable change in its strategic ALCM.

It is important to realize that preparing for unpredictable change by means of agility is likely to be costly, as agility implies investing in overcapacity (in the asset, the population or the organization). Therefore, it is likely to be more efficient to plan for predictable change, rather than to rely on agility to deal with such changes as well. In other words: both the planning for predictable change and the preparation for unpredictable change are important to safely and efficiently manoeuvre physical assets into the future.

10.3 Discussion

Throughout this dissertation, it has been argued that Asset Life Cycle Management fulfils the following five requirements:

1. a multidisciplinary practice;
2. in which the whole life cycle of a physical asset is taken into account;
3. with the goal of achieving certain specified objectives;
4. within acceptable limits of risk and relevant regimes; and
5. it should determine the allocation of resources.

Also, it has been shown how existing Asset Management approaches do not live up to these requirements (see section 2.4, p.40). Additionally, it was shown how the availability and reliability of information often limits the application of existing methods and tools in practice. Therefore, it is only fair to assess the tools, methods and frameworks presented in this dissertation on these six criteria. The outcomes of this assessment are shown in *Table 10.3.1*, and are summarized and discussed in section 10.3.1.

10.3.1 Assessment of the methods developed in this dissertation

Multidisciplinarity

As shown in *Table 10.3.1*, the different tools, methods and frameworks presented in this paper all relate to the five requirements of ALCM. However, on closer inspection, a few remarks can be made. First, the multidisciplinary approach is in some cases limited to multidisciplinary performance targets, which can still be aimed for in a predominantly technical way. In other cases, experts from different disciplines are brought together to share their knowledge and expertise to assess the future of the assets in the most effective way. But to fully exploit the value of multidisciplinarity in Asset Management, it is important that not just the tools are multidisciplinary, but also the mind-set of the asset manager is multidisciplinary. That is why the horizontal alignment capability is so important to develop as an Asset Management organization.

The complete life cycle

Second, rather than focusing on the complete life of the asset, most methods and tools presented in this dissertation just focus on the remainder of the asset's life. On the one hand, this makes sense, as going back to the design phase for existing assets may not be possible or would most likely be very expensive. On the other hand, learnings about the assets currently used may have important implications for the design and construction of new (similar) assets. Therefore, it is important not to limit oneself to the management of the existing assets, but to use the learnings from current assets for the benefit of (the design of) new assets. Additionally, the methods and tools developed in this research do not explicitly consider the estimation of the exact end of life point of the assets. Remaining

useful lifetime estimations may complement the tools presented in this paper, as long as one realizes that these estimations are only valuable if also the future changes relevant for the assets are addressed in its Asset Management.

The achievement of corporate objectives

Third, the focus on the realization of corporate objectives is a central characteristic of all the tools and methods presented in this dissertation. However, it is important to realize that the value of the assets does depend on the accuracy of these objectives. If the demand for one's products is in decline, aiming for a high availability of the assets may not be the best way to create value for the company. Rather, cutting maintenance costs may be the best strategy. Changes in one's context – lifetime impacts – may therefore also influence the corporate objectives. Even if these targets are not set by the Asset Management organization, it may be that changing the objectives would be the best way to create maximum asset value. One of the ALCM capabilities – exerting influence outside one's direct span of control – may prove valuable in such a situation.

Risks and regimes

The fourth characteristic addresses the need to consider risks and (changes in) regimes in Asset Management. The latter has clearly been addressed in this research. However, the former has not, even though lifetime impacts are often uncertain and therefore could be regarded as future risks. But the (short term, operational) risks of failures, safety incidents or quality defects have not been considered. Many existing approaches exist to identify, assess and mitigate risks. One of them is Reliability Centred Maintenance (RCM) (Moubray, 1997; Smith and Hinchcliffe, 2003), but many more exist. The methods, tools and frameworks presented in this research are meant as a complement to those methods and tools that deal with short-term, operational risks (and many other tools with different purposes, such as spare parts management (e.g. Cavalieri et al., 2008), life cycle costing (e.g. Woodward, 1997) or maintenance policy selection (e.g. Hong et al., 2012)). In other words: the tools and methods presented in this paper are not sufficient for an organization to do ALCM, but complement existing tools by repairing some of their deficiencies.

The use of resources

Fifth, the determination of the use of resources is, just as the management of risks, not fully covered by this research. Existing methods, such as RCM, were designed to help asset managers in deciding on the right type of maintenance for different possible failures. However, the existing methods did not cover the use of resources on long term, strategic issues and on the management of change. Therefore, in this research a tool was developed to find suitable solution strategies to effectively deal with future threats and opportunities.

Information availability and reliability

Finally, it was found that many existing tools and methods in the literature depend on accurate data, which are often not available in practice. This research showed how limited and possibly unreliable data can still be used to gain an integral overview of the future of an asset. This asks for a different, more strategic use of data: the fifth ALCM capability. Additionally, it was shown how much can be done with the information already available within the company. Rather than looking for more and better information, using the existing information – which may only be stored in the heads of people – in new ways may already deliver many new insights regarding the performance and future of the assets. Bringing people together from different backgrounds, structured expert sessions, acknowledging intuition and expertise and aligning with both management and the operations are all means to make more of existing information.

This does not mean that quantitative data is not valuable. Rather, it means that even in the absence of quantitative information, much can be done based on the available qualitative data, knowledge and expertise. This qualitative information can form a foundation to assess what (quantitative) information may be collected to increase one's understanding of the assets, their performance and their future. Additionally, this qualitative information can be used to assess the reliability of quantitative information. However, it is important to note that quantitative information can never cover the breath, depth and nuance of qualitative information. For future events, quantitative information may simply not be available (e.g. future failures cannot yet be measured). Furthermore, quantitative information always needs to be collected and stored, so it is likely that for newly raised questions data are not available as these have not (yet) been collected. Also, quantitative data often require additional information to rightly interpret these (e.g. context information (Braaksma et al., 2013)), which may very well be qualitative information or the expertise of technicians. In other words: quantitative information can be extremely useful, also for the methods and tools presented in this paper, but it is a fiction that all qualitative information used in these tools could (or according to some maybe even: should) be replaced by quantitative data.

To summarize this discussion of the methods and tools developed in this research, one may conclude that these methods and tools separately do not completely address the six limitations of the existing literature. Topics such as risk management, the use of resources or the estimation of the remaining useful life of the assets are not covered by the LICAM and the other tools presented in this dissertation. However, the newly developed methods and tools do complement the existing literature and maintenance concepts by repairing their deficiencies. Used together, they may help asset managers to safely and effectively manoeuvre their assets into the future.

Table 10.3.1 – an overview of how the different methods, tools and frameworks of this dissertation live up to the five requirements of ALCM (white cells) and deal with the additional practical challenge of information availability in Asset Management (light grey cells on the right)

method or tool	multidisciplinary	the whole life cycle	objectives	regimes	use of resources	information availability
ALCM control (chapter 3)	Multidisciplinary performance targets and performance measurements are needed, for example using the TECOCO perspectives to cover the different aspects relevant of the performance of the asset	The long lifetimes of the assets – as well as the long lead times of control measures to take effect – require a focus on both the short and the long term. The ALCP can establish this dual focus	Having a clear goal is one of the five requirements for effective ALCM control, the performance on each of these goals needs to be measured to stay on target	Information about the (future changes in the) context of the asset is crucial to keep the asset valuable to its owner	Only if sufficient control measures are available to adapt the performance of the assets to keep it aligned with the objectives, the asset manager is 'in control'	In the absence of quantitative data, performance can also be managed using qualitative descriptions. Information availability and the capacity to process information are important for effective ALCM control
LICAM (chapters 4,5 and 7)	Experts from different disciplines are brought together in expert sessions, lifetime impacts are identified using the (multidisciplinary) TECOCO perspectives	All future lifetime impacts are considered in the LICAM. The lifetime impacts may be used to make design changes for future assets. The end-of-life is not estimated in the LICAM	The LICAM reasons from the value created by the assets, changes in the objectives of the assets are considered in the organizational perspective of TECOCO	The LICAM aims to identify all relevant changes in regimes, using the five TECOCO perspectives	The LICAM assists the asset manager in finding appropriate solutions to each identified (high priority) lifetime impact to effectively manage each impact	The LICAM is primarily based on qualitative information (i.e. expert knowledge), complemented with the available quantitative information (checked by experts)
Asset Life Cycle Plans (chapters 6 and 8)	Multidisciplinary performance targets are used, lifetime impacts are identified using the (multidisciplinary) TECOCO perspectives in expert sessions	The complete (remainder of the) life cycle is taken into account, including all relevant future lifetime impacts	Separate chapters discuss the corporate objectives and the current and expected performance on these objectives	Lifetime impacts (identified using TECOCO) are reported, the ALCP is to be updated regularly to adjust to changing circumstances	The ALCP ends with an overview of recommended actions to keep the asset valuable to the company	Information (mainly quantitative) is collected in preparation for the expert session, which is used to complement this information
ALCM capabilities (chapter 8)	Horizontal alignment concerns the ability of the asset manager to create a joint, multidisciplinary understanding on the asset	An important capability is the ability to focus on both short term operational issues as well as long term strategic topics	Vertical alignment concerns the ability to relate with the concerns and objectives of the higher management, based on a clear understanding of the assets and operations	Horizontal and vertical alignment allows to identify changes ranging from different disciplines and organizational layers, as does the more strategic use of information	The final capability concerns the ability of the asset manager to exert influence outside his direct span of control, to make sure the right actions are taken for the assets	By using the available information in a strategic way and complementing it with knowledge and expertise, the limitations of (quantitative) information can (partly) be overcome
agile Asset Management (chapter 9)	Change from all TECOCO perspectives is taken into account, organizational (i.e. non-technical) solutions are also considered to deal with change	Agility is especially relevant due to the long lifetimes of the assets, therefore special attention is paid to the asset design (i.e. asset adaptability and resilience)	The continuous alignment between the assets, their context and the goals of the organization is the main goal of agile Asset Management	Agility is all about being prepared to deal with changes in an effective way	The framework shows the possibility to use organizational solutions (e.g. agile people) to asset problems. The (resource) cost of agility for the organization is acknowledged	Agile information & processes are acknowledged as an important agility enabler, as is the importance of the right skills to use information in the right way

10.4 Limitations

In this last chapter of this dissertation, the research question has been answered. But irrespective of the efforts made and care paid to this research, its results come with imperfections and limitations. In each chapter, the specific limitations of the results presented in that chapter have been addressed. In this section, some words of caution will be spent on the results of this complete research project.

First, a large part of this research has been carried out in a very specific context: the Asset Management department of Liander. This raises the important question: do the conclusions of this research have any value outside this context? Three arguments will be given why the findings of this research do indeed have value for other Asset Management organizations. First and foremost, all of this research has been embedded in the so-called ‘enfolding literature’ (Voss et al., 2002). The literature has been studied at the start of each project, and its findings have been related back to the literature. In this way, the literature has been used as a safeguard to finding results that were largely context dependent and had no value outside this setting. Additionally, this research aimed at uprooting underlying, generic principles, such as the generative mechanisms underlying the methods developed using the Design Science methodology. Through ‘theoretical generalization’ (Eisenhart, 2008) (also known as ‘analytic generalization’ (Yin, 2014)), the theory resulting from a study that has value outside the context of the study itself, rather than the specific results found within that specific setting. This is the logic through which the results from this study have value for the scientific community, as well as for other Asset Management organizations, even operating different assets in different sectors. However, the specificities of these organizations, assets and sectors need to be taken into account when translating the theory to these settings.

Apart from the logic of theoretical generalization, it should be noted that the researcher has not limited himself to this particular setting, but has been in contact with many other organizations as well. Partly, the results of these interactions have been presented in this dissertation (e.g. the survey study presented in chapter 2, the application of the LIA at Vattenfall (chapter 5) or the study of agility at the Netherlands Railways and the Royal Netherlands Defence (chapter 9)). But many more asset managers have been talked with, articles have been read and presentations have been given and responded to: all of these interactions were used to confront the findings of this research and the views of the researcher with other settings. The results from these studies and interactions corroborated the findings at Liander, which again shows the value of the findings outside the Liander setting.

Nevertheless, further testing of the models, tools and frameworks of this research, especially in other industries (e.g. aerospace or process industry) and countries may allow a deeper understanding of the theory. Additionally, it may increase the reliability and gen-

eralizability of the conclusions of this research, or otherwise: refute them and replace them for more accurate one's.

A second limitation of this study concerns the evaluation of the methods and tools developed in this research. As these methods aim to assist asset managers in creating value with their assets over the complete lifetime of these assets, testing if these methods indeed deliver this result would be a difficult exercise. It would require to monitor the value created by two identical assets, managed in two different ways: one managed in the 'old' way, and one in the way proposed by this research. The resulting values at the end of life of the two assets – which may be decades – then needs to be compared. Even if this would be feasible, it would not have fit the duration of this research project. Therefore, again, the literature and the theory have to come to aid. Rather than evaluating the final outcome of a method, one can evaluate the working of its underlying mechanisms (van Aken et al., 2016). If these work as expected, one may expect that the end result will be as expected as well. As the generative mechanisms of the methods were taken from the literature and tested by an application in practice, it may be expected that the methods will deliver the expected end results as well.

Relatedly, this research showed how different methodologies – ranging from survey and case study research to design science and action research – can be combined in one research, the strength of the one complementing the weakness of another, to make a contribution to both theory and practice. The combination of a literature review and a broad exploration of practice using a survey study helped to gain an understanding of the gaps in theory as well as in practice. A number of case studies allowed a deeper understanding of these gaps, as well as different ways how organizations in practice deal with some of these gaps. The Design Science again combined theory and practice by using generative mechanisms discussed in the literature to develop new solutions for practical problems. Finally, the Action Research helped to study the test of these solution designs from a different angle: the development of new ALCM capabilities.

Finally, as was discussed in the previous section (10.3), it is important to realize that the methods, tools and framework presented in this research do not aspire to offer all that it takes to effectively manage one's assets. Rather, these methods have been developed to address gaps in the existing Asset Management literature and tools. Hence, they need to be seen and used as complementary to existing methods and tools, repairing some of their deficiencies.

10.5 Implications

In this final section of this dissertation, the transition will be made from an inward focus on the contents of this research to an outward focus on the world outside this research. First, the implications of this research for the wider Operations Management community

will briefly be discussed. Then, four promising topics for further research will be presented. Finally, the main implications from this research for Asset Management practitioners will be discussed.

10.5.1 Implications for the wider field of Operations Management

Asset Management, and even the complete field of maintenance, is only a very small subject in Operations Management²⁴. However, this research has some important implications for this discipline, three of which will be discussed now. First, this research has put physical assets at the centre stage of the success of an organization. Admittedly, corporate strategy, supply chain management, innovation and human resource management are also important for the success of a company. But by focusing on the assets, this research has shown how physical assets may offer new possibilities to an organization (e.g. in enabling agility) but also may restrict a company (e.g. as adapting physical assets after their initial design tends to be difficult and expensive). The acknowledgement of the importance of physical assets and the alignment of the (use and management of the) assets is an important implication of this research.

Secondly, this research has addressed the question of how to cope with change. Much has been written about this topic in the Operations Management literature – ranging from a tool like the PEST analysis (Brown et al., 2013) and the importance of managing innovation (Keupp et al., 2012) to the impact of natural disasters on the supply chain (Klibi et al., 2010) – but not from the perspective of the particularities of physical assets that make coping with change especially difficult in Asset Management. In this research the LICAM was developed to deal with change, and this method may be a useful complement and for the Operations Management field.

Finally, this research has stressed the importance of alignment, both horizontal (multidisciplinary), vertical (operations to higher management) and in time (short and long term). Alignment is crucial in Operations Management as well. As Brown et al. (2013) argue, “[t]he net result of not understanding the strategic importance of operations seems to be that well intentioned senior-level managers – including vice presidents and CEOs – sometimes make decisions that are almost *designed* to ruin their organizations’ capabilities [original emphasis]” (Brown et al., 2013, p. xi). Alignment includes this understanding the importance of operations, and much more. This research has addressed the strategic importance of not just the operations, but of the physical assets and their management for the good of the organization at large. Additionally, it has discussed how Asset Life Cycle Plans may play a role in this alignment and help to develop the capabilities important for

²⁴ For example, in their textbook on ‘Strategic Operations Management’, Brown et al. (2013) do not explicitly address maintenance as an important function in operations management, and only touch upon Total Productive Maintenance (TPM) when they discuss the importance of quality management.

creating and upholding this alignment. Especially these capabilities may be beneficial to managers in Operations Management at large, and not just for asset managers.

10.5.2 For further research

This research has led to a deeper understanding of long term and strategic Asset Management. However, it has also raised new questions. Four promising topics for further research will be presented.

Firefighting

A first topic that emerged from this research was the concept of firefighting: being occupied with solving urgent problems, limiting one's ability to work on more long term and strategic issues. It is this firefighting that limits many Asset Management organizations in their long term, strategic Asset Management efforts. The concept of firefighting in a manufacturing context has been discussed by Bohn (2000), who argues that "firefighting is one of the most serious problems facing many managers of complex, change-driven processes" (p.82). This description suits the situation of many Asset Management organizations, which have to manage their assets in the face of change (such as Liander in the energy transition). Bohn also states that "[i]n most U.S. organizations, the hero is the one who puts out the biggest fires" (2000, p. 97), acknowledging the satisfaction and status that may result from firefighting. Interestingly, the same is stated Henderson et al. (2014), who discuss how the best maintenance people are 'firefighters', but also discuss how this high status of firefighting may result in a lack of attention for preventive measures.

This last citation shows how firefighting is more than just an operational problem: it reflects the organizational culture. This shows that there is a more strategic aspect to firefighting. Other authors note this as well. For example, Zoeteman (2006) discusses how managers and other stakeholders may often pursue short term goals at the expense of long term performance (e.g. investing in more expensive but higher quality assets), which leads to a short term focus. A similar situation is described by Haarman and Delehay (2004) and Amadi-Echendu et al. (2007). Because of the importance of the strategic aspects of Asset Management, studying how Asset Management organizations deal with firefighting and uphold a dual time focus on both short term issues and long term strategic matters may be an important and promising topic for further research. When studying this topic, the findings from the study of 'short termism' in management (Marginson and McAulay, 2008) and relatedly in stock markets (Martin, 2015) may be useful inputs.

Ambidexterity

A second and related concept that repeatedly came up during this research was the concept of ambidexterity (O'Reilly and Tushman, 2004). Ambidexterity addresses the difficulty companies face to uphold a dual focus on innovation (exploration) and efficiency (exploit-

tation). Strategic Asset Management also requires a dual focus, on both short term operational matters and long term strategic topics. Furthermore, different asset populations may require very different Asset Management strategies, as shown by the three generic life cycle strategies used by the Netherlands Railways (see chapter 3). These strategies may require very different mind-sets: innovations and investments for new assets, cost cuts for those close to their end of life. It is an interesting topic for further research to see how Asset Management organizations manage to uphold these different time focuses and life cycle strategies.

Asset Management organizational structures, ownership and trust

Also related to the Asset Management organization is the third topic: organizational structures, ownership and trust. As discussed in chapter 8, the change towards a more strategic Asset Management also changed the role of the asset manager, asking him to exert influence outside his direct span of control. In chapter 9, this 'span of control' was also discussed, this time in the context of agility: if an Asset Management organization can expand its span of control, it may find additional sources of agility (e.g. by influencing the demand for the services provided by the asset).

The span of control directly relates to the job description of the asset manager and the organizational structure of the Asset Management organization. The change towards strategic Asset Management may create a need to widen the span of control of the asset manager, and thus to restructure the organization. In this way, the asset manager may be (formally) allowed to operate in different functional silos (horizontal alignment) and both on the operational and the strategic level (vertical alignment), which may increase the value that can be realized with the assets. Restructuring the organization relates to the field of enterprise engineering (e.g. Kosanke et al., 1999; Vallejo et al., 2012), which studies the architecture of organizations and how information flows within an organization. An interesting topic for further study could be the organizational structure of strategic Asset Management organizations, to further support the transition towards strategic Asset Management.

This study on ALCM organizational structures could be complemented by a research into trust and ownership. In the literature, feeling responsibility and ownership for the performance of assets is an important theme (Chan et al., 2005; Longley et al., 2012; Sutton and Chadwick, 2014; Jooste and Vlok, 2015). Clear ownership, complemented by sufficient capabilities of the owners and the right formal powers, may allow higher management to trust that the performance of the asset is well-managed. If this trust does not exist, this may result in all kinds of questions (as was one of the reasons for this project – see chapter 9) or the exertion of direct control by the higher management. Having clear responsibilities and ownership, as well as trust in the competence of others, may facilitate (vertical) alignment. It is the opinion of the author that the right combination of organizational

structure and ownership – complemented by the right capabilities and formal powers – are crucial for an effective strategic Asset Management.

The human factor in Asset Management

If there is one thing remarkable about this dissertation about Asset Management, it is the rather limited share of attention paid to the physical assets and all the technology used to operate and maintain them. This is not because engineering and technology is not important, rather the contrary. However, the focus in Asset Management has primarily been on these technical aspects of the assets over the last decades and much progress has been made in these fields. But Asset Management is more than just a technical discipline. It is the other disciplines that have gained the majority of the attention in this research. In most expert sessions, other perspectives than the technological one yielded most lifetime impacts, most often the commercial and organizational ones. The ALCM capabilities emerging from the action research project were not technical in nature, but rather managerial and organizational. And regarding agility, it was found how organizational agility may help to cope with change, and that acknowledging this shows “optimization opportunities we are only starting to acknowledge” (chapter 9, p.252). The importance of non-technical aspects of Asset Management was also shown in a recent Delphi study (Akkermans et al., 2016) on the most important innovation priorities for maintenance in the Netherlands. The outcomes stressed the importance of ‘soft’ topics such as cultural change and knowledge management, next to (and conditional to) ‘hard’ topics as smart sensing, big data and life cycle costing (LCC). The opportunities for Asset Management in (collaboration with) non-technical disciplines is the main reason why organizational aspects are so important throughout this dissertation. Due to the large efforts made in the technical areas, it is often hard to make further improvements here. However, when increasing the span of control of Asset Management, many new variables come available that can be optimized.

This would require a changing role of asset managers: rather than technical specialist, they need to become ‘alignment specialists’. Starting from a thorough understanding of the physical asset and the operations, they need to be able to relate to the needs and desires of other stakeholders, including other divisions (horizontal alignment) and higher management (vertical alignment). They need to be able to understand the consequences of decisions on the short and the long term (time alignment). On the one hand, this change requires a change in the capabilities of asset managers. On the other hand, it asks for a recognition of the importance of Asset Management throughout the organization, from the board room to the operations. If the importance of Asset Management for the long term success of an organization is fully acknowledged as well as asset managers develop the required ALCM capabilities, a big step towards alignment may be made.

10.5.3 For Asset Management practitioners

For Asset Management practitioners, this dissertation has three main ‘take home messages’. First, asset managers should acknowledge that Asset Management is not just about engineering and technology, but ultimately about contributing to the business as a whole. Just as discussed in the previous section (‘the human factor in Asset Management’, page 274), acknowledging the non-technical aspects of Asset Management opens a wide variety of new opportunities to create even more value from the assets. Knowledge management, culture, change processes, collaboration, stakeholder management, communication skills, software and information systems all are crucially important for asset managers, especially in the face of change.

Secondly, Asset Management is all about alignment. The discussion of five ALCM capabilities in chapter 8 showed the importance of horizontal (multidisciplinary) and vertical (higher management to operations) alignment. Also, the capability to uphold a dual focus on the short as well as the long term – which can be called time-alignment – is crucial in Asset Management. Asset Life Cycle Plans (ALCPs) can help to create and uphold these three types of alignment within an Asset Management organization. Chapter 6 presented a practical twelve step approach to develop such ALCPs, which may also prove useful to develop the Asset Management Plans as required by the ISO 55000 standard (ISO, 2014).

The discussion of agility in Asset Management showed another type of alignment that is important: agility alignment. The level of agility of the organization should be aligned with the (expected) future amount of change in the goals and context of the assets. Too much agility would be a waste of resources, while too little agility may result in unnecessarily high costs or even not being able to cope with change (which may prevent the organization from reaching its objectives). Alignment requires a good understanding of the asset, its future and the organization, and the organizational and managerial skills to use all of this information to align all plans and activities related to the assets.

Thirdly, asset managers may profit from using the Lifetime Impact Centred Asset Management (LICAM) method, as presented in this research. It is this method that may assist asset managers in acknowledging the importance of change on their organization, and in identifying, prioritizing and managing these changes. If change is not suitably managed in Asset Management, one may create maximum value from the exploitation of the assets on the short term, but one cannot yield the maximum value from the asset over its complete life time. Therefore, the combination of planning for predictable change and preparation for unpredictable change is indispensable to safely and efficiently manoeuvre physical assets into the future.

Please allow me one last comment to all the asset managers who have managed to read through this dissertation. I highly appreciate your efforts to read through this lengthy and theoretical dissertation. But much more than that, I appreciate the work you do. I know

from my discussions with asset managers that your effort are not always appreciated as they should be, that the importance of the good work you do is often overlooked, and that Asset Management is only an issue to be discussed in case of failures or safety incidents. I would like to state that I appreciate the work you do. Throughout this research, I have aimed to develop knowledge and tools to assist you in doing your work, to hand you the tools to make your difficult job a little bit easier. I am fully aware that practice is always more complex than theory, that some parts of this research will not be applicable to your particular situation and that I have overlooked some challenges that are of utmost importance to you. I do not want to prescribe you how Asset Management should be done, I know you do know far more about that than I can learn from behind my desk and the many conversations I held with practitioners. Nevertheless, it is my hope that this research has offered you some insights, ideas of tools that can be of help in your daily work. Because Asset Management, like any type of management, is a skill, not a set of rules. Therefore, I would like to close this thesis with a quote from two important management scholars, with which I fully agree: “we have come to understand that management is about coping effectively with a kaleidoscope of opportunities, threats, constraints and imponderables in real time. The imposition of standard operating procedures, no matter how sophisticated, cannot adequately guide the fortunes of an enterprise – intelligent, proactive, creative, adaptable and prudent action is required” (Meredith and Francis, 2000, p. 137). Keep up the good work!

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References

As Isaac Newton once famously wrote, 'if I have seen further, it is by standing on the shoulders of Giants'. Progress in science depends on the labour of countless intelligent and inquisitive men and women before us. Therefore, I more than gratefully acknowledge the work of those scientists that have helped me in accomplishing this research project.

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Appendix

The Appendix presents the interview guides, evaluation forms and questionnaire used to collect the data for the research presented in this dissertation.

Appendix

A.1 Descriptives of the variables used to assess Asset Management practice

The next pages will present the descriptives of the variables used to assess Asset Management practice on the requirements of ALCM, as discussed in Chapter 2 (section 2.5): multidisciplinary (Table A.1.1), whole life cycle (Table A.1.2), performance management (Table A.1.3) and change management (Table A.1.4). Additionally, for all statistical tests carried out these tables will present the value of the Student's t-statistic, the degrees of freedom of the test and the 95% confidence interval of the estimate. The p-value reports the outcome of the test, of which the conclusion is presented in the final column of the tables.

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Table A.1.1 - the descriptives (number of responses, frequencies, mode (shaded), average and standard deviation) and tests (t-value, degrees of freedom, p-value (one-tailed test) and conclusion) of the variable 'multidisciplinary' and its underlying items

	N	scale	1	2	3	4	5	Ave.	St. Dev.	t-value	df	95% CI	p-value	concl.
Likert scale variable (based on items below)														
Multidisciplinary	100	never - continuously			continuous (1-5)			3,40	0,60	-1,670	99	(-∞, -0,001)	0,049	rejected
Individual items														
Engineering	100	never - continuously	2,0%	8,0%	21,0%	41,0%	28,0%	3,85	0,99	3,540	99	(-∞, 0,514)	1,000	not rejected
Finance	100	never - continuously	4,0%	11,0%	22,0%	40,0%	23,0%	3,67	1,07	1,583	99	(-∞, 0,348)	0,942	not rejected
Compliance	100	never - continuously	1,0%	23,0%	25,0%	28,0%	23,0%	3,49	1,12	-0,090	99	(-∞, 0,175)	0,465	not rejected
Customer desires (e.g. sales)	100	never - continuously	9,0%	30,0%	22,0%	31,0%	8,0%	2,99	1,14	-4,468	99	(-∞, -0,320)	0,000	rejected
Strategy / Top management	100	never - continuously	2,0%	27,0%	25,0%	30,0%	16,0%	3,31	1,10	-1,730	99	(-∞, -0,008)	0,044	rejected
Sustainability	100	never - continuously	5,0%	47,0%	28,0%	13,0%	7,0%	2,70	1,00	-8,000	99	(-∞, -0,634)	0,000	rejected
Data management and analysis	100	never - continuously	2,0%	16,0%	28,0%	38,0%	16,0%	3,50	1,01	0,000	99	(-∞, 0,168)	0,500	not rejected
Purchasing	100	never - continuously	4,0%	17,0%	35,0%	36,0%	8,0%	3,27	0,97	-2,364	99	(-∞, -0,068)	0,010	rejected
OEM / supplier	99	never - continuously	1,0%	26,3%	33,3%	33,3%	6,1%	3,17	0,93	-3,526	98	(-∞, -0,174)	0,001	rejected
Maintenance planning + execution	100	never - continuously	0,0%	9,0%	20,0%	30,0%	41,0%	4,03	0,99	5,357	99	(-∞, 0,694)	1,000	not rejected
Production / operations	100	never - continuously	3,0%	14,0%	22,0%	28,0%	33,0%	3,74	1,15	2,084	99	(-∞, 0,431)	0,980	not rejected
Innovation	99	never - continuously	1,0%	28,3%	38,4%	28,3%	4,0%	3,06	0,88	-4,976	98	(-∞, -0,293)	0,001	rejected

Table A.1.2 - the descriptives (number of responses, frequencies, mode (shaded), average and standard deviation) and tests (t-value, degrees of freedom, p-value (one-tailed test) and conclusion) of the variable 'whole life cycle', its underlying items, the variables on time spending (for the two different groups) and on future plans

	N	scale	1	2	3	4	5	Ave.	St. Dev.	t-value	df	95% CI	p-value	concl.
Likert scale variable (based on items below)														
Whole life cycle	97	no influence at all - very large influence			continuous (1-5)			3,51	0,667	0,190	96	(-∞, 0,125)	0,575	not rejected
Individual items														
Design	97	no influence at all - very large influence	5,2%	22,7%	32,0%	23,7%	16,5%	3,24	1,13	-2,282	96	(-∞, -0,072)	0,013	rejected
Purchase	96	idem	7,3%	19,8%	29,2%	28,1%	15,6%	3,25	1,16	-2,110	95	(-∞, -0,053)	0,019	rejected
Build	96	idem	6,3%	24,0%	32,3%	28,1%	9,4%	3,10	1,07	-3,621	95	(-∞, -0,214)	0,000	rejected
Commission	95	idem	2,1%	7,4%	27,4%	46,3%	16,8%	3,68	0,91	1,964	94	(-∞, 0,340)	0,974	not rejected
Operate/use	96	idem	3,1%	19,8%	26,0%	26,0%	25,0%	3,50	1,16	0,000	95	(-∞, 0,197)	0,500	not rejected
Maintain	97	idem	0,0%	2,1%	8,2%	29,9%	59,8%	4,47	0,74	13,014	96	(-∞, 1,099)	1,000	not rejected
Modify	97	idem	0,0%	4,1%	12,4%	39,2%	44,3%	4,24	0,83	8,786	96	(-∞, 0,876)	1,000	not rejected
Decommission	90	idem	3,3%	23,3%	27,8%	22,2%	23,3%	3,39	1,18	-0,895	89	(-∞, 0,095)	0,187	not rejected
Recycle/resale	88	idem	15,9%	35,2%	27,3%	12,5%	9,1%	2,64	1,17	-6,946	87	(-∞, -0,657)	0,000	rejected
Time spending														
operational (satisfied)	43	% of time			continuous			20,93	18,91					
operational (unsatisfied)	53	% of time			continuous			33,77	23,61	-2,959	93,00*	(-21,460, -4,227)	0,004	group means differ significantly
tactical (satisfied)	43	% of time			continuous			46,74	19,42	0,937	91,56*	(-4,277, 11,917)	0,351	group means do not differ significantly
tactical (unsatisfied)	53	% of time			continuous			42,92	20,39					
strategic (satisfied)	43	% of time			continuous			32,33	21,61	2,320	72,42*	(1,272, 16,776)	0,023	group means differ significantly
strategic (unsatisfied)	53	% of time			continuous			23,30	15,03					
Other variables														
use of future plans	96	# of years into the future	S2	2-5	5-10	10-20	RUL							
			25,0%	31,3%	20,8%	8,3%	14,6%	2,56	1,34	-	-	-	-	-

*as Levene's test for the equality of variances was significant for two of the three variables, the test values for 'equal variances not assumed' are reported.

Table A.1.3 - the descriptives (number of responses, frequencies, mode (shaded), average and standard deviation) and tests (t-value, degrees of freedom, p-value (one-tailed test) and conclusion) of the variable 'performance management', its underlying items and the variables influence on performance

	N	scale	1	2	3	4	5	Ave.	St. Dev.	t-value	df	95% CI	p-value	concl.
Likert scale variable (based on items below)														
Performance management	97	completely disagree - completely agree	continuous (1-5)					3,49	0,71	-0,081	96	(-∞, 0,114)	0,468	not rejected
Individual items														
measurable targets	94	completely disagree - completely agree	1,1%	9,6%	20,2%	47,9%	21,3%	3,79	0,93	3,007	93	(-∞, 0,446)	0,999	not rejected
active performance management	95	idem	1,1%	4,2%	11,6%	52,6%	30,5%	4,07	0,83	6,751	94	(-∞, 0,715)	1,000	not rejected
known outcomes	96	idem	0,0%	21,9%	20,8%	44,8%	12,5%	3,49	0,97	-0,210	95	(-∞, 0,144)	0,417	not rejected
understanding of future performance (1 year)	96	idem	2,1%	13,5%	31,3%	45,8%	7,3%	3,43	0,89	-0,801	95	(-∞, 0,078)	0,213	not rejected
understanding of future performance (5 years)	96	idem	2,1%	28,1%	44,8%	24,0%	1,0%	2,94	0,81	-6,843	95	(-∞, -0,426)	0,000	rejected
Other variables														
influence on performance (3 months)	88	see above	<1%	1-3%	3-10	10-20	>20%							
influence on performance (1 year)	90	see above	39,8%	23,9%	23,9%	6,8%	5,7%	2,15	1,19	-	-	-	-	-
influence on performance (5 years)	87	see above	10,0%	23,3%	42,2%	12,2%	12,2%	2,93	1,12	-	-	-	-	-
			2,3%	11,5%	32,2%	25,3%	28,7%	3,67	1,09	-	-	-	-	-

Table A.1.4 - the descriptives (number of responses, frequencies, mode (shaded), average and standard deviation) and tests (t-value, degrees of freedom, p-value (one-tailed test) and conclusion) of the variable 'management of change', its underlying items and the variables 'impact of changes in...'

	N	scale	1	2	3	4	5	Ave.	St. Dev.	t-value	df	95% CI	p-value	concl.
Impact of changes in...														
Finances	96	very little influence - major influence	0,0%	7,3%	11,5%	61,5%	19,8%	3,94	0,78	5,504	95	(-∞, 0,570)	1,000	not rejected
Market demand	96	idem	3,1%	15,6%	18,8%	45,8%	16,7%	3,57	1,04	0,685	95	(-∞, 0,250)	0,753	not rejected
Safety	96	idem	0,0%	7,3%	18,8%	52,1%	21,9%	3,89	0,83	4,540	95	(-∞, 0,526)	1,000	not rejected
Regulation	96	idem	2,1%	6,3%	18,8%	51,0%	21,9%	3,84	0,91	3,701	95	(-∞, 0,498)	1,000	not rejected
Availability of skilled employees	96	idem	1,0%	5,2%	19,8%	59,4%	14,6%	3,81	0,79	3,898	95	(-∞, 0,446)	1,000	not rejected
Information quality and availability	94	idem	1,1%	5,3%	17,0%	42,0%	8,4%	3,82	0,76	4,064	93	(-∞, 0,450)	1,000	not rejected
Likert scale variable (based on items below)														
management of change	96	completely disagree - completely agree	continuous (1-5)					3,43	0,63	-1,088	95	(-∞, 0,037)	0,140	not rejected
Individual items														
long term developments are known	95	completely disagree - completely agree	0,0%	9,5%	24,2%	58,9%	7,4%	3,64	0,76	1,830	94	(-∞, 0,271)	0,965	not rejected
consequences of developments are known	93	idem	0,0%	16,1%	36,6%	44,1%	3,2%	3,34	0,79	-1,910	92	(-∞, -0,020)	0,030	rejected
information available to adjust performance	93	idem	0,0%	18,3%	32,3%	45,2%	4,3%	3,35	0,83	-1,688	92	(-∞, -0,002)	0,048	rejected
preparatory actions are taken	96	idem	2,1%	14,6%	22,9%	53,1%	7,3%	3,49	0,91	-0,113	95	(-∞, 0,143)	0,456	not rejected
long term scenarios	96	idem	5,2%	18,8%	21,9%	49,0%	5,2%	3,30	1,01	-1,927	95	(-∞, -0,027)	0,029	rejected

A.2 Interview guide ALCM control (in Dutch)

Algemene introductie

1. Mag ik dit interview opnemen? Ik zal de opname gebruiken voor het uitwerken van het interview. De interviewresultaten worden enkel anoniem openbaar gemaakt.
2. Korte kennismaking
 - functie
 - expertise (binnen en buiten de NS)
 - bij welke assets betrokken? Sinds wanneer?
 - belangrijkste activiteiten op dit moment
3. Wat zijn volgens jou op dit moment de grootste uitdagingen voor Asset Management binnen de NS?
 - voor de NS als geheel
 - voor jou als de materieel manager van een specifiek treintype

Kort toelichten van dit interview: het gaat om de besturing van materieelprestaties dmv het LLP.

- kenmerken van ALCM: multidisciplinair, hele levensloop, risico's, externe ontwikkelingen en resources
- kenmerken van besturing: doel, model, informatie, maatregelen en informatie-verwerkende capaciteit

Introductie LLP bij de NS

4. Kun je in een paar zinnen beschrijven wat een LLP is bij de NS?
5. Wat is de functie van het LLP voor de NS?
6. Wat heb jij in je dagelijks werk aan het LLP?
7. Hoe zou het Asset Management van jouw materieelserie eruit zien als er geen LLP was?
8. Wat hoort er voor jou wel in een LLP, en wat niet?
9. Hoe komt een LLP tot stand? (proces, wie zijn hierbij betrokken, ...)

Asset Life Cycle Management

10. Het LLP legt sterk de nadruk op de komende 5 jaar. Ik mis aandacht voor de periode daarna. Hoe past die in het LLP?
 - Zijn er andere documenten of afdelingen die bezig zijn met de lange termijn van de [type trein]? (nieuwe wetgeving, reizigersprognoses, etc)
11. Hoe worden de risico's en (externe) ontwikkelingen met een impact op de asset in beeld gebracht? Hoe zorgen jullie dat jullie een compleet beeld hebben?

12. In eerdere LLP's was er een apart hoofdstuk over risico's, in de 2015 versie niet meer. Waarom? Wat vind je daarvan?
13. In het LLP lees ik maar weinig over kansen en innovaties, op welke manier spelen die een rol?

Besturing

14. Hoe zijn de materieelprestatie-indicatoren ontwikkeld?
15. Wie stelt de doelen voor de assets, zoals die in het LLP staan?
 - Zijn dit doelen of prognoses, of allebei?
 - Op welke manier worden deze doelen afgestemd met andere afdelingen?
16. Hoe krijg je informatie over de prestaties op deze doelstellingen?
17. Zijn er ook doelen voor op de lange termijn (na 5 jaar)?
18. Jouw materieeltype is net (per 2013) van 'garanderen' naar 'uitfaseren' gegaan.
 - waarom in 2013 (5 jaar voor start uitfaseren)?
 - wat betekent dit voor het dagelijks beheer van deze treinserie?
 - is het leuk om materieelmanager van een uitfaseren-serie te zijn?
 - ...
19. Als ik het LLP lees krijg ik het idee dat je 'vanuit een helikopter' naar de asset kijkt. Je gaat ervan uit dat alle processen volgens instructie lopen (bediening, onderhoud) en bent alleen bezig met bijsturen. Klopt dat?
 - wat zijn de 'standaardprocessen' die op de achtergrond lopen?
 - wat is de rol van instandhoudingsresearch?
 - het vergroten van onderhoudstermijnen, hoort dat voor jou in het LLP?
 - wat zijn voor jou de 'controlemaatregelen' waarover je als materieelmanager beschikt?
 - verschil 'harde en zachte afspraken tbv materieelcontract'? (genoemd in instructie bij hfst 4 – besturing materieelprestaties)
20. Ik zie verschillende typen stuurmaatregelen in het LLP: procesmaatregelen, kennis vergaren en constructiewijzigingen. Welke zijn het belangrijkste?
21. Er is enorm veel informatie over een asset, en je kunt met alles tegelijk bezig zijn. Lukt het jullie om alle relevante informatie te verzamelen en op tijd te verwerken tot stuurmaatregelen?
 - Waarom (niet)?
 - Hoe? (eventueel doorvragen op 'informatieverwerkende capaciteit', bijv rol van LLP daarin)
22. Als je jouw materieelserie vergelijkt met een andere materieelserie, wat zijn dan de verschillen in bestuurbaarheid?
23. Hoe bestuurbaar zijn de prestaties van jouw treintype? Waardoor komt dit?
 - levenslooppfase
 - oud materieel: liefst zo min mogelijk wijzigen
 - beschikbaarheid van geld, ook gezien korte restlevensduur
 - obsolescence van onderdelen??

24. Hoe bestuurbaar zijn de materieelkosten?

Reflectie

25. Wat zijn voor jou de belangrijkste veranderingen in het beheer van jouw treinserie de laatste jaren?

26. Wat zijn de belangrijkste leerpunten geweest in het beheer van jouw treinserie?

27. Helpt het LLP jullie bij het continue verbeteren en leren van de assetprestaties?

28. Ben je tevreden met hoe het LLP nu is? Wat zou je anders willen?

Treinserie-specifieke vragen

29. [afhankelijk van de bestudeerde LLP's, hier enkel een voorbeeld] Hoe ga je om met de (grote) verschillen tussen sub-populaties van jouw treinserie? 2tjes en 3tjes, leeftijd

Afsluiting

30. Zijn er nog dingen die we nog niet hebben besproken, maar die jou belangrijk lijken voor dit onderzoek?

31. Zou ik je eventueel nog een keer mogen bellen als ik vervolgvragen heb?

A.3 Interview guide ALCPs (in Dutch)

1. Korte kennismaking
 - functie
 - expertise (binnen en buiten Liander)
 - bij welke assets betrokken?
 - belangrijkste activiteiten op dit moment
2. Wat zijn volgens jou op dit moment de grootste uitdagingen voor Asset Management binnen Liander?
 - voor AM als geheel
 - voor de respondent in zijn/haar functie (oa Asset Groep)
3. In hoeverre is de gehele levensduur van assets op dit moment bij Liander (AM) goed in beeld?
4. Welke aspecten zijn er relevant om de gehele levensduur van een asset in beeld te brengen? [primes hieronder]
 - korte vs. lange termijn
 - welke verschillende invalshoeken? (TECKO)
 - scenario's
 - onzekerheden (en hoe worden deze nu gemanaged?)
 - cijfers en analyses (=kwantitatief)
 - kennis van praktijkmensen (=kwalitatief)
 - strategie vs. operatie
 - functie vs. fysiek
5. Er is binnen AM B&S al veel gezegd over levensloopplannen. Welk beeld heb jij bij de term 'levensloopplan' (LLP)? [in één zin]
6. In welke behoeften zou een LLP moeten voorzien? [doelen]
7. Wat zou er naar jouw idee in een LLP moeten zitten? [terugkomen op eerder genoemde uitdagingen]

Vervolgens geef ik een korte inleiding van ons werk tot nu toe en de opzet van de LLP's.

8. Wat vind je van deze opzet?
9. Welke onderdelen zou je graag toe willen voegen?
10. Welke onderdelen kunnen wat jou betreft geschrapt worden?
11. Is een dergelijk LLP volgens jou een aanvulling voor Liander AM?
12. Is een dergelijk LLP volgens jou een aanvulling voor jouw eigen werk?

A.4 Interview questions ALCP evaluation interview (in Dutch)

Proces

Hoe vond je het om een LLP op te stellen?

Wat vond je lastig?

Wat vond je meevallen?

Was er voldoende informatie beschikbaar?

Had je achteraf graag ook een expertsessie gehouden?

Hoe vond je de begeleiding/ondersteuning?

Hoe was het om met twee personen een LLP op te stellen? Wat was jullie taakverdeling?

Hoeveel werktijd en doorlooptijd ben je ermee bezig geweest? Wat kostte vooral veel tijd?

Hoe was de reactie van het MT AM? [preaccordering, bespreking in MT AM, na afloop]

Lessons learned

Is het LLP een aanvulling tov eerdere beleidsstukken? Zo ja, wat? [multidisciplinair, doelen expliciet, hele levenscyclus in kaart]

Wat zou je een volgende keer anders aanpakken bij het opstellen van een LLP?

Wat zijn dingen die je geleerd hebt van/tijdens het opstellen van het LLP?

Welke tips heb je voor degenen die binnenkort voor het eerst een LLP gaan opstellen?

Inhoud

Geeft het LLP een compleet beeld van hoe de beschreven populatie ervoor staat?

Maakt het LLP dat je meer 'in control' bent met deze assetpopulatie?

Heeft het opstellen van het LLP je nieuwe inzichten opgeleverd?

Heeft de kapstok je geholpen bij het opstellen van het LLP?

Welke punten kunnen wat jou betreft uit het LLP gehaald worden?

Welke punten zouden er wat jou betreft nog bij moeten?

Opbrengst

Ben je tevreden met het LLP zoals het er nu ligt (product)?

Wat levert het LLP voor jou als beleidsmedewerker op?

Heeft het LLP invloed op hoe goed je kunt sturen op deze assetpopulatie?

Heeft het LLP al tot nieuwe initiatieven of samenwerkingen geleid?

Verbeterpunten

Wat zou er in een volgende versie van het LLP beter kunnen?

Wat zou je er graag aan toevoegen?

Wat zou je er graag uitlaten?

Waar zie je de belangrijkste hobbels om het LLP een stap verder te krijgen?

Waar zou je graag met het LLP antwoord op geven wat je nu niet gelukt is?

A.5 ALCP valuation form (in Dutch)

TECKO-analyse van de [naam van de populatie]

De TECKO-analyse heeft geholpen om nieuwe bedreigingen voor de [naam van de populatie] te herkennen.

[totaal mee oneens 1 – 2 – 3 – 4 – 5 – 6 – 7 totaal mee eens]

De TECKO-analyse heeft geholpen om nieuwe kansen voor de [populatie] te herkennen.

[totaal mee oneens 1 – 2 – 3 – 4 – 5 – 6 – 7 totaal mee eens]

Wat vind je van het idee om je voor de levensloopplannen te focussen op de vijf TECKO-gebieden?

.....

Hoe belangrijk is het technische perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het economische perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het compliancy perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het klant perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het organisatorische perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Kon je alle relevante issues voor de [naam van de populatie] kwijt in de vijf TECKO-perspectieven? Zo nee, welke niet?

Ja / nee

Levensloopplan

Vond je het leuk om aan dit LLP te werken?

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Waarom?

.....

Reageer op de volgende stellingen:

Het LLP is nuttig voor mijn dagelijks werk.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik denk dat het LLP nuttig is voor het bedrijf als geheel.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik heb nieuwe kennis opgedaan dankzij het LLP.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik heb nieuwe ideeën opgedaan dankzij het LLP.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik denk dat het LLP ons zal helpen om meer waarde voor het bedrijf te creëren met de [naam van de populatie].

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Wat vind jij de toegevoegde waarde van een LLP?

.....

A.6 Expert session evaluation form (in Dutch)

Algemeen

Naam:

Functie:

Aantal jaar in dienst bij Alliander (en rechtsvoorgangers):

TECKO-analyse van de [naam van de asset populatie]

De TECKO-analyse heeft geholpen om nieuwe bedreigingen voor de [naam van de populatie] te herkennen.

[totaal mee oneens 1 – 2 – 3 – 4 – 5 – 6 – 7 totaal mee eens]

De TECKO-analyse heeft geholpen om nieuwe kansen voor de [populatie] te herkennen.

[totaal mee oneens 1 – 2 – 3 – 4 – 5 – 6 – 7 totaal mee eens]

Hoe belangrijk is het *technische* perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het *economische* perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het *compliance* perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het *klant* perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Hoe belangrijk is het *organisatorische* perspectief voor de toekomst van de [populatie]?

[totaal niet belangrijk 1 – 2 – 3 – 4 – 5 – 6 – 7 extreem belangrijk]

Zijn er nog dingen die je graag in had willen brengen, maar wat niet gelukt is? Zo ja, welke?

Ja / nee

Wat is voor jou de belangrijkste bedreiging voor de [naam van de populatie] die je vandaag gehoord hebt? Waarom?

.....

Wat is voor jou de belangrijkste kans voor de [naam van de populatie] die je vandaag gehoord hebt? Waarom?

.....

Expertsessie

Vond je het leuk om aan deze expertsessie mee te doen?

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Waarom vond je het leuk om mee te doen?

Reageer op de volgende stellingen

De expertsessie was nuttig voor mijn dagelijks werk.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik denk dat de expertsessie nuttig was voor het bedrijf als geheel.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik heb nieuwe kennis opgedaan in deze expertsessie.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik heb nieuwe ideeën opgedaan in deze expertsessie.

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Ik denk dat deze expertsessie ons zal helpen om meer waarde voor het bedrijf te creëren met de [naam van de populatie].

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 in zeer grote mate]

Wat vind jij de toegevoegde waarde van een expertsessie als deze?

Heb je ideeën hoe we een expertsessie als deze kunnen verbeteren? *Bijvoorbeeld: lengte, structuur, thema's, groepsgrootte, ...*

Wat vond je van de lengte van de expertsessie?

[te kort 1 – 2 – 3 – 4 – 5 – 6 – 7 te lang]

Heb je alles in kunnen brengen wat je over de [naam van de populatie] te zeggen had?

[totaal niet 1 – 2 – 3 – 4 – 5 – 6 – 7 volledig]

Zou je een sessie als deze vaker willen doen? Zo ja, hoe vaak?

Ja / nee

Hartelijk bedankt voor het invullen!

A.7 Interview guide Prioritization model (by Tijmen van Diepen)

This interview guide was developed by Tijmen van Diepen as a part of his MSc graduation project at Liander (van Diepen, 2016, pp. 125–126).

Introduction

Thank you for taking the time for an interview.

I am a graduation student from the University of Twente at the study mechanical engineering. My assignment is dealing with Asset Life Cycle Plans and the expert session. During an expert session a large number of lifetime impacts are identified, but not all lifetime impacts are equally important. So I am trying to create a method that can determine what is important and what is not.

Interview

1. What is your function and what are your job responsibilities? (Expertise, assets, activities, knowledge and expertise with ALCP)
2. What are the largest future challenges for your asset?
3. What is your definition of an Asset Life Cycle Plan? (purpose, vision, origin, added value)
4. What do you think can be improved upon in an Asset Life Cycle Plan, from the perspective of your type of asset? (connection between purpose and vision, certain problems that arise)
5. Explaining my assignment. An important part of ALCPs are the lifetime impacts, or the future threats and opportunities. Are all lifetime impacts currently taken into account in Asset Management of your asset type? (If yes, how?)
6. If no, how is the decision made between “important” and “less important” lifetime impacts?
7. Should all lifetime impacts be taken into account in an ALCP? (If yes, how?)
8. If no, how should a choice be made in an ACLP?
9. Explanation of the difference between “certain” and “uncertain” lifetime impacts. How are uncertainties managed in your asset type? And how risks?
10. What criteria should the model fulfil?

A.8 Interview protocol Agility in Asset Management (in Dutch)

Algemene introductie

1. Mag ik dit interview opnemen? Ik zal de opname gebruiken voor het uitwerken van het interview. De interviewresultaten worden enkel anoniem openbaar gemaakt.
2. Korte kennismaking
 - functie
 - expertise (binnen en buiten defensie)
 - bij welke assets betrokken, en hoe lang al?
 - belangrijkste activiteiten op dit moment in zijn werk
3. Wat zijn volgens jou op dit moment de grootste uitdagingen voor Asset Management binnen jullie organisatie?
 - voor het Asset Management binnen de hele organisatie
 - voor hem als asset manager van een specifieke populatie

➔ **het gaat in het interview om die specifieke populatie en de functie die die heeft!**

Toelichting van het interview

Kort toelichten van dit interview: het gaat om de flexibiliteit in het benutten van de assets:

- flexibiliteit: de mate waarin het mogelijk is binnen een bepaalde tijd het beheer (en gebruik/inzet) van de assets aan te passen, als gevolg van veranderende omstandigheden en/of andere doelstellingen.
- hoeveel veranderingen zijn er in de omgeving van de asset?
- hoeveel veranderen de doelstellingen met de asset daardoor?
- hoeveel flexibiliteit zit er in het ontwerp van de asset zelf?
- wat zijn andere bronnen van flexibiliteit om veranderende asset-doelen te halen?

Doelstellingen van Asset Management binnen de organisatie

4. Wat is de belangrijkste doelstelling in het Asset Management in jullie organisatie?
5. Wat zijn de specifieke doelen die jullie nastreven?
6. Zijn deze ook concreet meetbaar gemaakt?
7. Zijn deze doelstellingen de afgelopen jaren veranderd? Waarom (niet)?
8. Verwacht je dat deze doelstellingen in de komende 5 jaar zullen veranderen? Waarom (niet)?

Drivers van agile Asset Management

9. Is er veel behoefte aan flexibiliteit in het Asset Management? Waarom (niet)?

10. Wat zijn de belangrijkste (mogelijke) veranderingen binnen de organisatie die invloed (kunnen) hebben op het beheer en de inzet van de assets? [TECKO]
11. Hoe voorspelbaar zijn deze veranderingen vanuit de organisatie? [veranderlijke omgeving?]
12. Wat zijn de belangrijkste (mogelijke) veranderingen buiten de organisatie die invloed (kunnen) hebben op het beheer en de inzet van de assets? [TECKO]
13. Hoe voorspelbaar zijn deze veranderingen van buiten de organisatie? [veranderlijke omgeving?]

Flexibiliteit algemeen

14. Hoe flexibel zijn de prestaties van jullie assets (tov de verandering van de omgeving en/of doelstellingen)?
 - Is dit voldoende? Waarom (niet)?
 - Is dit (ook) voldoende richting de toekomst?
15. Waar zit deze flexibiliteit voornamelijk in?
16. Is er veel focus op flexibiliteit binnen het Asset Management? Waarom (niet)? Was dit altijd al zo?
17. Zou je jullie organisatie omschrijven als reactief of proactief? Waarom?

Uitleggen: aantal aspecten van flexibiliteit, die wil ik één voor één langslopen (zie figuur).

Flexibiliteit van de asset (individuele asset)

18. Hoeveel flexibiliteit zit er in de assets zelf?
19. Waarin zit dit?
 - robuust ontwerp (overgedimensioneerd)
 - overcapaciteit (tov de gevraagde prestaties)
 - modulair ontwerp (zeer eenvoudig en snel aan te passen)
 - ...
20. Hoe snel is deze flexibiliteit te realiseren?

Flexibiliteit van de inzet van de asset (populatie)

21. Hoeveel flexibiliteit zit er in de inzet van de assets? Bijvoorbeeld in de planning van het onderhoud of de intensiteit van het gebruik?
22. Waarin zit die flexibiliteit voornamelijk?
- planning van het onderhoud
 - planning van de inzet (oa intensiteit van gebruik)
 - overcapaciteit in de totale assetpopulatie
 - reservestelling
 - beïnvloeding van de vraag (bijv bij Liander: nachtstroom)
 - ...
23. Hoe snel is deze flexibiliteit te realiseren?

Bronnen van flexibiliteit in de organisatie

Mensen (kennis en kunde)

24. Hoeveel flexibiliteit bieden jullie mensen jullie?
25. Waarin zit die flexibiliteit?
- training (bijv. op verschillende plaatsen inzetbaar)
 - motivatie
 - samenwerking in teams
 - verantwoordelijkheid en beslissingsbevoegdheid
 - ...
26. Hoe snel is deze flexibiliteit te realiseren?

Data & Informatie

27. Hoeveel flexibiliteit wordt er geboden door data en informatie(systemen)?
28. Waarin zit die flexibiliteit?
- data(analyse): voorspellen
 - informatiesystemen (snel en flexibel uitwisselen van kennis)
 - lerende organisatie (feedback, evaluatie, delen van leerervaringen, etc)
 - (besluitvormings)processen
 - ...
29. Hoe snel is deze flexibiliteit te realiseren?

Samenwerking (intern en extern)

30. Hoeveel flexibiliteit wordt er geboden door samenwerking met andere afdelingen (intern)?
31. Waarin zit die flexibiliteit?
- onderlinge afstemming
 - kennisdeling
 - ...
32. Hoe snel is deze flexibiliteit te realiseren?
33. Hoeveel flexibiliteit wordt er geboden door samenwerking met andere organisaties (extern)?

34. Waarin zit die flexibiliteit?

- inhuur
- outsourcing
- kennisdeling
- ...

35. Hoe snel is deze flexibiliteit te realiseren?

Strategie (vooruit kijken en hierop aanpassen)

36. Hoeveel flexibiliteit wordt er geboden door rekening te houden met toekomstige ontwikkelingen?

37. Waarin zit die flexibiliteit?

- vooruit kijken (veranderingen op tijd zien aankomen)
 - hoe? hoe lang van tevoren?
- tijdig plannen maken / maatregelen nemen
- ontwikkelprojecten / pilots
- ...

38. Hoe snel is deze flexibiliteit te realiseren?

Overig

39. Zijn er nog andere manieren waarop jullie organisatie flexibiliteit in de organisatie heeft? Welke?

40. Hoe snel is deze flexibiliteit te realiseren?

Mate van flexibiliteit

41. Hoe flexibel zou je jullie organisatie noemen?

42. Zijn jullie in staat om passend en op tijd te reageren op alle veranderingen (al dan niet verwacht) die er binnen een maand kunnen gebeuren? Waarom (niet)?

43. Zijn jullie in staat om passend en op tijd te reageren op alle veranderingen (al dan niet verwacht) die er binnen een jaar kunnen gebeuren? Waarom (niet)?

44. Zijn jullie in staat om passend en op tijd te reageren op alle veranderingen (al dan niet verwacht) die er binnen vijf jaar kunnen gebeuren? Waarom (niet)?

Afsluiting

45. Zijn er nog dingen die we nog niet hebben besproken, maar die jou belangrijk lijken voor dit onderzoek?

46. Zou ik je eventueel nog een keer mogen bellen als ik vervolgvragen heb?

Ik ga een aantal interviews houden binnen deze organisatie. Op basis daarvan zal ik een korte samenvatting maken van de flexibiliteit binnen de organisatie. Deze zal ik toesturen, dan kunt u kijken of ik daarin een goede samenvatting geef van wat u gezegd heeft.

A.9 Data extraction form Agility in Asset Management

Table A.9.1 - data extraction form

General information	
name of interviewee	...
function	...
type of asset	...
life expectancy of the asset(s) (design)	...
current age of the asset(s)	...
number of asset(s)	...
function of asset(s)	...
description of maintenance on the asset(s)	...
Agility drivers	
technological change	...
economic change	...
compliance change	...
commercial change	...
organizational change	...
development of change level	
Agility enablers	
within the physical asset	...
deployment of the asset(s)	...
people	...
internal collaboration	...
external collaboration	...
strategy	...
information and data	...
processes	...
learning organization	...
other	...
Agile performance	
sufficiently flexible?	...
development of flexibility level	...
reactive vs proactive Asset Management	...
speed of adaptation	...

A.10 The Asset Management practice survey (in Dutch)

As explained in section 2.5.1, the survey was aimed at a very specific target audience. Therefore, different routes were designed to lead different types of respondents (e.g. asset owners and managers versus service providers) through the questions. Only those respondents who stated to have influence on the performance of the assets (question 45) were asked to answer the ALCM questions. Table A.10.1 below lists all the questions used in the result sections of chapter 2. Some questions were asked on multiple routes, indicated by the question numbers between brackets (these are all questions similar to the first question). For example, question 9 was used in three different routes, resulting in three question numbers for this single question: 9, 18 and 25.

*Table A.10.1 - an overview of all the questions used in chapter 2, with the corresponding numbers.
The text of these questions can be found in the original survey, presented on the next pages.*

Theme of questions	Question numbers	Topic of questions	Remarks
Background on the respondent	1, 57 (91)	Role, years of experience	
Background on the assets	9 (18,25), 10 (19,26), 13 (21,27), 14 (22,28), 15 (23,29), 16 (24,30), 31	Sector, type of assets, replacement value, maintenance costs, design life, position in life cycle,	
Influence on the asset performance	45	is the respondent an asset manager?	Qualifier for the ALCM questions
Influence on maintenance efficiency	46	is the respondent a maintenance manager?	
Multidisciplinary	59	Collaboration with other disciplines	
Whole life cycle	60, 61, 62, 84	Influence on decisions in life cycle phases, time distribution, future plans	
Performance management	63, 64, 66, 67, 78, 79	Main objective, performance management, influence on future performance	
Risks and regimes	82, 83	Influence of changes, anticipation of change	

The complete survey is available online, using the QR-code (or the link) presented below. The table above (Table A.10.1) can be used to find the original questions on which the answers were used in chapter 2.

Scan the QR code above with your mobile device or browse to <http://bit.ly/2vTRmle>. The file "Appendix dissertation - Asset Management survey" presents the original survey.

Physical assets – machinery, bridges, trains and factories – are crucial to support our daily lives. Assets typically have lifetimes of several decades. Over such long periods, many changes may happen: technical innovations, changing customer requirements, new regulations or a new corporate strategy. However, Asset Management theory and practice often overlook the impact of change.

This dissertation shows asset managers how to safely manoeuvre their assets into the future. A method is presented to identify and manage future threats and opportunities. Asset Life Cycle Plans – as asked for in ISO 55000 – are presented to plan for predictable change. Additionally, a framework of Asset Management agility shows how an organization can prepare for unpredictable change.

“The framework presented by Richard Ruitenburg is valuable for organizations with a large physical asset base like Schiphol Airport. It provides a variety of approaches to cope with changes. This approach has successfully been applied at Schiphol. It has changed a completely asset based solution for increased baggage handling capacity into a combination of asset and non-asset solutions. This mixed solution delivered the highest performance for the lowest investment.”