Categorizing and prioritizing lifetime impacts for Asset Life Cycle Plans

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Categorizing and prioritizing lifetime impacts for Asset Life Cycle Plans

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Preface

The report lying in front of you is the result of my graduation assignment, the last hurdle of my studies at the University of Twente. And hereafter I can call myself, after six and half years of study, Master of Science. Everything I have learned and experienced in these six and half years has ultimately resulted into this report, a strange idea.

During the graduation period at Liander, I learned more and more about the energy distribution networks in Netherlands. And during this period I got to respect and to be amazed by it. It is the backbone and nerve system of our society, a key stone that keeps us in the digitalization age, a keystone that has to adapt rapidly due to external influences, and a keystone that everybody takes for granted every day.

It was a good experience to be able to work on the energy distribution network for nine months. And helping in making it even more ready for the future changes.

Acknowledgments

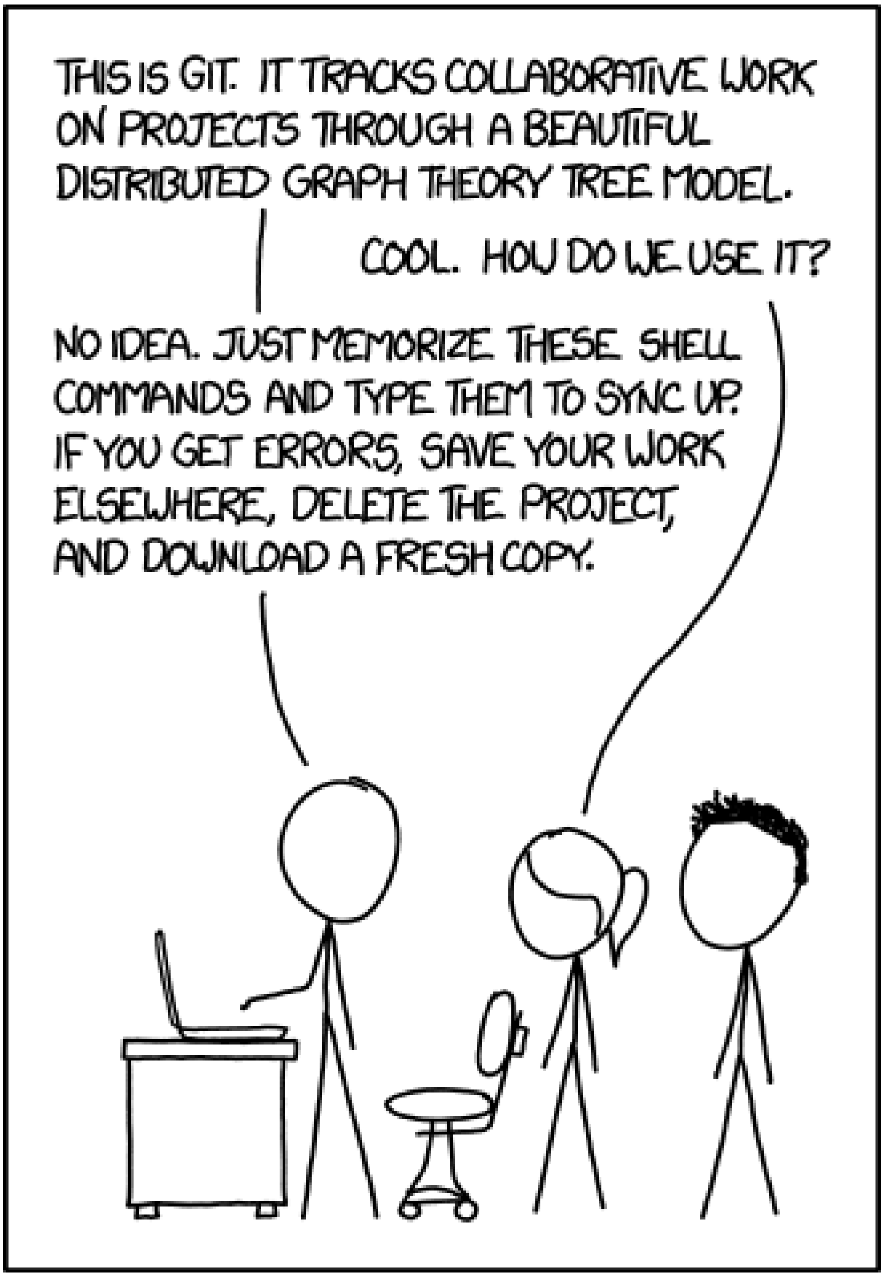
Because I will definitely forget somebody, I would like to keep the acknowledgments simple. I want to thank everybody at Liander that took the time to speak with me about Asset Life Cycle Plans and decision making. And everybody that was patient enough to brainstorm with me and to come up with new solutions.

Furthermore I would like to thank the chair of maintenance engineering, for providing the assignment and supervision. Which was really useful to have a non Liander perspective on the total assignment.

A special thanks goes out to Richard Ruitenburg, my personal supervisor. He did inspire, push, and guide me to a successful result. But to which I also owe an apology for keeping none of our conversations below the one hour mark (I just like talking to much).

And a final thanks to everybody that was somewhat involved in the project, or that took the time to read my thesis.

Tijmen van Diepen



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Abstract

Asset Life Cycle Management (ALCM) is the management of assets over their complete lifecycle, from acquisition to disposal, taking economic, environmental, social, and technical factors and performances into account. ALCM can be implemented at a company by means of Asset Life Cycle Plans. These plans consist of four parts: current performances, strategic goals, expected performances, and policy measures. This research focusses on the part “expected performances”, which is determined using, amongst others, lifetime impacts. Lifetime impacts are probable (technical and non-technical) events that may have an influence on the lifetime of an asset (physical property of a company) in the intermediate or long term. Using lifetime impacts ensures that an ALCP is a multidisciplinary document that improves asset management. The problem is the large number of lifetime impacts that are identified, while a structured decision making process to identify the most important lifetime impacts is currently missing in practice and in literature. Therefore this research aims to answer the question: “*How can lifetime impacts be categorized and prioritized?*”. The result is a structured and transparent decision making model that consists of three steps; filtering, categorizing, and prioritizing the lifetime impacts. Lifetime impacts are filtered using three criteria and it aims is to eliminate impacts that do not correspond to the purpose of the ALCP. Preventing that effort is wasted in the next steps. Categorizing the lifetime impacts allows clustering similar lifetime impacts and standardizing their format. This is achieved by determining the lifecycle phase of the lifetime impact and if it is a threat or an opportunity. During the final step, prioritizing, the lifetime impacts are listed on importance by determining its impact on the company values, its probability of occurrence in a specific future scenario, and the effort necessary to manage the lifetime impact. The model has been made in close collaboration with Liander, a distribution network operator that has implemented ALCPs. The model has also been tested by means of two case applications at Liander. The results showed that the model is able to prioritize the lifetime impacts in a structured way and it provides additional insight into the lifetime impacts themselves. Furthermore Liander has the intention to structurally implement the model in their asset management system.

Samenvatting

Maintenance management heeft de afgelopen decennia veel ontwikkelingen doorgemaakt en een van de huidige ontwikkelingen is de opkomst van Asset Life Cycle Management (ALCM), ofwel levenscyclus management. Een methode om ALCM te implementeren in een bedrijf is het introduceren van Asset Life Cycle Plans (levensloopplannen). Een levensloopplan bestaat uit vier delen; huidige prestaties, strategische doelstellingen, verwachte prestaties en beleidsmaatregelen. Een belangrijk hulpmiddel bij het opstellen van een levensloopplan zijn lifetime impacts, omdat ze zorgen voor de benodigde multidisciplinariteit van het document. Lifetime impacts zijn eventuele gebeurtenissen die de levensduur en/of prestaties van een asset positief of negatief beïnvloeden. De impacts worden bepaald tijdens een expertsessie waarbij verschillende experts van een gevarieerde achtergrond de asset evalueren vanuit vijf perspectieven: technisch, economisch, compliance, klant en organisatorisch.

Liander is een netbeheerder in Nederland die levensloopplannen heeft geïmplementeerd in hun dagelijkse werkzaamheden. Een van de problemen waar Liander tegenaan loopt is dat er een groot aantal lifetime impacts geïdentificeerd worden tijdens een expertsessie. Deze kunnen niet allemaal meegenomen worden in een levensloopplan en daarom zal een selectie gemaakt moeten worden. Het is echter mogelijk dat verschillende personen een andere selectie maken en daardoor de verwachte restlevensduur per persoon verschilt. Daarom is dit onderzoek gestart om een gestructureerde methode op te stellen die de lifetime impacts kan prioriteren. Hiervoor is de volgende hoofdvraag opgesteld:

"Hoe kunnen lifetime impact gecategoriseerd en geprioriteerd worden?".

Het doel van het onderzoek is om Liander te helpen met het implementeren van levensloopplannen. Daarnaast moet het onderzoek een toegevoegde waarde leveren voor de wetenschap over levensloopplannen.

Methodologie
Het onderzoek is uitgevoerd door middel van design science in combinatie met de productontwerp methodiek. Dit betekent dat het onderzoek in drie delen is gesplitst; een analysefase, een ontwerpfase en een evaluatiefase. En elke fase is gekoppeld aan een van de zeven richtlijnen van design science.

Fase 1: De analysefase
De analysefase bestaat uit twee delen, een literatuurstudie en een caseonderzoek bij Liander. In het literatuuronderzoek zijn lifetime impacts en levensloopplannen verder onderzocht. Het blijkt echter dat er een beperkte hoeveelheid literatuur beschikbaar is over beide onderwerpen. Daarom is het onderzoek uitgebreid door te kijken naar levenscyclus management, scenario based strategy en risicomanagement. Een ander deel van de literatuurstudie onderzoekt besluitvorming in asset management om te bepalen hoe er gecategoriseerd en geprioriteerd kan worden. Het resultaat van de literatuurstudie zijn meerdere eisen waar het model aan moet voldoen. De belangrijkste twee zijn dat het model

een gestructureerde en transparante methode moet zijn en dat de lifetime impacts geprioriteerd worden in meerdere stappen.

Het caseonderzoek bestaat uit semigestructureerde interviews en het analyseren van relevante bestanden en processen binnen Liander. De semigestructureerde interviews zijn uitgevoerd met vijftien verschillende stakeholders van het project en geven een duidelijk beeld van het perspectief van Liander op lifetime impacts, levensloopplannen en de eisen van Liander voor een verbeterd keuzeproces. Het resultaat van de interviews is dat er binnen Liander nog geen duidelijkheid is over de inhoud van levensloopplannen. Maar de noodzaak voor een verbeterd keuzeproces wordt wel door bijna iedereen onderschreven. Door het analyseren van documenten en processen binnen Liander is inspiratie opgedaan voor het uiteindelijke proces. De voornaamste is een analyse van het INP proces, dit is een gestructureerd proces om met risico's om te kunnen gaan bij Liander op basis van onder andere een risico matrix. De belangrijkste resultaten van het caseonderzoek zijn dat het verbeterede proces gebruik moet maken van experts van het bedrijf en dat de bedrijfswaarden gebruikt moeten worden voor het prioriteren.

Daarnaast is het proces van het opstellen van een levensloopplan doorlopen door mee te werken bij het opstellen van het plan voor vermogenstransformatoren. Het opstellen biedt de mogelijkheid om bekend te raken met lifetime impacts en levensloopplannen in de praktijk en het stelt de onderzoeker in staat snel nieuwe ideeën te kunnen testen. Het resultaat is dat er een groot aantal lifetime impacts zijn die erg van elkaar verschillen.

De bevindingen van het caseonderzoek en de literatuurstudie zijn samengevat in een programma van eisen. De eisen zijn opgedeeld in noodzakelijke eisen en gewenste eisen. Het uiteindelijke model moet voldoen aan de noodzakelijke eisen. De gewenste eisen geven een indicatie van de bruikbaarheid van het model. Tevens zijn ook de wensen van Liander in kaart gebracht om het wetenschappelijke model voor hen te kunnen optimaliseren. Als laatste zijn er ontwerpprincipes opgesteld die helpen in het vervullen van de eisen.

Fase 2: De ontwerpfase

Het model is opgesteld op basis van design science. Dit houdt in dat eerst een conceptmodel is opgesteld en die is vervolgens geoptimaliseerd door middel van een iteratief proces wat bestaat uit het bespreken van het concept met verschillende stakeholders en het verwerken van de geleverde feedback. Na vijftien rondes is het proces afgerond en het model klaar om getest te worden. Het resultaat is een model wat bestaat uit drie stappen; filteren, categoriseren en prioriteren.

In de eerste stap wordt de input dat geen lifetime impact gefilterd is. Dit gebeurt door de impacts te testen aan de hand van de volgende drie criteria:

- De impact moet invloed hebben op de restlevensduur van de asset populatie
- De impact moet plaatsvinden in de lange termijn
- De impact moet generiek zijn voor de asset populatie

In de tweede stap worden de lifetime impacts gecategoriseerd. De voornaamste reden hiervoor is dat de uiteindelijke output van het keuzeproces beter te interpreteren is. Het categoriseren wordt gedaan door eerst de levensfase waarin een lifetime impact invloed heeft te bepalen (nieuwe assets, bestaande assets of verwijderde assets). Vervolgens wordt bepaald in of deze invloed positief of negatief is. In totaal zijn er dus zes categorieën. Een aanvullende stap bij het categoriseren is het elimineren van dubbele lifetime impacts. Dit biedt tevens de mogelijkheid om de lifetime impacts te herschrijven waardoor ze uniform geformuleerd zijn.

In de laatste stap worden de overgebleven lifetime impacts geprioriteerd om de meest belangrijke lifetime impacts te bepalen. Dit gebeurt op basis van:

- De impact per bedrijfswaarde
- De waarschijnlijkheid van gebeuren
- De inspanning om de lifetime impact te mitigeren

Elke lifetime impact wordt met een linguïstische waarde (bijv. laag of hoog) getest per criteria. Deze waardes worden vervolgens vertaald naar een numerieke waarde waardoor de verschillende lifetime impacts met elkaar te vergeleken zijn. Daarbij geldt dat de hoogste waarde de hoogste prioriteit heeft. Het prioriteren wordt uitgevoerd door meerdere stakeholders waardoor een objectief beeld ontstaat, draagvlak voor de uitkomst wordt gegenereerd en dit biedt de mogelijkheid om uiteenlopende prioriteringen met elkaar te bediscussiëren.

Fase 3: De evaluatiefase
De evaluatie is uitgevoerd door het model te testen met het programma van eisen en door het te gebruiken voor een levensloopplan. Het testen aan het programma van eisen is gedaan door vier verschillende personen; de onderzoeker en drie mensen die het model gebruikt hebben voor hun levensloopplan. Het resultaat is dat het model voldoet aan alle noodzakelijke eisen. Daarnaast hebben de gewenste eisen een gemiddelde score van 5.5 op een schaal van 1.0 – 7.0.

Het tweede deel van het testen is het model gebruiken voor het levensloopplan van vermogenstransformatoren en gasstations. En het gebruik evalueren door middel van semigestructureerde interviews en door het resultaat te analyseren. De interviews tonen aan dat het model toegevoegde waarde biedt en extra inzicht geeft voor het levensloopplan. Verder geven de gebruikers aan het model vaker te willen toepassen bij het opstellen van een levensloopplan. Maar dat daarbij nog wel een ondersteunend document nodig is.

Conclusie
Al met al is de hoofdvraag van het onderzoek beantwoord door een functionerend model te creëren dat lifetime impacts kan categoriseren en prioriteren. De generaliseerbaarheid van het onderzoek is echter nog een discussiepunt. Dit komt doordat het onderzoek is uitgevoerd bij en voor Liander. Dit zorgt ervoor dat het model bruikbaar is voor Liander, maar dat de wetenschappelijke gedegenheid van het onderzoek en resulterend model gelimiteerd is. Bijvoorbeeld de keuze voor de criteria waarmee geprioriteerd wordt zijn voornamelijk gefocust op Liander. Om het model verder te optimaliseren zou het getest moeten worden door andere bedrijven en met meerdere experts in asset management en besluitvorming.

Nomenclature

Assets
Physical property of a company, for Liander the equipment that enables the transportation and distribution of energy.

Asset group
A combination of assets that have the same function. For example, power transformers that transform the power from high to medium voltage (At Liander the term asset group has a different definition, but not used in this thesis).

Asset management
Coordinated activity of an organization to realize value from assets.

Gas delivery stations
An asset that reduces the pressure of the gas so it can be distributed.

No regret decisions
A decision that will have the same outcome in all possible future scenarios.

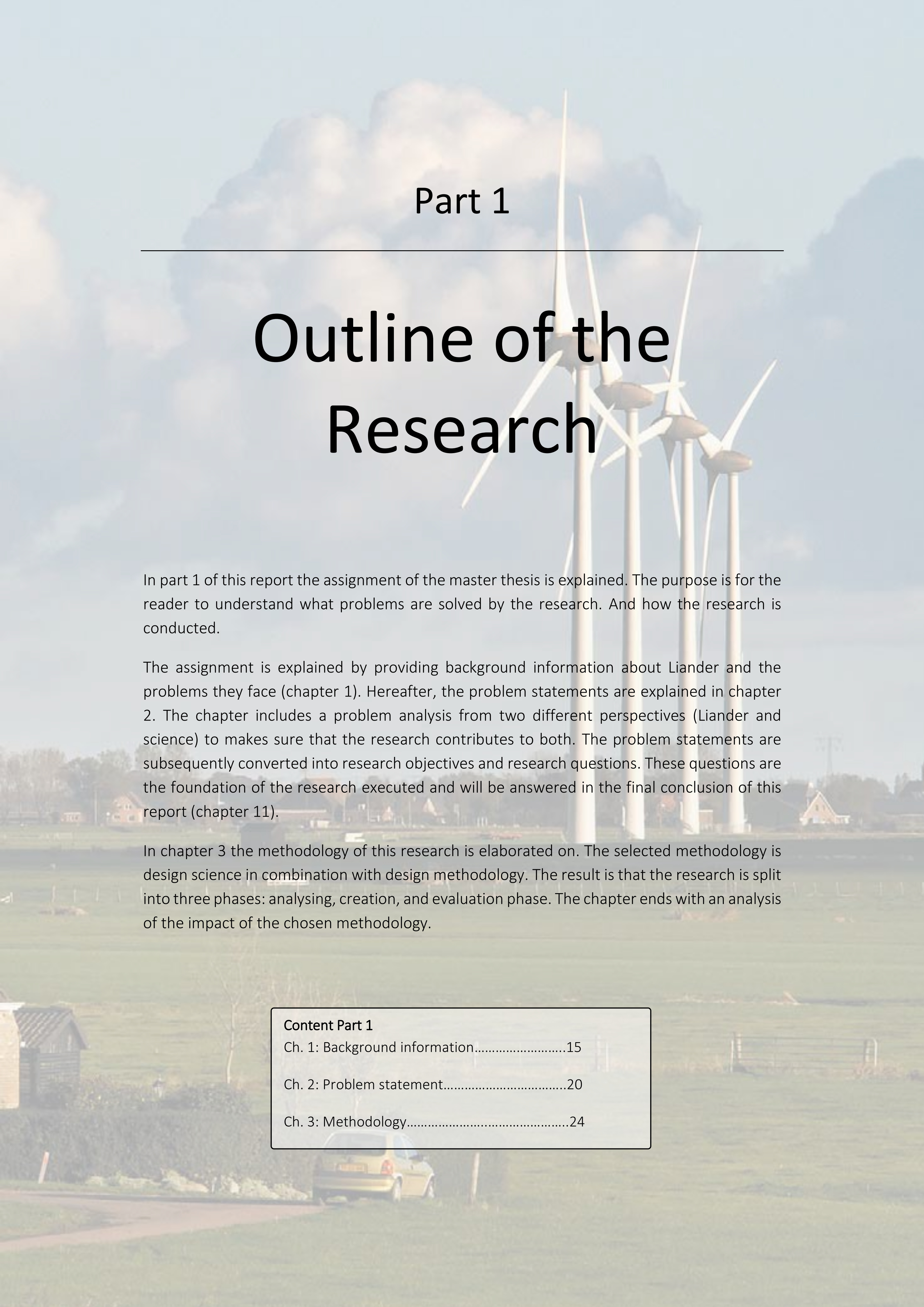
Power transformers
An asset that transforms the electricity from high to medium voltage.

Replacement wave
A large number of asset that have to be replaced in a short period of time.

Risk matrix
A matrix that shows the relation between the impact and probability of a risk.

Abbreviations

ALCM	–	Asset Life Cycle Management
ALCP	–	Asset Life Cycle Plan
DNO	–	Distribution Network Operator
FMEA	–	Failure Mode and Effect Analysis
IAM	–	Impact Assessment Method
INP	–	Integrated Net Planning (process)
LIIA	–	Lifetime Impact Identification Method
LIPN	–	Lifetime Impact Priority Number
MCDM	–	Multi Criteria Decision Model
PIB	–	Project Investment Board
RUL	–	Remaining Useful Lifetime
SAIDI	–	System Average Interruption Duration Index (SVBM)
SAMP	–	Strategic Asset Management Plan
SVBM	–	Storing Verbruikers Minuten (SAIDI)
TECKO	–	Technical, Economical, Compliance, Commercial, Organizational



Part 1

Outline of the Research

In part 1 of this report the assignment of the master thesis is explained. The purpose is for the reader to understand what problems are solved by the research. And how the research is conducted.

The assignment is explained by providing background information about Liander and the problems they face (chapter 1). Hereafter, the problem statements are explained in chapter 2. The chapter includes a problem analysis from two different perspectives (Liander and science) to makes sure that the research contributes to both. The problem statements are subsequently converted into research objectives and research questions. These questions are the foundation of the research executed and will be answered in the final conclusion of this report (chapter 11).

In chapter 3 the methodology of this research is elaborated on. The selected methodology is design science in combination with design methodology. The result is that the research is split into three phases: analysing, creation, and evaluation phase. The chapter ends with an analysis of the impact of the chosen methodology.

Content Part 1

1. Background information

Chapter 1 shows the background information by first understanding why the assignment is necessary in section 1.1. Hereafter Liander, the company where the assignment is executed, is discussed in section 1.2.

1.1 The current situation

On March 27, 2015 a failure is reported in a high voltage substation of TenneT. The mechanics think they know the cause of the problem and repair the station according to their assumption. When the power is turned back on, the station short circuits which causes an electric arc. Due to a particularly strong wind, the electric arc leaps to a redundant high voltage substation causing a second short circuit. Maintenance engineers quickly repair both stations and in one hour and 43 minutes they both function again. However by then the largest power outage in the history of the Netherlands has already taken place (TenneT B.V., 2015). The effect of the outage is devastating, including chaos in the public transport system, evacuation of buildings due to failure of security and safety systems, hundreds of people stuck in elevators, and many more.

The situation above is a perfect example of our dependency of electricity. And of how fragile that dependency is. The outage was cause for concerns by politicians, resulting into questions about the reliability and security of our network (Tweede Kamer, 2015). These questions are not unsubstantiated, since it is expected that frequency and consequences of failures will only increase (United States Environmental Protection Agency, 2010).

The cause for this tendency can be dedicated to two trends. First uncertainty about the future role of energy in the Netherlands. Second the average age of the current distribution network (Liander N.V., 2015c). Both trends will be explained briefly.

1.1.1 Uncertainty of the future

“What will the future look like?”. An impossible to answer question with 100% certainty. But it is one of the most important questions for businesses and governments (Durance & Godet, 2010). What makes this question especially important for energy distribution companies, is that the energy market is at the brink of very large changes (de Ridder, 2012). For example a rapid increase in number of solar panels and electric cars, as well as controversies about using gas[1] or coal.

1.1.2 Age of the current distribution network

The current distribution network is mostly build in the decades after the Second World War. And the expected maximum age of the assets is around 40 to 60 years (Jongepier, 2007). So the end of life of most of the assets is coming closer. The result of this can be a replacement wave; a large number of replacements in a short period of time (Haarman & Verhoev, 2007).

[1] The production of gas takes place often in instable countries and the small earthquakes in Groningen will most probably reduce production of gas in the coming years in the Netherlands (Weidenaar, Bekkering, & van Eekelen, 2012).

Such a wave will cause large problems for Liander, both financially and organisationally. And should be prevented.

1.2 Explaining Liander

The master thesis is executed at Liander N.V. (in short Liander). Liander is the largest distribution network operator (DNO) in the Netherlands. Providing their services in (parts of) Noord-Holland, Gelderland, Flevoland, Friesland and Zuid-Holland. As can be seen in more detail in Figure 1-1. Within these areas Liander has the obligation to provide electricity and gas services to everybody who wants it, resulting into 3.0 million customer connections for electricity (ACM, 2015) and 2.3 million customer connections for gas (Liander N.V., 2015a).

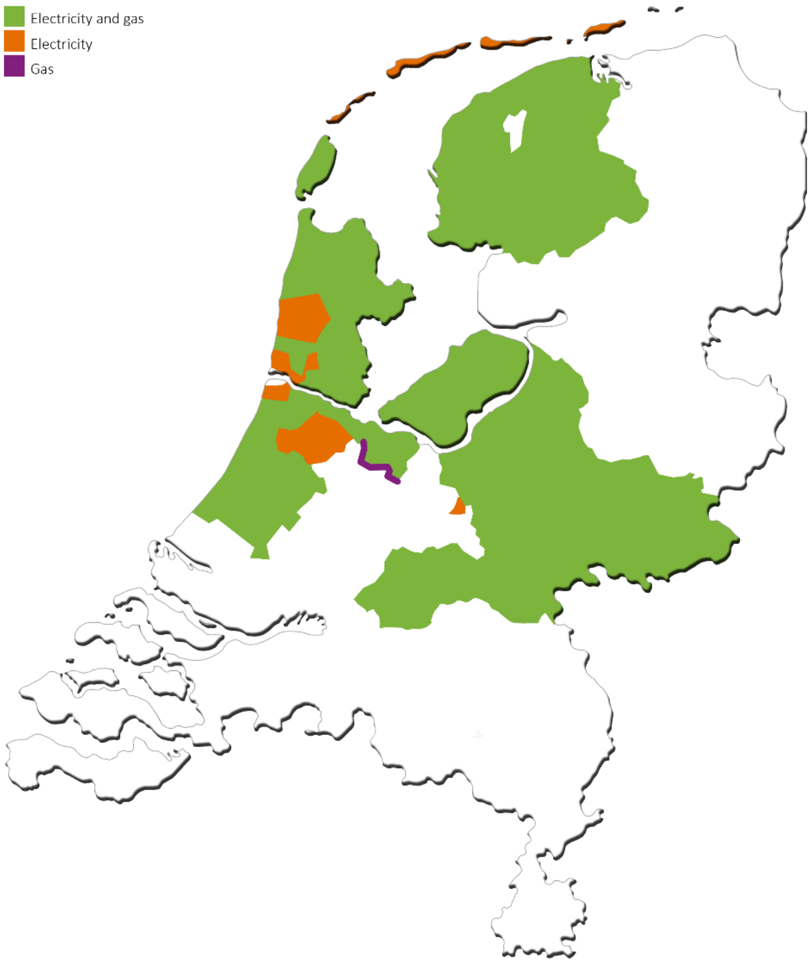


Figure 1-1: Overview of the area of activity of Liander (Liander N.V., 2013).

1.2.1 The network structure of Liander

To distribute the electricity the network is divided into high, medium, and low voltage. For the gas network a similar structure is used, using high and low pressure. The networks itself are a combination of different assets consisting of over 85.000 kilometres (km) of cables for electricity, over 35.000 km of pipelines for gas (Liander N.V., 2015a), as well as tens of thousands of transformers, switchgears, gas delivery stations and more. An outline of the physical structure of the electricity network of Liander can be found in appendix I.

The responsibility of Liander only include the distribution of energy. The generation and mass distribution of energy is the responsibility of other parties, namely TenneT (electricity) and GasUnie (gas). This has been the case since the introduction of the Independent Network Operation Act (Wet Onafhankelijk Netbeheer) created in 2007 (Tweede Kamer, 2007).

1.2.2 Performance measures

Since the Independent Network Operation Act, Liander is a public owned company with all the shares being owned by Dutch provinces (Tweede Kamer, 2007). A similar situation for all DNOs in the Netherlands, meaning that the DNOs do no compete commercially with each other. They do however compete based on their performance, which determines their annual fee received from the Dutch Authority for Consumers and Markets (Autoriteit Consument en Markt (ACM)). The measurement of the performance is a complex procedure, but two of the main factors that are inspected are the efficiency (costs) and the system average interruption duration index (SAIDI) (Storingverbruikersminuten (SVBM)) of the DNO. SAIDI is the average outage duration per customer per year. This is calculated by summing the total time of all outage of all customers and dividing this by the total number of customers. So the SAIDI influences the budget of Liander and it is thus important to reduce this.

To show the quality of service of Liander, the SAIDI of the electricity network was in 2013 only 24.3 minutes. Average compared to the other two largest DNOs in the Netherlands. With Enexis having 17.7 minutes and Stedin 25.2 minutes (ACM, 2013). Making it one of the most reliable networks compared to other developed countries in 2014, as can be seen in Figure 1-2 (Liander N.V., 2014c).

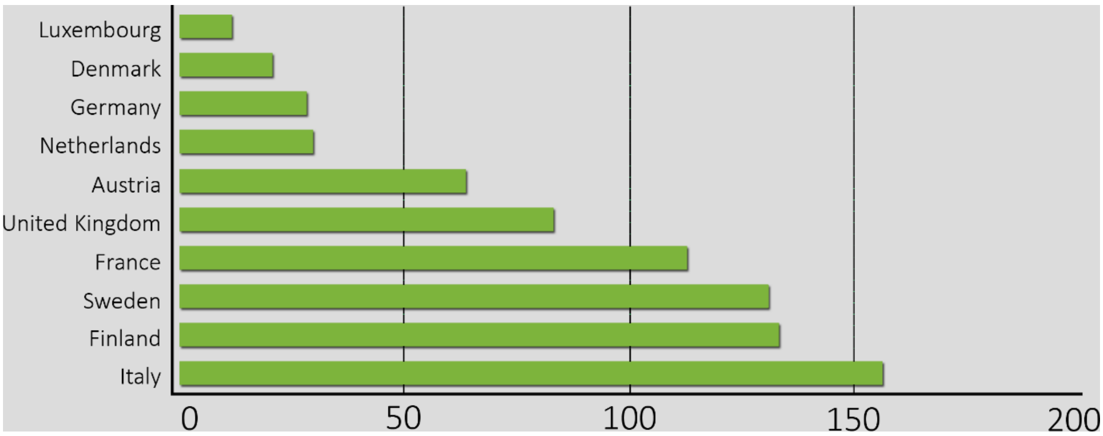


Figure 1-2: Overview of the overage SAIDI in ten western nations in 2014. The x-axis depicts the SAIDI in minutes (Liander N.V., 2014c).

1.2.3 Organisation structure of Liander

The organisation structure of Liander can be found in Figure 1-3. As can be seen is Liander a subsidiary of Alliander N.V.. The department of Liander that is responsible for the quality and capacity of the distribution networks is “Asset Management”. Within the department, the business unit “Policy and Standardization” is responsible for writing the policies. And on its turn does “Policy and Standardization” consist of several policy advisers that are responsible for a certain type of asset. These policy advisers are also responsible for the creation of the Asset Life Cycle Plans (ALCP), the topic of this research. An ALCP is about an asset population within a type of asset (described in the next section), the business unit “Policy and Standardization” is therefore thus the provider of the assignment and the location where the assignment is executed.

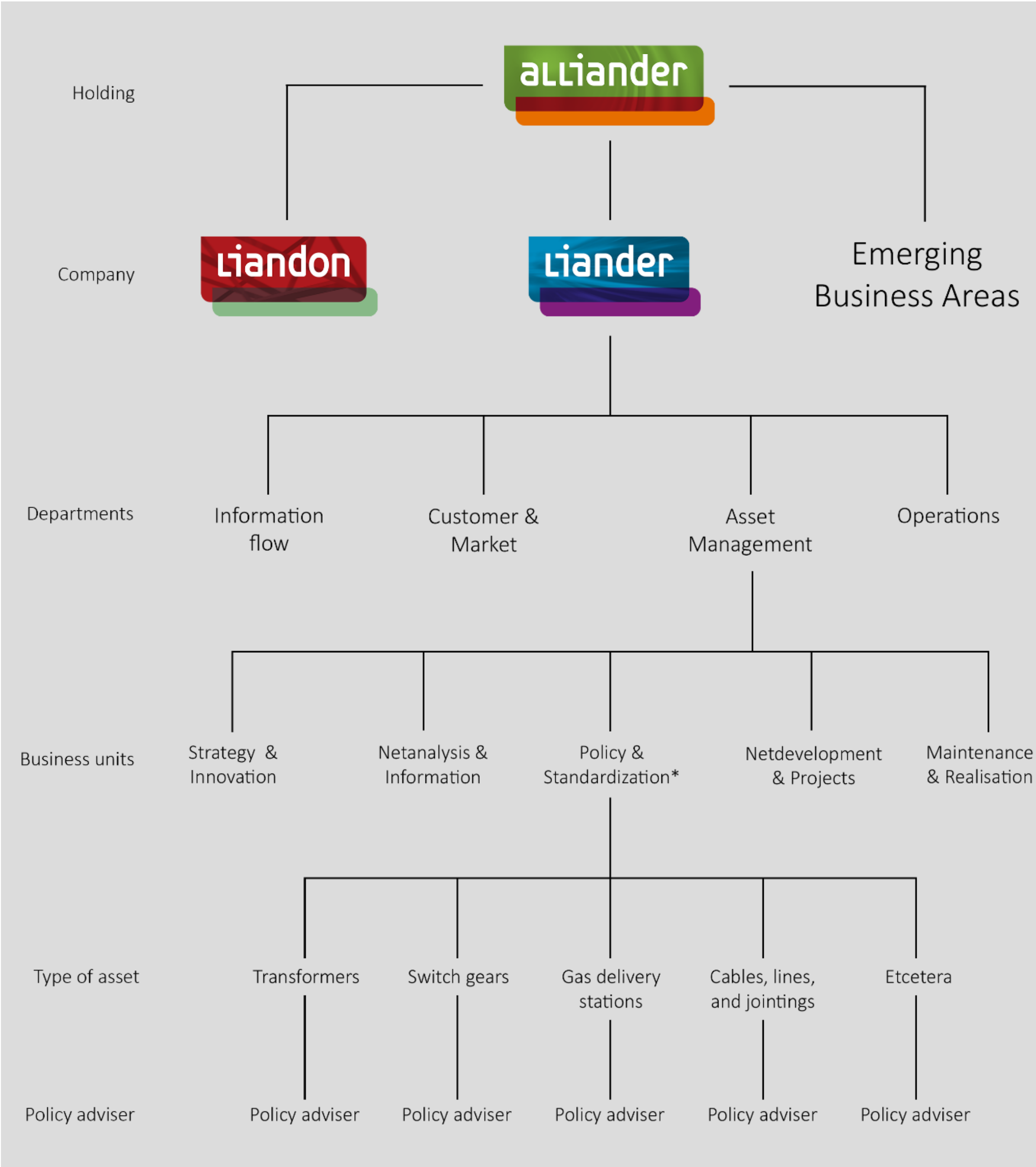


Figure 1-3: Organizational structure of Liander. An Asset Life Cycle Plan is made by a policy adviser for an asset population within a type of asset.

1.2.4 Definition of an asset

In this report the terms asset(s), asset group(s), type(s) of asset, and asset population(s) are used. This can cause confusion, and therefore these terms will be explained.

- Asset(s): Indicates one or several assets, for example a powertransformer.
- Asset group: The collection of assets that have a similar function. For example the asset group powertransformers which all have the function to transform high voltage to medium voltage.
- Type of asset(s): Collection of assets which all have the same general function. For example transforming electricity. A policy adviser at “Policy and Standardization” is generally responsible for a specific type of asset.
- Asset population(s): The subject of an ALCP and can vary between a specific collection of assets of for example the same brand up to a whole asset group.

1.3 Conclusion

The background information shows that there are two trends that have a large impact on the performance of the energy distributions networks. And the network is a complex structure consisting of many assets. Creating a difficult task for the business unit “Policy and Standardization” to maintain the network and make it futureproof. One of the methods to do this is the implementation of ALCPs.

2. Problem statement

In chapter 2 the underlying problem why the research is executed will be explained. This starts with stating the problem that Liander and science encounter with ALCPs in section 2.1. These problems statements are translated into an assignment description including the main research question, and supporting sub-questions (section 2.2). Finally, the structure of the thesis and a reading guide can be found in section 2.3.

2.1 Problem statements

In 2013 a Ph.D. research project at Liander has been started by Richard Ruitenburg. The project aims to assist Liander in managing the trends discussed in section 1.1. This is done by developing new methods and tools so Liander can implement Asset Life Cycle Management. One of the tools implemented by the research are Asset Life Cycle Plans. These are plans that can be used to manage the asset population over their whole Life Cycle. To create an ALCP the strategic goals, the current performances, and the expected performances of an asset need to be defined. The strategic goals and the current performances are relatively easy to define for Liander. The strategic goals are created by the management team and are stated in the Strategic Asset Management Plan (SAMP) and the Vision and Mission (Koers en Kalender). The current performance of the asset can be determined from current and historical data. The expected performances are harder to identify since they depend for a large part on external developments (like the energy transition or changes in prices). And to structure this process the concept of lifetime impacts are used.

Lifetime impacts are:

Probable (technical and non-technical) events or trends that may have a positive or negative influence on the remaining lifetime of the asset in the intermediate or long term (Ruitenburg, Braaksma, & van Dongen, 2014)

They are obtained using an expert session with multiple experts on an asset. During the first expert session at Liander a large number of lifetime impacts were identified. And the nature of lifetime impacts and the expert session implies that this will happen in the future as well. Furthermore, not all lifetime impacts should be implemented in an ALCP because some impact costs more to mitigate then it damages and the available resources to mitigate are limited. So to determine which lifetime impacts should be mentioned, the priority of each should be determined. This demands for a structured process to decide which lifetime impacts are the most important. However, the current process can be improved upon since it is not a structured and transparent process that follows a certain method. This reduces the reliability of the selected lifetime impacts and this makes it more difficult to notify and manage changes in priority. Which ultimately reduces the usability of an ALCP.

The usage of lifetime impacts can also be found in literature, where the impacts are used to determine the remaining useful lifetime (RUL) of the asset. In literature the same problem is encountered and has not been solved yet. Here the problem is stated as the absence of a structured method to valuate lifetime impacts (Ruitenburg et al., 2014). Up till now a solution to this problem is still lacking.

These problems together create the following problem statement of this research:

Problem statement 1: *"The absence of a structured decision making process to identify the most important lifetime impacts".* (Liander and Science)

An additional problem of the absence of a structured decision making process encountered at Liander, is that by definition the opinion on the expected performance of different policy advisers are different. Resulting that the view on the condition of the asset can differ per person. This should be managed properly, so that the different arguments that substantiate the opinions are clear. This way an ambiguous view of the condition of the asset is created.

An example: ALCP 1 states that the economy is going upwards and therefore Liander should invest in the distribution network. While ALCP 2 states that the economy will stagnate, with the consequence that investments should be postponed. Both cases can have large influence on the asset population and on the distribution network as a whole. And in both cases the ALCP might be right. So the most important factor is to manage the difference properly.

Problem statement 2: *"The absence of a structured decision making process to provide an unambiguous view of the effects of future trends for all the assets".* (Liander)

2.2 Assignment description

The problems addressed in the problem statements ask for an improvement of the decision making process when selecting the most important lifetime impacts for science and for Liander. So a decision has to be made between lifetime impacts based on to be determined criteria. Whereas the act of decision making is described as "The thought process of selecting a logical choice from the available options." *(Jarrard, 2011)*

A logical choice implies that the most valuable should be selected, so the lifetime impacts should be prioritized. And a selection process implies that there are different options between which can be decided, so the lifetime impacts should be categorized. Summarized, this leads to the main research question stated as follows:

How can lifetime impacts be categorized and prioritized?

The main research question is supported by the following sub-questions.

Q1. What are lifetime impacts and how are they currently identified?

An analysis of what lifetime impacts actually are, both from the perspective of literature and from Liander. The purpose is to define the characteristics of lifetime impacts and use those to create a categorisation and prioritization model. To get a complete image of lifetime impacts are the principles of RUL, Asset Life Cycle Plans, and Asset Life Cycle Management also analysed and explained further.

Q2. How are lifetime impacts currently categorized by Liander?
To improve a method a benchmark should be created. So by analysing the current method it is possible to create an improved method. Besides, Liander makes lots of decisions about their assets, risks, etc. So by analysing these methods, design principles for creating a structured process that prioritizes lifetime impacts can be derived.

Q3. How are lifetime impacts currently prioritized by Liander?
The goal of this sub-question is similar to sub-question 2. The difference is that this question focusses on prioritizing lifetime impacts. So it will include different possible criteria to prioritize.

Q4. How are lifetime impacts or comparable principles categorized in other science disciplines?
Making decisions is a research topic on itself (Triantaphyllou & Chi-Tun, 1996). So literature can provide background information on how to categorize the lifetime impacts using a suitable method. The purpose is to define requirements of a good categorization process, as well as design principles for creating one for lifetime impacts.

Q5. How are lifetime impacts or comparable principles prioritized in other science disciplines?
The goal of this sub-question is similar to sub-question 4. The difference is that it focusses on prioritizing lifetime impacts.

2.3 Thesis outline

The thesis outline can be seen in Figure 2-1 and it consists of five parts. The first part is the outline of the research including background information, problem statements, assignment description, and the methodology. Part 2 is the theoretical background to this research. This discusses the principle of ALCP, lifetime impacts, and decision making from the perspective of science and of Liander. Part 3 discusses the guidelines of the model. These are a program of requirements and design principles originating from part 2. The information from this are the building blocks to create and test the model, which is done in part 4 of this research. Part 5 provides a conclusion, discussion, and the recommendations for further research.

Depending on the interest of the reader, one can decide to read everything or parts of the report because each part can be read independently. To understand the purpose of the research it is recommended to read part 1. To get a deeper understanding on lifetime impacts, ALCPs, and decision making one can best read part 2. If the interest is only in the requirements and design principles derived from the theoretical background, part 3 should be read. When one wants to know the final result of this research or has interest in a decision making model that can help improve asset management, that person should read part 4. And for further research possibilities or other findings during the study, part 5 is especially interesting. Each part also has a short introduction to explain the subject and purpose of that specific part.

2.4 Conclusion

Using Asset Life Cycle Plans is a method of to implement Asset Life Cycle Management and are currently introduced at Liander. A major part of creating an ALCP is identifying threats and opportunities that influence the remaining useful lifetime of the asset. These are called lifetime impacts and these are obtained by means of an expert session. At Liander, a large number of lifetime impacts are derived and the current method of determining which is the most important can be improved upon. Also the current study on lifetime impacts indicates that a method to value the lifetime impacts is still missing. This research aims to solve these problems by optimizing the decision making process of selecting the most important lifetime impacts.

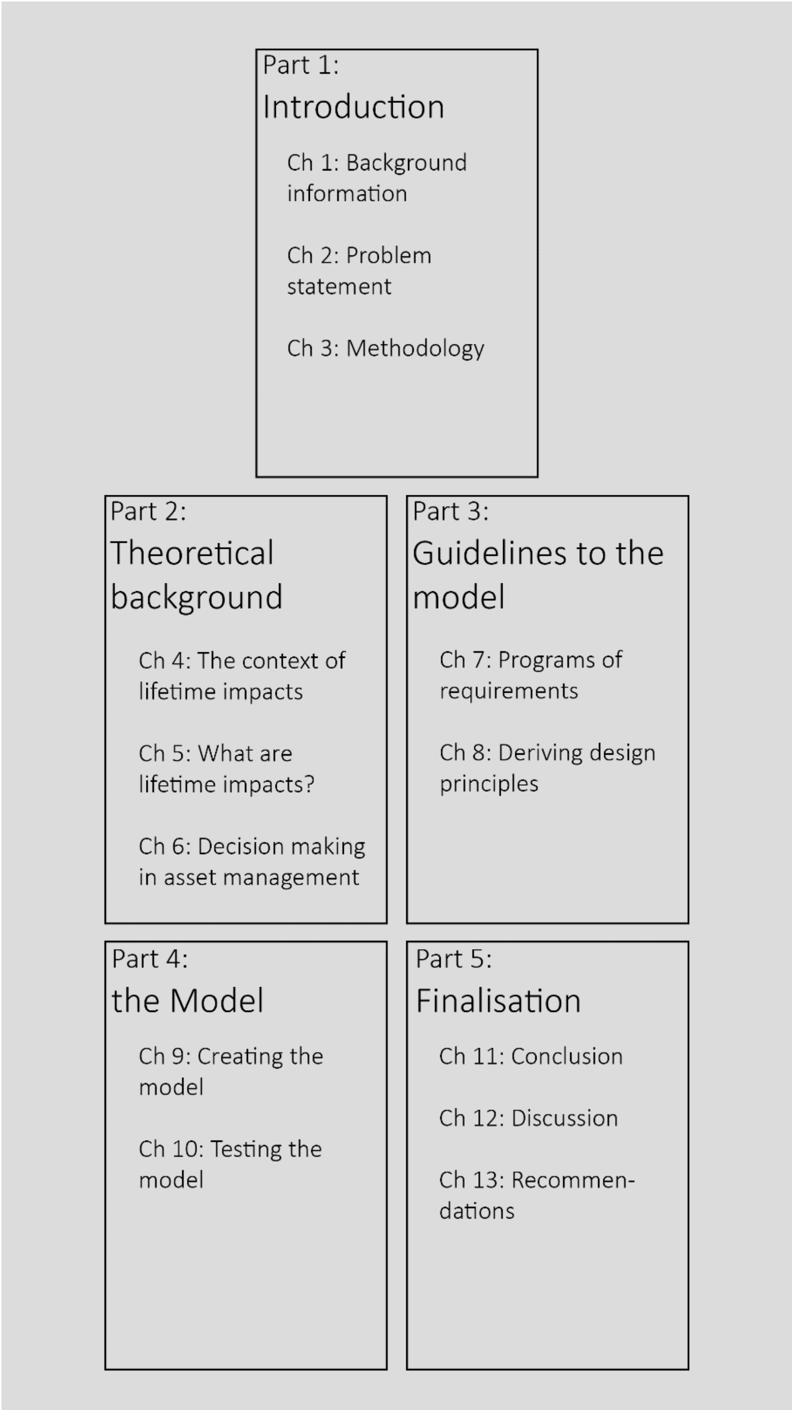


Figure 2-1: Thesis outline consisting of 5 parts and 13 chapters.

3. Methodology

Chapter 3 discusses the research methodology. First, in section 3.1 the outline of the used methodology is shown. Hereafter the three phases (analyse, create, and evaluate) are inspected more closely. In section 3.2 the drawbacks and influences on the results of the methodology are analysed. These points will later be used in the evaluation of the final results in chapter 12.

3.1 Methodology

The goal of this research is to improve the current decision making process for lifetime impacts. The final result should provide added value for practice (Liander) by being reliable and relevant. And for theory by being reliable and generalizable. To structure the research, a methodology is searched for that can combine practice and science and that aims to deliver a final product (a structured decision making process). The selected methodology is a combination of two methodologies; design science and the design methodology.

3.1.1 Design science

Design science is a research methodology that consists of developing and evaluating products (product) that are a solution to an organizationally problem (business need). The purpose is to obtain added value to the business need (utility). Making use of existing knowledge (knowledge base) (Hevner, March, Park, & Ram, 2004). So design science is especially useful for providing added value to both Liander and science and is therefore selected. Implementing this methodology for this research can be seen in Table 3-1. An additional advantage of using design science is that it can be used for tackling ill-structured problems in a systematic manner (Holmström, Ketokivi, & Hameri, 2009). Which is preferable because the problem of prioritizing lifetime impacts was at the start of the research an ill-structured problem and there was room for improvement.

Table 3-1: Determining the four elements of design science for this research.

Product	The optimized decision making process for lifetime impacts
Business need	The absence of a structured decision making process to identify the most important lifetime impacts
Utility	Improvement of Asset Life Cycle Plans and Asset Life Cycle Management at Liander and for science
Knowledge base	Available knowledge at Liander and in science on lifetime impacts, ALCPs, and decision making in asset management

3.1.2 Design methodology

A major drawback of design science is the absence of a broadly accepted structure to conduct and present a design science research (Hevner et al., 2004; Holmström et al., 2009; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Therefore a method to structure the research is searched for. This method has to fulfil the following three criteria:

- It should be able to structure the research
- It should aim for a result while focussing on both theory and practice
- The researcher should be familiar with the method

Taking these three criteria into account the general design structure is selected. This method provides structure in a project in which a final product should be delivered, using user based experiences and corresponding literature. Additionally, with a background in design engineering the researcher is familiar with this method.

The remaining step is to combine the two methodologies. Design processes consists out of three phases: "Analysis phase, creation phase, evaluation phase". While Hevner et al established seven guidelines for design science, seen in Table 3-2 (Hevner et al., 2004). Combining those results into the methodology as seen in Figure 3-1 on the next page.

Table 3-2: Design science guidelines (Hevner et al., 2004).

Guideline 1: Design as an artefact	Design science research must provide a viable artefact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem relevance	The objective of design science research is to develop technology based solutions to important and relevant business problems.
Guideline 3: Design evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well executed evaluation methods.
Guideline 4: Research contributions	Effective design science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations and/or design methodologies.
Guideline 5: Research rigor	Design science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
Guideline 6: Design as a research process	The search for an effective artefact requires utilizing available means to reach designed ends while satisfying laws in the problem environment.
Guideline 7: Communication of research	Design science research must be presented effectively both to technology oriented as well as management oriented audiences.

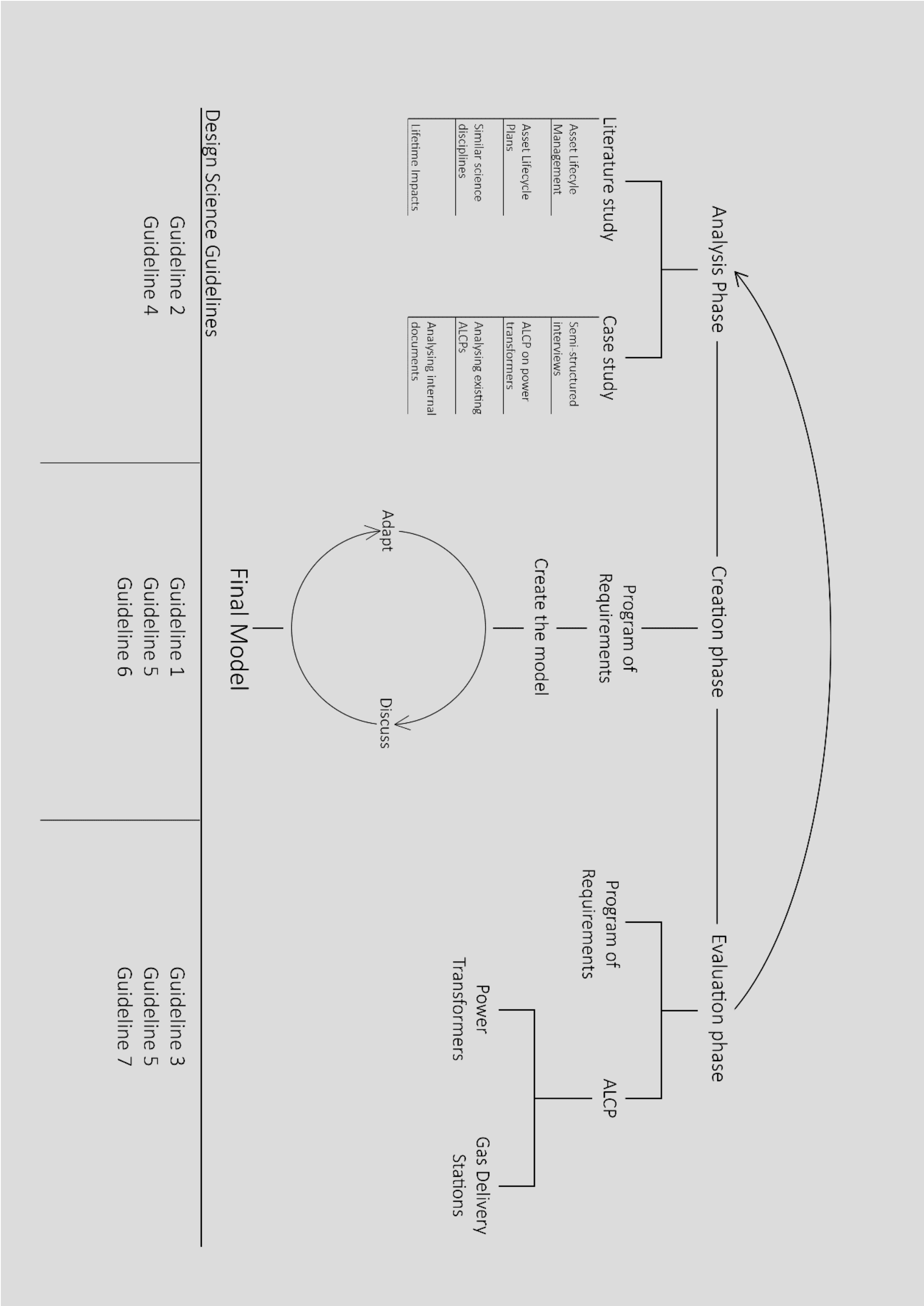


Figure 3-1: Outline of the methodology of the research. The bottom part shows the Design Science guidelines corresponding to that phase in the research.

In the remaining part of this section each phase of the methodology will be discussed in more detail.

3.1.3 Phase 1: The analysis phase

The first step of the analysis phase is to explore the problem and the context of the problem. This started in chapter 2 “Problem statement”, which also shows the practical and theoretical relevance of the research fulfilling design sciences’ guideline 2: “Problem relevance”. To solve the problem statements, the problem is described as: “the differences between a goal state and the current state of a system” (Hevner et al., 2004). The current state is obtained by analysing the current decision making process more closely. And the goal state is derived by obtaining requirements from literature and by determining Lianders’ expected goal state. The requirements can be found in the text at the corresponding section where the requirements are derived from. By optimizing the current state into the goal state for both science and practice the research fulfils fourth guideline 4: “Research contributions” (Hevner et al., 2004).

Literature

To ensure theoretical relevance of the research, a literature study on lifetime impacts, and categorization and prioritization is conducted. The possibilities for a focussed literature study on lifetime impacts is limited due to absence of literature on the subject[2]. Which is understandable because using lifetime impacts in the field of asset management is unique in the Ph.D. research of Richard Ruitenburg (as far as the researcher is aware). Therefore a wider view of the problem is taken by researching topics related to lifetime impacts. This expands the literature study to the topics of Asset Life Cycle Plans, Asset (Life Cycle) Management, scenario based strategy, risk, and maintenance management. The latter two are entirely different topics showing strong similarities with ALCPs. Researching these areas ensures a more objective and complete research. It is possible to extent the literature study even more, but this would enlarge the scope which is not preferable for reasons explained later in this section.

For the literature study on the categorization and prioritization, the focus is on researching decision making in asset management. This is done by answering the question: “What is decision making?”. The research includes an extensive literature review of 29 papers (discussed in section 6.4) to derive requirements of a decision making model. Hereafter a shortlist of five different decision making is created and analysed. The shortlist is based on selecting the methods that are used for asset management, risk prevention, and that are corresponding to the characteristics of the lifetime impacts. For each model the working principle, advantages, and disadvantages are researched and design principles are derived.

Case study

In (asset) management related research the relevance to practitioners should be just as important as the relevance to scientists (van Aken, 2004; Zuber-Skerritt & Perry, 2002). In line with the explanatory nature of this research (How are lifetime impacts currently categorized and prioritized?), the object of study (Liander), and to ensure the practitioners relevance, a case study is used as the methodological approach (Voss, Tsikriktsis, & Frohlich, 2002; Yin,

[2] The phrase “TITLE-ABSTR-KEY ("lifetime impacts")” returns 19 results at the sciencedirect.com. Of the nineteen only one relates to the topic of “asset” or “asset management”. (Derived in 2015)

2009). The topic of the case study is making the Asset Life Cycle Plan for power transformers. The specific ALCP is created during the period this research is conducted and is therefore a suitable case. Furthermore, it allows the researcher to get used to Liander, their method of working and to the concept of Asset Life Cycle Plans and lifetime impacts. The case study also provides the opportunity to test new ideas and to gain understanding on how the lifetime impacts are selected. From the perspective of Liander, participating in the case study is advantageous because of a new and fresh look at the subject. Which fulfils criteria 4: "Research contributions" of Hevner et al.. The purpose of the case study is similar to the purpose of the literature study. So researching what lifetime impacts are and how to categorize and prioritize them. The case study consisted out of three parts; participating in the creation of the ALCP on power transformers, semi-structured interviews with experts, and reading and analysing internal documents of Liander.

Participating in creating the ALCP included at least one meeting a week of around one hour to discuss the content of the plan and its process. During this meeting characteristics of lifetime impacts were discussed, gaining helpful insight to create the method. Additionally the opinions of the stakeholders of the project was derived.

The second part are interviews with people at the division "Policy and Standardization" and the management team. This consisted of fifteen semi-structured interviews of about an hour up to an hour and a half. The interviewees were selected because they either had experience with creating an ALCP or were involved in creating one. The interviews with people that had more experience with ALCPs were more extensive and into detail. The management was selected because they are also involved in the process of creating an ALCP, since they have to approve an ALCP. So by knowing the criteria by which they inspect an ALCP, the expected result of the categorization and prioritization can be deduced.

All semi-structured interviews were prepared by creating a list of questions which was approved by the supervisor of the project (Richard Ruitenburg), which can be found in appendix II. To help processing the interviews, notes were taken and directly worked out in the lay-out of the interview questions. Hereafter the notes were processed by summarizing the different answers per question per interview and combining the statements of different interviews. This allowed the researcher to detect similar answers and to count how often an answer was given. This process makes the results usable for analysis and anonymous. Something that was requested by different interviewees.

The third part is reading and analysing multiple internal documents on the topics of policy making and ALCPs. Most documents were analysed by extracting and listing requirements and design principles for a decision making model. In this report these documents can be found by looking at the author "Liander N.V.". The analysis of the internal documents include different versions of the finished ALCPs and the ALCPs in process (in total over twenty versions). The purpose of analysing the ALCPs was to discover patterns in how lifetime impacts are currently selected. The analysis was executed by marking the lifetime impacts per document, and each type of lifetime impacts (TECKO) was marked by its own sign. Hereafter the number of lifetime impacts were listed, creating an overview.

To generate design principles for a model, internal documents on decision making processes at Liander were analysed. These processes are the Integrated Network Planning (INP), ENTSO-E, innovation funnel, and Security Management System (SMS). The analysis showed that the INP process has the most similarities with reducing the number of lifetime impacts and is therefore inspected more closely. This is done by conducting two semi structured interviews of one and a half hour with experts on the process and by participating in a two hour discussion session in which the most important risks were selected by the risk expert panel (Risico Expert Panel). Additionally the innovation funnel is further inspected during one one and a half hour interview.

The result of the case study are requirements and design principles used to create the model. Additionally, wishes of Liander on the improved decision making process were derived.

3.1.4 Phase 2: The creation phase

The second phase of the research is creating the process that is an improvement on the current decision making process. In other words, creating the viable artefact according to guideline 1: “Design as an artefact” of Hevner et al. The model should be based on theory and be applicable in practice by Liander, as is stated in guideline 6: “Design as a research process”. To ensure this, the results from the literature study and the case study are combined with each other. The combination allows the researcher to deduce common characteristics and to create three programs of requirements. Necessary requirements which are used to create the model. Desirable requirements used to test the model. And wishes from Liander, to test the suitability of the model for Liander. The necessary and desirable requirements originate from Liander and science, ensuring rigour from both stakeholders of the project (guideline 6).

The process of creating the model is executed using an iterative process prescribed by Hevner (Hevner et al., 2004). The process consists of creating a concept model, discussing it with a stakeholder, optimizing the model, discussing with another stakeholder, etc. The process is repeated fifteen times with different stakeholders by means of discussions based on semi structured interviews. The drawback of the iterative process is that it can go on for a long period of time and that new opinions can always differ with the existing ones. Therefore the number of interviews is limited, optimizing both the process and the end result. During the process it is important to preserve the large picture of the model, so that the feedback during the final discussion does not alter the whole model. And that the model is still in according the literature. This is achieved by testing the final model to the requirements. Following this structured process, guideline 5: “Research rigor” of design science is fulfilled.

3.1.5 Phase 3: The evaluation phase

After the creation phase, the model is evaluated by testing it to the program of requirements and by means of two ALCPs. The program of requirements is tested by the researcher, as well as three persons who have used the model for their ALCP. By doing this the opinion of Liander on the model is obtained, the test are made more reliable, and the researcher is able to optimize the model for Liander.

The first ALCP which is used to test the model, is the ALCP on power transformers. However the ALCP is used to create the model, limiting the objectivity of the test. Therefore the ALCP on gas delivery stations is also used to test the model. The planning of this ALCP is similar to the planning of creating the model. So when they start selecting the most important lifetime impacts, the (concept) model will be ready. This is according to guideline 3: “Design evaluation” and guideline 5: “Research rigour” of Hevner et al.. Finally the results will be presented to the whole team, fulfilling guideline 7: “Communication of research”.

3.2 Discussion on the methodology

According to Heisenberg, the method by which a research is conducted has an influence on the final result (Heisenberg, 1927). Therefore the effect of the proposed methodology will be discussed.

A large part of the research is executed at Liander (about one day every two weeks is spend at the University of Twente, the rest at Lianders’ office) which can result in a too close relationship with Liander. This might limit the researcher from executing an objective research potentially introducing bias (Duffy, 1986). This negative effect is amplified by Lianders’ focus on introducing Asset Life Cycle Management and Asset Life Cycle Plans. This means that Liander needs a viable result while the pressure for a useful result can harm the scientific rigour (Ellis & Crookes, 1998). To prevent this, the researcher needs to maintain distance and remain unbiased by using diplomatic and communication skills. To aid in this process the project started with writing a project proposal and getting approval from the University of Twente and Liander. The proposal states the benefits for science and for Liander, so when necessary the researcher can refer to the approved project proposal. Furthermore the researcher focusses on literature from different scientific areas, helping in creating an objective view on the subject.

The chosen methodology mainly focusses on creating and testing the method and not on implementing it at Liander. This is a deliberate decision since implementation would require a change in how Liander currently prioritizes the lifetime impacts. And implementing a change in a company affects the employees, making it a difficult and time-consuming process which is rarely in the capacity of one individual (Hunt, 1987). It is therefore decided that it is up to Liander to implement the model once it is finished. This decision does limit the abilities to test and evaluate the method thoroughly.

The case study selection for an ALCP on power transformers implies that the decision making process will be usable for prioritizing lifetime impacts of power transformers. However the characteristics of power transformers will influence the (type of) lifetime impacts that are generated. For example a power transformer is relatively expensive (from €400.000 to €900.000,-) and low in number (about 600 pieces in the Liander network) compared to other assets of Liander (e.g. there are over 40.000 distribution transformers). Since the model is tested using these lifetime impacts, it is possible that the model can only handle these types of impacts. This is partly solved by testing the model for the ALCP on gas delivery stations and by testing it to the requirements from the literature study.

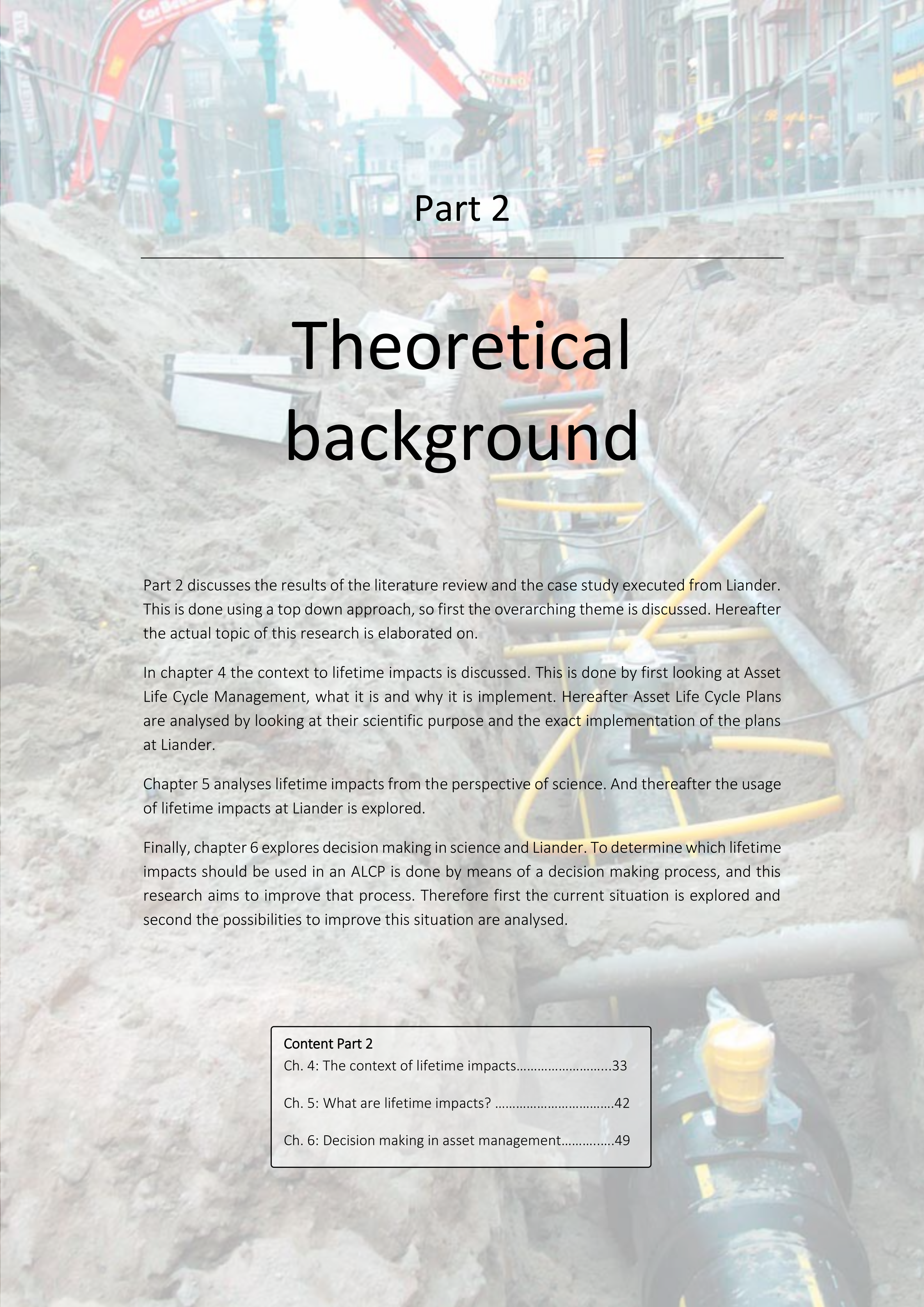
Finally, the decision for a case study consisting of interviews, thoroughly analysing internal documents, creating the ALCP, and the relatively short time-span of the project (nine months[3]) implies executing a qualitative study (de Goede, Boeije, & ’t Hart, 2005). The drawback is that

[3] Nine months is the standard available time for conducting a master thesis research

a quantitative study would enable the research to conduct more interviews, or multiple interviews with the same persons. Furthermore a quantitative study would allow for testing the model more thoroughly using multiple ALCPs. The advantage of a qualitative study is that decision making processes and ALCPs are examined thoroughly and that a clear image on the subject is obtained.

3.3 Conclusion

The research is executed based on a methodology that is a combination of design science and design methodology. The result is that the research is executed in three phases: analysis, design, and evaluation. The guidelines of Hevner et al are all linked to one of the three phases to ensure a structured process. Since the research is conducted at Liander, a combination of a literature study and case study is selected. The decision for this methodology will most likely influence the final result of the study. But this is inevitable since all research has its limitations and by acknowledging and discussing them, recommendation for further research can be made. This will be discussed at the end of the report (part 5).



Part 2

Theoretical background

Part 2 discusses the results of the literature review and the case study executed from Liander. This is done using a top down approach, so first the overarching theme is discussed. Hereafter the actual topic of this research is elaborated on.

In chapter 4 the context to lifetime impacts is discussed. This is done by first looking at Asset Life Cycle Management, what it is and why it is implement. Hereafter Asset Life Cycle Plans are analysed by looking at their scientific purpose and the exact implementation of the plans at Liander.

Chapter 5 analyses lifetime impacts from the perspective of science. And thereafter the usage of lifetime impacts at Liander is explored.

Finally, chapter 6 explores decision making in science and Liander. To determine which lifetime impacts should be used in an ALCP is done by means of a decision making process, and this research aims to improve that process. Therefore first the current situation is explored and second the possibilities to improve this situation are analysed.

Content Part 2

4. The context of lifetime impacts

The research for this thesis is an extension of the Ph.D. research started in December 2013 by Richard Ruitenburg and it aims to solve a problem he encountered during his research. The topic of the Ph.D. research is Asset Life Cycle Management (ALCM) and helping Liander implementing this principle by using Asset Life Cycle Plans (ALCP). To understand the scope and the context of this research, the principles of ALCP and ALCM will be explored into more detail in this chapter. This is done by researching what the scientific principles are and by understanding the purpose of these principles at Liander. This is first done for ALCM is section 4.1, and hereafter for ALCP for section 4.2, highlighted as the grey parts of Figure 4-1. In the next chapter the principle of lifetime impacts will be elaborated on.

The purpose of this chapter is to get an understanding of the scope and context of the problem, both from the perspective of literature as from the perspective of Liander. As can be seen in Figure 4-1 are lifetime impacts a part of ALCP which is on its turn a part of ALCM. So it is already possible to identify requirements to improve the decision making process for lifetime impacts by researching ALCP and ALCM since the output of the model should benefit them. These requirements are stated at the section of text where the requirements originate from. Each requirement is only stated once, but most requirements originate from different areas of literature and Liander.

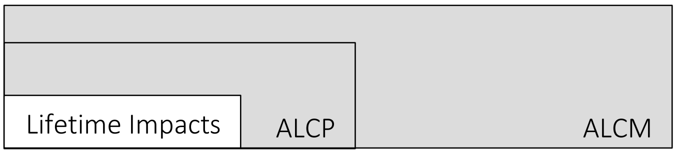


Figure 4-1: Overview of the scope and context of this research. The figure clearly shows that lifetime impacts are a part of ALCPs, and that ALCPs on its turn are a part of ALCM. These latter two topics will be discussed in this chapter.

4.1 Understanding Asset Life Cycle Management

Asset Life Cycle Management can be interpreted as a continuation in a long tradition of research on maintenance. According to Parida and Kumar maintenance has developed itself from “necessary evil” in 1940 up to the current view that it creates added value (Kumar & Liyanage, 2003; Parida & Kumar, 2008). This is mostly due to increasing costs of assets, and increasing financial and social consequences of a failure (L. A. M. van Dongen, 2011).

In the current view on maintenance management, maintenance should play a role during the whole lifecycle of an asset. Including creation, usage and disposal of an asset (L. A. M. van Dongen, 2011). This transition can be allocated to several factors. Stavenuiter identifies increasing complexity, costs, and size of capital assets in combination with a shorter economic lifetime as the main drivers (Stavenuiter, 2003). According to Mitchel the reason for ALCM is the necessity to maintain and often increase, operational effectiveness, revenue and customer satisfaction, while simultaneously reducing capital, operating and support costs (Mitchell, 2002). Schuman and Brent add that ALCM is necessary because costs are often isolated and fragmented to different life stages (Schuman & Brent, 2005). Finally, Komonen mentions that overcapacity, low return, and increase of turbulence are the main drivers (Komonen, Kortelainen, & Raikkonen, 2000). Summarized it can be stated that lifecycle thinking is added to asset management due to an increase in the complexity of the assets and due to the demand for reducing total costs. These changes are also noticed at Liander and they have therefore decided to implement ALCM.

To able to comply with these changes Asset Life Cycle Management "refers to the management of assets over their complete life cycle, from before acquisition to disposal, taking into account economic, environmental, social and technical factors and performances" (Haffejee & Brent, 2008). Other definitions state that ALCM is: "Optimizing lifecycle costs by using the asset economically effective and efficient over its whole life" (National Treasury, 2004). Or "a is multidisciplinary and long-term management of capital assets" (Braaksma, Veldman, & Vis, 2014).

Liander has converted the above definition into one definition of ALCM by which they implement the principle. This is:

"Managing assets so they add maximum value to the company values over their entire lifecycle, taking relevant risks, and internal and external developments into account. ALCM is a multidisciplinary field, with technical, financial, organizational, regulatory, and customer perspective as the main perspectives." (Liander N.V., 2015d)

Comparing the definitions of ALCM from science and Liander shows that ALCM should be a multidisciplinary practice, it should manage an asset over its whole lifecycle, and it should focus on the long-term management of the asset. Here the whole lifecycle is identified from acquisition all the way up to disposal of the asset. This is translated into the following requirements to improve the decision making process.

Requirement 1: The decision making process should be multidisciplinary practice
Requirement 2: The decision making process should take the whole lifecycle into account
Requirement 3: The decision making process should focus on the intermediate and long term

4.2 Understanding Asset Life Cycle Plans

One of the methods to implement Asset Life Cycle Management, is using Asset Life Cycle Plans. These plans are originally developed by NedTrain in collaboration with the research group Maintenance Engineering and Design for Maintenance at the University of Twente. NedTrain is a Dutch company responsible for the maintenance, management, and performance of the fleet of the Netherlands Railways (Nederlandse Spoorwegen (NS)). Similar to how Liander is responsible for the maintenance management and performance of the energy network. Due to the good experiences of implementing ALCPs at NedTrain, Liander decided to implement ALCPs as well. And Richard Ruitenburg will guide them in this process during his Ph.D. research (Ruitenburg, 2014a).

To understand the concept of Asset Life Cycle Plans they are inspected more closely. However, until so far NedTrain and Liander are the only companies using ALCPs[4] limiting research

[4] As far as the author is aware.

possibilities. Furthermore, the research is executed at Liander and lifetime impacts (the topic of this research) are introduced in ALCPs at Liander. Therefore the principle of Asset Life Cycle Plans will be discussed from the view of Liander, who uses the following definition for ALCPs:

> *An Asset Life Cycle Plan combines all relevant information and developments of an asset population to create an integral overview of the asset population which is used to manage the asset population (if necessary) to accomplish certain objectives, eliminate threats, and seize opportunities. By doing this Liander remains in control of the assets* (Liander N.V., 2014a).

And their purpose is to answer the question: "How do we get a strategic, businesswise, and comprehensive overview of the remaining useful lifetime and the 'futureproofness[5]' of our assets, and how can we remain 'in control' of our assets?". The definition shows what an ALCP and what is should solve, but the question remains why the plans are necessary. This will be explored in section 4.2.1 and the structure and the implementation of ALCPs are discussed in respectively section 4.2.2 up to 4.2.4.

4.2.1 The reason for Asset Life Cycle Plans at Liander

The internal document "ALCPs at Liander" (Kaderdocument levensloopplannen) identifies several factors that moved Liander to implement Asset Life Cycle Plans in November 2013. These factors can be summarized into four themes (Liander N.V., 2014b).

1. Ageing assets
2. Uncertain future
3. Lifecycle management is the new standard
4. Fragmented image on the assets

Ageing assets refers to the fact Liander has numerous capital intensive assets from all ages. Some of which are were installed in the 1950s and the 1960s and have an estimated remaining lifetime is about 15-40 years. Others assets are newer, but also have a shorter estimated lifetime. So the collection of assets is diverse and dynamic with different capabilities and conditions. This makes it difficult to determine the historical, current, and expected performances of the asset.

The second theme is the uncertainty about future changes that have a large influence on the energy network. For example, the exact influence of the energy transition on the network is unpredictable and can range from almost nothing to extremely large (see section 1.1).

Thirdly, asset management standards like PAS55, NTA 8120, and ISO55000 all mention lifecycle management as a part of good asset management (Peters, 2015). At Liander these standards are regarded highly and therefore they constantly try to improve their implementation of lifecycle management. One method of doing this is using ALCPs.

[5] Futureproof is a term used at Liander to indicate in which extend the assets can deal with future changes without large investments

Lastly, there were about 180 policy documents that provided a fragmented image of future performance and condition of the assets. Additionally, the large number of documents also make it more difficult to provide an instant answer to questions from the management team about the condition of the asset.

4.2.2 Structure of Asset Life Cycle Plans

To make sure that an ALCP solves the four themes and answers the main question, a standard structure is developed. The structure, seen in Figure 4-2, consists out of four parts which are discussed briefly. In the part "current performances" the current condition, performances, and maintenance policies of the asset are analysed. This includes an overview of the population, the average age, and an estimation of the number of failing assets per year based on their age. In the part "strategic goals" the company goals relevant for the asset are stated. These goals are based on the company values, which are: Safety, Quality of Delivery, Financial, Laws and Regulations, Customers and Image, and Sustainability[6]. The definition of each value can be found in appendix III. The part "expected performances" describes what the asset should be able to do and what changes in performance can be expected. These are hard to quantify, and will be elaborated on in section 5.2.6. The final part of an ALCP is creating "policy measures". The aim of this part is to compare the current performances with the expected performances and strategic goals, and to bridge the gap by creating policy measures.

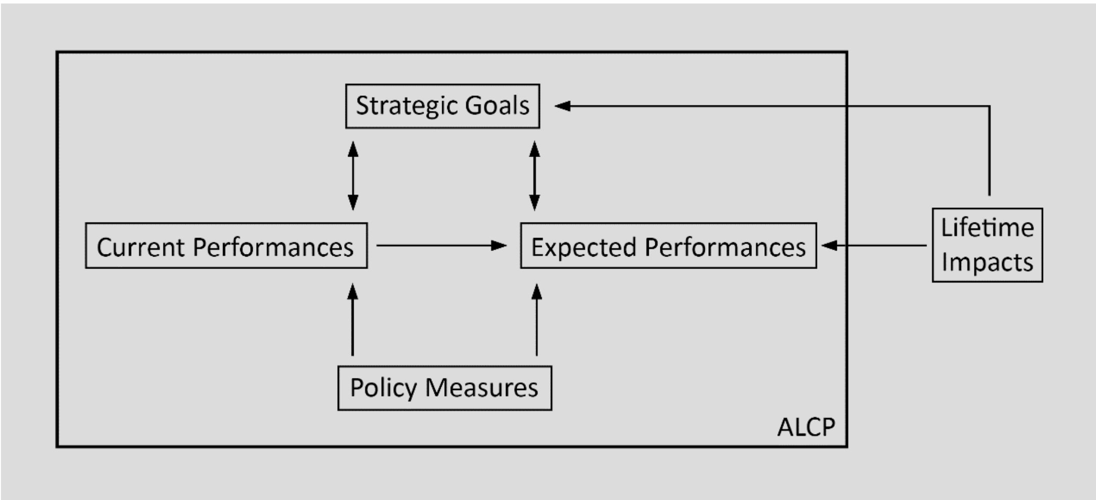


Figure 4-2: Structure of an ALCP, as can be seen are lifetime impacts not an actual part of ALCPs but instead it helps creating one.

[6] In Dutch; Veiligheid, Kwaliteit van Levering, Financieel, Wet en Regelgeving; Klant en Imago en Duurzaamheid.

4.2.3 Implementation of Asset Life Cycle Plans at NedTrain

From the above the theoretical structure and purpose of ALCPs at Liander is clear, but they could be different in practice. Therefore the implementation of the plans is analysed more closely. However, at the moment of analysis only three ALCPs are finished and five are in progress at Liander (November 20th 2015). This limited number makes it hard to discover trends. And because the plans are relatively new, the final form of the plans is most likely not fixed. To solve this problem the implementation of ALCPs at NedTrain is analysed. The plans are implemented in there 2004, so they are more mature and larger in number.

At NedTrain the following definition of ALCPs is used:

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. (Ruitenburg, Braaksma, & van Dongen, 2015)

Through the years this definition has remained the same, however since 2004 the content of ALCPs at NedTrain has made significant developments. This is clearly depicted by Figure 4-3, which is the result of a study on different ALCPs at NedTrain (Ruitenburg et al., 2015). The figure shows the number of pages per chapter in eight different ALCPs. Examining the figure shows that the number of total pages decreases over the years and that the type of chapters have changed. The most significant change happened in 2010 with the addition of a chapter on strategy and the elimination of the description of the characteristics of the trains. Ruitenburg et al researched the reduction and change in content, and discovered four findings (Ruitenburg et al., 2015). Trough time the ALCPs at NedTrain:

1. changed from an operational to a strategic document.
2. changed from a handbook for asset managers to a document for the management.
3. became a shorter document.
4. changed from a primary technical document to a multidisciplinary document.

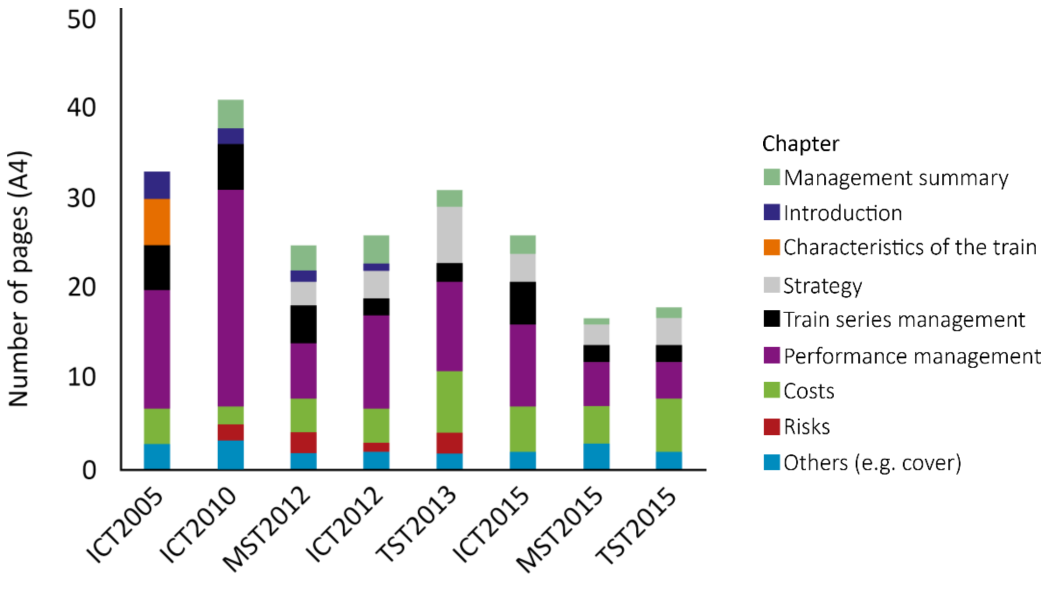


Figure 4-3: Overview of the research executed by Ruitenburg et al on trends in ALCPs at NedTrain (Ruitenburg et al., 2015).

4.2.4 Implementation of Asset Life Cycle Plans at Liander

The four trends at NedTrain are significant changes which also might happen at Liander. And these changes will influence the requirements for the decision making process. Therefore the implementation at Liander is analysed. This is done using three methods:

1. Interviews with policy advisers and management team
2. Analysing the finished ALCPs
3. Experience of developing the ALCP on power transformers

Interviews with policy advisers and management team

The first method are five interviews with members of the management team (MT) and ten interviews with policy advisers of Asset Management (AM). The structure of the interviews can be found in appendix II, and they included the questions: “What is your definition of an ALCP?” and “What is your vision on an ALCP?”. The answers to these questions are analysed and the most common answers can be found in Table 4-1 on the next page. Appendix IV shows a more complete overview of the results. Two conclusions can be derived from the answers:

- The policy advisers believe that the focus of an ALCP lies on describing the future of the asset and determining the policy that should be executed to comply with that future.
- The management team believes that the focus is on communication with the management team, as well as describing the necessary policy measures.

This shows that the two stakeholders of an ALCP have different interests and opinions, which can be expected for these kind of documents. Comparing this with the second identified change at NedTrain, it can be assumed that the ALCP will most likely become a document for the management. So it will be a strategic document, resulting that the output of the improved decision making process should also be strategic. Additionally the trend shows that the decision making process should have output for two different stakeholders. Therefore the following requirements are determined.

Requirement 4: The output of the decision making process should be strategic
Requirement 5: The out of the put decision making process should be able to provide information for multiple stakeholders

A different analysis of the results of the interviews is comparing them with the original definition of Asset Life Cycle Plans. When doing this, statement 7 draws attention. Statement 7 implies that an ALCP should only provide an overview and not make decisions. Whereas the original definition shows that the ALCP should contain policy measures to mitigate future risks. The difference substantiates that ALCPs are still in the development phase. Meaning that different persons have a different perspective on ALCPs and the opinions are subject to change due to new insights. And that the document will most likely change in content. This is also substantiated by the fact that the most common answer is only provided ten times from a total fifteen interviews. Whereas when a common view is present, the most common answer would be provided more often. The decision making should thus be able to cope with these changes by being structured and transparent.

Table 4-1: Overview of the answer provided by Liander on the questions "What is your definition of an ALCP?" and "What is your vision on an ALCP?". The interviews were conducted five members of the management team (MT) and ten policy advisers (PA). The last two column show how often the answer is given by each group.

#	Definition Asset Life Cycle Plan	MT	PA
1	An ALCP is a document that describes the future of an asset (group)	2	8
2	An ALCP is a document that determines the policy that should be executed	3	6
3	An ALCP is a document to communicate with the management team	3	1
4	An ALCP is a document that describes the current situation of an asset	2	1
5	An ALCP is a document that uses statistical models to predict the expected performances of an asset	2	0
6	An ALCP is a document that determines the expected performances of an asset	1	1
7	An ALCP is document that provides an overview and that does not make decisions	1	1
8	An ALCP is a document that optimizes the whole lifecycle of an asset	1	1

Analyzing finished ALCPs

The second method to understand the implementation is analysing the different ALCPs as seen in Table 4-2. The first observation is that the subject of the plans of Liander changed over time. The first ALCP was on SVS switchgears, a specific asset type (brand) within the asset group switchgears. The second ALCP was on the asset population distribution transformers, which includes transformers of many different brands and types. This is a significant change because the number of SVS switchgears is about 2500, while there are about 47.000 distribution transformers. So the ALCP changed from a detailed document to a generic document. The reason for this change is that a generic document would reduce the total number of documents required, making them more manageable.

Since the following ALCPs are also on an asset population, it can be deduced that the transition was according to the view of Liander. This implies that the improved decision making process should focus on creating generic output and thus strategic.

A similar study to the one of Ruitenburg et al by counting the pages as discussed in section 4.2.3 is executed as well. However, this showed no significant changes. This can most likely be allocated to the fact that the implementation of ALCPs at Liander is still in an early phase.

Table 4-2: Overview of the ALCPs at Liander and their progress in September 2015

#	Subject	Stage
1	SVS Switchgears	Finished (01/2013)
2	Distribution transformers	Finished (08/2014)
3	Switchgears	Finished (06/2015)
4	Gas pipelines	Finishing
5	Cables, lines, and cable joints	Finishing
6	Power transformers	Halfway
7	Gas delivery stations	Data generation
8	High voltage switchgears	Start

Experience of developing the ALCP on power transformers

During the researcher's period at Liander several observations regarding the implementation of ALCPs were made. The most notorious is that Asset Life Cycle Plans are a new and innovative concept at Liander. Meaning that the perspective on and the content of the plans is still subject to change. The reasons for the changes are partly to optimize them for usage at Liander, ensuring that the document provides added value and is not just another document. But mostly because the different users have a different vision on the document. The main users of ALCPs are policy advisers and the management team, which is different from other policy documents[7]. The policy advisers write the plans and use them as a reference document during their daily activities and therefore need background information. Whereas the management team approves the ALCP and uses them to get an understanding on the (expected) condition of the asset and therefore only require a synopsis. The described transition is a part of the planned step by step implementation process of ALCPs at Liander conducted in collaboration with the Ph.D. researcher.

> Requirement 6: The decision making process should aid in improving ALCPs by being able to determine what is important to take into account and what not.
> Requirement 7: The output of the decision making process should be easy to use in an ALCP[8]

To be able to comply with both demands, Liander has adopted the Minto Pyramid Principle. This is a writing methodology that aids in to the point and short writing. Central for the Minto Principle are a key message and a storyboard (for the management team) and further analyses (for asset manager) should be put to the appendices (Minto, 2008). The first ALCP (on power transformers) constructed using the Minto principle is reviewed positively by both stakeholders and it is expected that the method will be used for all future plans. However the Minto Principle does not ensure that the different stakeholder have a similar view on ALCPs. Therefore the researcher extended the scope of the research to scenario based strategy. This is a scientific area that aims to clarify present actions in light of future occurrences which can regarded as similar to ALCPs (Durance & Godet, 2010). The results of the study on scenario based strategy can be found in appendix V. The most important result is that it is of high importance that a scenario is supported by the entire organization. This is accomplished by involving management and multiple divisions into decision making (Durance & Godet, 2010; Ratcliffe, 2000). Similarly should the ALCP be supported by all stakeholders, therefore the following requirement are stated to improve the decision making process.

> Requirement 8: The decision making process should involve management to make a decision
> Requirement 9: The decision making process should involve different divisions to make a decision

[7] Other policy documents have three main stakeholders; writers, approvers (management), and users. The writers are the policy advisers of the division "Policy and Standardization", the approvers are the PIB (Project Investment Board). But the users are mostly people of the implementation department of Alliander.

[8] Easy to use is defined as a clear overview of the lifetime impacts.

4.3 Conclusion

Chapter 4 provides context to lifetime impacts by exploring the concepts of ALCM and ALCP. ALCM is needed because of increasingly complex assets and the need to reduce total costs. Using ALCPs is the methodology by which ALCM is implemented, and its purpose is to get a strategic, businesswise, and comprehensive overview of the remaining useful lifetime and the 'futureproofness' of the assets. The implementation however showed that the plans are still subject to change and the decision making process should take this into account.

The result of the chapter on ALCP and ALCM are nine requirements to improve the decision making process. These are:

Requirement 1	The decision making process should be multidisciplinary practice
Requirement 2	The decision making process should take the whole lifecycle into account
Requirement 3	The decision making process should focus on the intermediate and long term
Requirement 4	The output of the decision making process should be strategic
Requirement 5	The out of the put decision making process should be able to provide information for multiple stakeholders
Requirement 6	The decision making process should aid in improving ALCPs by being able to determine what is important to take into account and what not.
Requirement 7	The output of the decision making process should be easy to use in an ALCP
Requirement 8	The decision making process should involve management to make a decision
Requirement 9	The decision making process should involve different divisions to make a decision

5. What are lifetime impacts?

Chapter 5 will elaborated on in lifetime impacts by first exploring the principle of the remaining useful lifetime of an asset in section 5.1. Hereafter the principle of lifetime impacts are analysed in section 5.2. And finally the method of obtaining them is discussed in section 5.3. So the chapter will discuss the grey part of Figure 5-1 below. Similar to the previous chapter is the purpose to determine requirements on improving the decision making process.

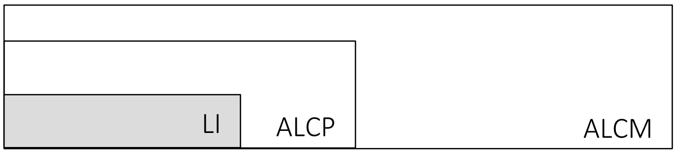


Figure 5-1: Overview of the scope and context of this research. The figure clearly shows that lifetime impacts are a part of ALCPs, and that ALCPs on its turn are a part of ALCM. In this chapter the focus is on lifetime impacts.

5.1 Exploring the remaining useful lifetime

The main question at Liander that led to the implementation of ALCP mentions "an overview of remaining useful lifetime" (see section 4.2). This principle, the remaining useful lifetime (RUL), will be explored more closely. The RUL is described as "the length from the current time to the end of the useful life", where the useful life is described as "the period during which an asset or property is expected to be usable for the purpose it was acquired (for)" (Si, Wang, Hua, & Zhou, 2011). Knowing the RUL is of high importance for good asset management, because it can be used to exploit an asset for its total lifetime (Ruitenburg et al., 2015). In the most ideal case one can replace an asset moments before the useful lifetime ends, avoiding destruction of capital and preventing a failure (Ruitenburg et al., 2014). Knowing the RUL creates a long term image of the asset, shows the performance objectives, and it is expected to be a useful method to communicate with management.

5.1.1 Weaknesses of the remaining useful lifetime

There are however several weaknesses to the approach of using the remaining useful lifetime (RUL). In this research we will focus on one of the weaknesses; the mono-disciplinary approach of determining the RUL. Often the RUL is translated to the technical remaining lifetime and/or the economic remaining lifetime (Asiedu & Gu, 1998; Campbell, Jardine, & McGlynn, 2010; Frangopol, Saydam, & Kim, 2012; Garg & Deshmukh, 2006; Márquez, Márquez, Fernández, Campos, & González-Prida Díaz, 2012; R. van Dongen, 2011). The technical remaining lifetime is when the useful life can be regarded as the period during which an asset can perform its function without breaking down (R. van Dongen, 2011). In the economic remaining lifetime the useful life can be regarded as the period in which the exploitation costs are lower than the benefits, so the asset still makes a profit (R. van Dongen, 2011). The focus on just technical and economics is in contrast to definition of asset management: "*Asset Life Cycle management should include economic, environmental, social, and technical factors and performances*" (Haffejee & Brent, 2008). That a multidisciplinary view is required for asset management is further substantiated by Pudney who states that "governance, geo-political, economic, social, demographic, and technological" aspects should be taken into account (Pudney, 2010). And also by Woodward who states that “functional, physical, technological, economic, and social and legal life are important” (Woodward, 1997). So it is apparent that the RUL should be identified from a multidisciplinary perspective. An aspect that is also mentioned in the definition of ALCP and ALCM, two concepts for which the RUL is used.

The problem is that the technical lifetime can be measured by placing sensors on an asset and the economic lifetime can be calculated. But there is no data to determine for example the legal life of an asset. Demanding for a structured methodology to determine the RUL from a multidisciplinary perspective.

5.2 An analysis of lifetime impacts

The proposed methodology to identify the remaining useful lifetime of an asset from a multidisciplinary perspective is in twofold. First the initial technical of economical RUL of an asset is determined, and secondly trends and events that influence the determined RUL are identified. These trends and events are called lifetime impacts and are the main topic of this research. By determining them from a multidisciplinary perspective the RUL and thus the ALCP becomes multidisciplinary (Ruitenburg et al., 2014). For example, the initial RUL for a bicycle can be ten years, but due to the lifetime impacts: “changes in regulations regarding bicycle lighting” the RUL can be reduced to just five years.

Lifetime impacts are defined as:

Probable (technical and non-technical) events or trends that may have a positive or negative influence on the remaining lifetime of the asset in the intermediate or long term (Ruitenburg et al., 2014)

To get a better understanding of lifetime impacts, the definition is analysed more closely by focussing on five different aspects of the definition: probable, technical and non-technical, events or trends, positive or negative, and intermediate or long term. And an example of lifetime impacts for a car can be found in Table 5-1 below.

Table 5-1: Examples of lifetime impacts for a car.

Lifetime Impact	Negative Impact	Positive Impact
Technical	Rusting chassis	MOT inspection
Economical	Replacement of tires	Decreasing oil prices
Compliance	Mandatory winter tires in Germany	Low additional tax for hybrid cars
Commercial (K)	No satellite navigation	Extra backseats for planned children
Organizational	No knowledge of cars	Free warranty for five years

5.2.1 Probable

A lifetime impacts is a probable event meaning that it is not 100% certain a lifetime impact really happens or that it actually influences the RUL. This makes lifetime impacts harder to process, since they include uncertainty. But by looking at probable events a wider perspective can be taken, increasing the chance of identifying all relevant impacts. Besides identifying future events inherently deals with incomplete knowledge, which is identical to uncertainty (ICH Expert Working Group, 2005). Admitting that there will be a variability in the RUL.

5.2.2 Technical and non-technical

By focussing on technical and non-technical impacts, the required multidisciplinary nature of the RUL is ensured. And to ensure that they are on technical and non-technical, lifetime impacts are obtained from the five TECKO perspectives. TECKO stands for Technical, Economical, Compliance, Commercial (K), and Organizational. The first two perspectives are standard and often used, the remaining three perspectives are not. The compliance perspective analyses if the asset complies with norms, rules, and regulations. The commercial perspective provides a look whether the asset fulfils the demands of the market. And the organizational perspective is used to check if the owner is able to support the asset (Ruitenburg et al., 2014). And using these five perspectives on the asset a holistic view on the RUL is obtained.

5.2.3 Event or trend

A lifetime impact is an event or trend that influences the remaining useful lifetime. So an event that has no influence at all or an event that is already taken into account is not a lifetime impact. For example, normal wear of a bearing is not a lifetime impact, because the principle is already known and taken into account during production and in its RUL. Changes in the environment of the bearing can be a lifetime impact, since it reduces the remaining lifetime and is not taken into account during the procurement of the bearing.

5.2.4 Positive or negative

Lifetime impacts are events that may have a positive influence on the RUL, lengthening the remaining lifetime. Or a negative influence, shortening the remaining lifetime. The inclusion of positive effects is rather unique. Analysing 29 papers on decision making in asset management, only resulted in models that can manage threats and not opportunities[9]. The benefit of looking at opportunities is that it allows for constant optimization. While in a risk based situation a system is only improved when a threat is identified. This leads to the following requirement.

> Requirement 10: The improved process should be able to deal with both threat and opportunities

[9] The 29 papers will be discussed more closely in the next chapter, including their references.

5.2.5 Intermediate and long term

Lifetime impacts look at intermediate and long term impacts which is done for three reasons.

1. It prevents firefighting on daily problems
2. It provides the opportunity to mitigate long term high costs risks, for small costs at this moment. Similar to an insurance policy, where a monthly fee is paid to “save money” for high costs in the future.
3. Recognizing long term events enables a company to plan actions carefully, enabling the first time right principle which reduces costs and risks (Halpin, 1966; Linneman & Klein, 1985).

The focus on long term makes lifetime impacts unique as normally the focus is on the short term. This is because people prefer to work with certainties and short term impacts often have a high rate of certainty (Linneman & Klein, 1985). While intermediate and long term events are by definition less certain. This paragraph thereby substantiates requirement 3 from the previous chapter.

5.2.6 Understanding the role of lifetime impacts at Liander

As discussed in section 4.2.2 are the expected performances of an asset population hard to determine. However, events that influence the remaining useful lifetime of an asset can help in determining the expected performance of the asset. Therefore Liander uses the principles of lifetime impacts to help determine the expected performances of the asset. So the lifetime impact that influences the RUL the most is also the most important lifetime impact for the expected performances. The need to determine the most important lifetime impacts is explained in the next section. For this section the following requirement is stated.

> Requirement 11: The improved process should be able to select the lifetime impact that influences the remaining useful lifetime of the asset population the most.

5.3 The method of obtaining lifetime impacts

Now we know what lifetime impacts are and what their role is in science and Liander. Next the method of obtaining is discussed by looking at the Lifetime Impact Indicator Analysis (LIIA) (Ruitenburg et al., 2014). This methodology consists out of five steps:

1. Asset selection
2. Collection of general asset information
3. Discussion of the asset in expert sessions
4. Writing the Asset Life Cycle Plan
5. Evaluation

In the first two steps the asset is selected and information about the asset is acquired. The asset information include among others the asset characteristics, current performances, objectives, and policies of the assets. In the third step the actual lifetime impacts are identified by means of an expert session, which is the most significant step for this research. In the fourth step the obtained information is used to write the actual Asset Life Cycle Plan. And in the final step the process and results are evaluated.

5.3.1 An explanation of the expert session

The expert session is a structured methodology to obtain the lifetime impacts. A detailed description of the process can be found in “Handleiding TECKO methodiek” (Ruitenburg, 2014b). This section will provide a brief overview of the most important aspects of the expert session for this research.

The expert session is a structured brainstorm with multiple experts from different backgrounds about events and trends that might influence the remaining useful lifetime of the asset population from the five TECKO perspectives. Doing this by means of a brainstorm implies that lifetime impacts are largely based on tacit knowledge. Tacit knowledge is the knowledge which resides in workers under the form of skills, know-how, capabilities, and feeling (Waeyenbergh & Pintelon, 2002).

To get a holistic view on the asset population the brainstorm should be as extensive as possible. But to determine the importance of each lifetime impacts the number of lifetime impacts should be limited, or the expert session could be extremely long. However as the expert session already takes up to four hours, which is regarded as the maximum time. And a holistic and multidisciplinary view on the asset is regarded to be most important. It is decided that as many lifetime impacts as possible should be determined during the expert session. And that prioritizing the lifetime impacts should not be included. Taking the above into account the following requirements for the improved process are created.

> Requirement 12: The process should be able to deal with tacit and non-tacit knowledge
> Requirement 13: The improved process should exclude evaluation during the expert session

5.3.2 Results of the expert sessions

To further understand lifetime impacts the result of different expert sessions are analysed, which led to three observations.

1. A large number of lifetime impacts are identified. The session on SVS switchgears resulted in 76 lifetime impacts and for power transformers over 130 were acquired.
2. Lifetime impacts differ a lot from each other. From specific risks for the whole asset group, up to vague statements on how an asset should be managed. An attempt was made to standardize the lifetime impacts by determining the cause and effect of each lifetime impact. However the large range of different impacts make it difficult to spot trends. Additionally the standardization attempt took a lot of time (about 8 hours for 130 impacts). Therefore the attempt failed.
3. The expert sessions were reviewed positively by the participants. A questionary after two session showed 6.6 and a 5.9 on a 1-7 scale for the question “The TECKO analyses provides added value for Liander”. Or as one participant mentioned: “*It is a good opportunity to involve different people into determining the future of an asset*” Due to the positive results and feedback, Liander has the intention to use the expert session methodology for all new ALCPs.

From the analysis of the results of the expert session the following requirements are derived:

Requirement 14: The improved process should be able to deal with a large number of lifetime impacts
Requirement 15: The improved process should be able to deal with a wide variety of lifetime impacts

The above also shows the need for a decision making process for lifetime impacts. First, not all lifetime impacts can be included in an ALCP, regarding the large number and that the ALCP should be a short and strategic document. Second, not all lifetime impacts are equally important. Third, in the future the expert session will be used as well due to the positive results.

5.3.3 Lifetime impacts in different ALCPs

To understand more about the lifetime impacts at Liander the impacts of different versions of five ALCPs are analysed[10]. The result can be found in appendix VI and a summary can be seen in Table 5-2. The analysis consisted of counting the impacts that are identified in each version of an ALCP, categorized per term (short, medium, and long term) and per TECKO perspective. What can be noticed, and is clearly depicted in Table 5-2, is the distribution of the type of impacts. Technical and/or short term impacts are most frequent, which is explainable because Liander has a structured process that focusses on short term risks, called bottlenecks (knelpunten). Additionally, the experts that participate in the TECKO analysis all have a technical background. However, focus on the short term does not correspond with the definition of lifetime impacts. Showing that a decision making process should be able to select the intermediate and long term impacts (requirement 3)

The analysis also shows that all different types of lifetime impacts are identified. Showing that the TECKO successfully makes people think outside their comfort zone and it thus a successful method

Table 5-2: Percentage of the type of lifetime impacts identified split per TECKO perspective and per short, medium, and long term.

	T	E	C	K	O	Total
Short term	17%	10%	7%	7%	10%	51%
Intermediate term	10%	6%	4%	4%	6%	30%
Long term	7%	4%	2%	4%	2%	19%
Total	34%	20%	13%	15%	18%	

[10] The ALCPs inspected are on SVS Switchgears, distribution transformers, switchgears, gas pipelines, and cables, lines, and cable joints. So lifetime impacts from expert's session and individual sessions were analysed.

5.4 Conclusion

Chapter 5 analyses lifetime impacts, their purpose, and how they are obtained. So in retrospect, lifetime impacts are used at Liander to determine the expected performances of the asset. The expected performances are one of the four parts of an Asset Life Cycle Plan, and it is the most difficult part to determine. Finally using ALCPs is a method to implement Asset Life Cycle Management at a company, in this case Liander. By using lifetime impacts the multidisciplinarity of ALCPs and ALCMs is guaranteed. To understand the actual problem why an improved decision making method is necessary, the method of obtaining lifetime impacts is inspected more closely. This showed that an expert session results into numerous and very different lifetime impacts. These cannot all be taken into account in an ALCP meaning that a decision making process to make the selection is necessary. Furthermore, it is assumed that the expert session will be used in the future due to the positive feedback and the useful results.

The result of chapter 5 are the following requirements.

Requirement 10	The improved process should be able to deal with both threats and opportunities
Requirement 11	The improved process should be able to select the lifetime impact that influences the remaining useful lifetime of the asset population the most.
Requirement 12	The process should be able to deal with tacit and non-tacit knowledge
Requirement 13	The improved process should exclude evaluation during the expert session
Requirement 14	The improved process should be able to deal with a large number of lifetime impacts
Requirement 15	The improved process should be able to deal with different lifetime impacts

6. Decision making in asset management

In the previous chapters lifetime impacts and its context are discussed. In this chapter the interface between lifetime impacts and ALCP will be discussed, as depicted in Figure 6-1. The previous part showed that there are numerous lifetime impacts identified, and that not all lifetime impacts can be implemented in an ALCP. Furthermore the problem statement showed that the current decision making process to determine which lifetime impacts to include can be improved upon. To be able to do this, first the current state of decision making at Liander is analysed in section 6.1. Hereafter the desired state is discussed by exploring what decision making is in science (section 6.2).

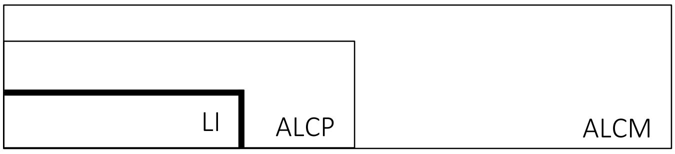


Figure 6-1: Overview of the scope and context of this research. The figure clearly shows that lifetime impacts are a part of ALCPs, and that ALCPs on its turn are a part of ALCM. This chapter focusses on the interface between lifetime impacts and ALCPs.

6.1 The current decision making process

The same interviews as used in section 4.2.4 are used to determine the current decision making process for the lifetime impacts. This is done by asking the questions: *"How does Liander currently make a decision between important and less important future events?"* This question was favoured over directly asking how lifetime impacts are selected, because not all interviewees had experience with lifetime impacts. The results of the interviews can be seen in appendix VII. From the provided answers, the following six observations can be made.

1. Policy advisers based their decisions mostly on their knowledge, experience, and opinions
2. Emotions play a large role in decision making in ALCPs
3. Decision are made in consultation with each other
4. Decisions are based on multiple criteria, like external influences, certainties, and financial consequences
5. Only one of the fifteen interviewees mentions a structured method
6. The most common answer is provided eight out of a maximum fifteen times.

From these observations, the fifth and sixth observation substantiate the problem statement in section 2.1 that a common and transparent decision making process is currently lacking. So the current state is described as "*a decision making process that is not structured and transparent*".

The six observations also show that Liander is familiar with using their own knowledge, experience and opinions to make a decision. And it is preferable to use methods that persons are already familiar with when optimizing a process (Hunt, 1987). Therefore the requirement 16 is derived from the interviews. Other requirements that could be derived are overlapping with previously mentioned requirements and are therefore not explicitly mentioned.

Requirement 16: The decision making process should use the knowledge and experience of experts at the company

6.2 The need for a new and structured process

This section shows the need for a new and structured decision making process for lifetime impacts at Liander. Since selecting the most important lifetime impacts does not have to be an extremely hard task, and one could argue why a special process for decision making in lifetime impacts is necessary.

6.2.1 The need for a structured process

There are two main reasons derived from literature that show the need for a structured process. These are:

- Imprecision of human judgment
- Difficulty of the decision making in asset management

The first reason for a structured process is that people tend to choose for the familiar and tangible, unconsciously distorting information in favour of those (Woodhouse, 2005b). Or as Catrina and Nordgard state; “the imprecision of human judgement” (Catrinu & Nordgård, 2011). Explaining why people tend to buy the car they have seen more often in a commercial, or favouring songs that are played more often on the radio. This also takes place in asset management, for example favouring a lifetime impact because it was discussed during a previous meeting.

The second reason is that asset management decisions are generally multi-criteria decisions (Catrinu & Nordgård, 2011). Involving multiple factors and different objectives and constraints (Sun, Fidge, & Ma, 2012). The rule is that the more factors, the more difficult the decision will be (Brugha, 2004). So decisions on lifetime impacts are especially difficult, because it involves numerous factors (as discussed in chapter 5). The result is that asset managers often have to simplify the decision and thereby they do not take all criteria into account in a structured way (Catrinu & Nordgård, 2011). This can be improved upon when a structured and transparent process is used, an aspect substantiated by several other researches (Rommert Dekker & Scarf, 1998; Lounis, Vanier, Lacasse, & Kyle, 1998). From this section the following requirements are derived.

Requirement 17: Different users of the decision making process should get comparable results
Requirement 18: The decision making process should be structured and transparent

6.2.2 The need for a new process

So the need for a decision support system is apparent, but there are already several available tools, for example (Campbell et al., 2010; Catrinu & Nordgård, 2011; Schuman & Brent, 2005; Sun et al., 2012; Woodhouse, 2005a). Which can make one wonder why one of these is not selected and used to select the most important lifetime impacts. There are three reasons why a new process is necessary. The first reason is that a good decision making process is a “mix and match” of different tools (Woodhouse, 2005b). So it is often not possible to select one tool that can be implemented in an organization.

Secondly, decision making involves a lot of money especially on the strategic level of Asset Life Cycle Plans (as seen in section 4.2). Not just because of the risk of losing money when the wrong decision is made, but also potentially saving millions when making the right decision (Rommert Dekker & Scarf, 1998). Making it worthwhile to pay more attention on how decisions are made.

Thirdly, according to Chopra and Sodhi there are no silver bullet strategies on deciding which risks to mitigate (Chopra & Sodhi, 2004). Meaning that every company has to have their own strategy. As explained in section 5.2.4 are lifetime impact comparable with risks, so a strategy to select lifetime impacts should also be unique.

From the above it can be concluded that to improve the decision making process at Liander, a new decision making model to categorize and prioritize lifetime impacts has to be developed. Therefore the goal state of this research is: "*a structured and transparent decision making model to select the most important lifetime impacts*".

Furthermore the above shows that the desired model should be adaptable (unique) per company. Resulting in the following requirement.

Requirement 19: The decision making process should be generalizable for various environments

6.3 What is decision making?

After determining how decisions are made and why a model is necessary, the question "What is decision making?" is answered. Decision making is selecting the best among alternatives (Sun et al., 2012). For example, choosing your favourite model when buying a new car in a showroom. Woodhouse elaborates on it by stating that decision making is doing the right things (be effective) and doing the things right (be efficient) (Woodhouse, 2005a). Of these two goals the most important contribution to success is the first; do the right things. Focussing on the other goal, doing things right, can result into doing a wrong thing 20% cheaper of more effective (Woodhouse, 2005b). Using the same example, buying your most favourite bicycle without realising you actually need a car.

6.3.1 Determining the criteria

Doing the right things depend on what the right things are, or otherwise stated it depends on certain criteria. These criteria can differ per situation and separate decision. And it is important that the right criteria are selected before a decision is made (Geary, 2002). For example, the current criteria for buying a new car would result into a small and cheap car. While in few years the criteria can change so a large station wagon is preferred.

To be able to select the right criteria the type of decisions should be identified. Decision making in ALCP or using lifetime impacts cannot be found in literature, since both topics are relatively new. However decision making in asset management is a topic on which research is executed. Sun et al identify four types of asset management decisions: "AM strategic decisions, AM technical decisions, AM implementation decisions, and reactive decisions" (Sun et al., 2012). As Asset Life Cycle Plans are strategic documents about the future of an asset, are the type of decisions also strategic decisions. Strategic decisions are: "consistent with the asset management policy and strategy, as well as the business objectives in an organization, and developing long-term AM strategic plans for deciding on each asset's operational, maintenance and capital investment policies. (…) AM strategic decisions are normally made annually, every five years, or over an even longer period." (Sun et al., 2012). From this it is deduced that the business objectives stated by the company are important criteria. Additionally, the decisions should focus on the long-term future of the asset.

The type of decision making also depends on the importance of the decision (Aqlan & Mustafa Ali, 2014). The number of lifetime impacts identified during a TECKO analysis is generally over 100. So examining all lifetime impacts thoroughly using multiple experts and statistical data to select the most important is expected to be an elaborate task demanding for lots of resources. This is not preferable or even possible, so not all the lifetime impacts can be examined thoroughly. To prevent this, Woodhouse proposes a multi-layered system in which decisions are made in different layers based on their importance (Woodhouse, 2005b). The base of the system is that only 5-10% of the decisions need quantitative assessment and analysis. The next 40-60% only need template and rule-based methods such as RCM (Reliability Centred Maintenance discussed in section 8.1.2). Finally, the lowest layer only requires a quick and crude filter. Determining to which layer a decision belongs is based on the relevance to the bigger picture of the decision. The process of dividing the decisions in different layers in which they get different amount of attention shows great similarities with the Pareto-rule. A widely accepted principle that states that 20% of the actions determine 80% of the output (Newman, 2004). From this section the following two requirements are derived:

Requirement 20: The decision making process should use the policy and strategy of the company as input
Requirement 21: The decision making process should involve multiple steps

6.3.2 Scoring the criteria

The selected criteria should also be scored to make a decision. Scoring can be done using human judgement and/or data. Using data is valuable because it shows an unbiased and undistorted image. For example, a Weibull curve provides a good and unbiased depiction of the estimated remaining lifetime of an asset population (Smit, 2011). As well as the costs of executing an action "A" are relatively easy to calculate. There are however four identified drawbacks of using data.

1. It is difficult to quantify the benefits of a decision, especially on the long term (R. Dekker, 1995).
2. Generation of reliable data is often extremely difficult, so only focussing at data can create a false sense of certainty and reality (Rommert Dekker & Scarf, 1998).
3. Using lots of data draws the focus on acquiring data, instead on decision making (Eason, 1984).
4. Using too much data can cause analysis paralysis, meaning that the decision is not made due to too much input. (Woodhouse, 2005b).

Therefore is human judgement as input for decision making vital (Catrinu & Nordgård, 2011; Rogerson & Lambert, 2012). The drawback of using humans to make decisions are elaborated on in section 6.2. So the ideally a decision is made using both principles. This leads to the new requirement.

> Requirement 22: The decision making process should use both human judgment and data.

6.4 Requirements for decision making models in Asset Management

For this study, numerous decision making models are analysed as well as literature on decision making in asset management. The result of the analysis are a list of requirements for the model. As well as design principles derived from existing decision making models which are explained in section 8.1.

6.4.1 Requirements on decision making model from science

Requirements for decision making in asset management are derived by analysing 29 different papers on decision making in asset and/or maintenance management. The result of this can be found in Table 6-1 below and a more extensive table can be found in appendix VIII which also shows the sources of the papers. The appendix also shows what paper mentions what requirement. The requirements are filtered so they are general applicable in asset management and not for a specific company or case. This ensures that the criteria can be used to create and test the decision making model to categorize and prioritize lifetime impacts. Some requirements derived from this analysis correspond to earlier mentioned requirements in this research. The ones that do not correspond have an asterisk and are copied as an actual requirement for the model.

Table 6-1: Requirements for decision making in asset management derived from 29 papers. Requirements with an asterisk are not earlier mentioned and taken into account to create the model. The sources can be found in appendix VIII.

#	Requirements for decision making in asset management
#I	A decision making model should be able to deal with multiple and conflicting criteria
#II	A decision making model requires the input of experts at the company
#III	A decision making model should be able to handle (future) uncertainties*
#IV	A decision making model should be easy to use by all users without having prior knowledge*
#V	A decision making model should be able to deal with both qualitative and quantitative information*
#VI	A decision making model should not consider every aspect of the decision, but focus on the most important
#VII	A decision making model should be transparent
#VIII	A decision making model should be able to improve over time*
#IX	Users should get similar results when using the decision making model more than once*
#X	The decision making model should be flexible since every decision is different
#XI	The decision making models should be able to select the best among alternatives

Not all requirements are immediately clear, therefore several are elaborated on. Requirement #III states that: “A decision making model should be able to handle (future) uncertainties”. When making a decision the outcome is never a 100% sure, especially not when regarding future changes. Therefore the model should show uncertainties and be able to cope with them, instead of avoiding them altogether.

Requirement #VI states that: “A decision making model should not consider every aspect of the decision, but focus on the most important”. This requirement means that when making a decision, the analysis to make the decision should not be very extensive. Instead the analysis should only focus on the relevant aspects. This is clustered with requirement 21.

Requirement #VIII states that: “A decision making model should be able to improve over time”. Meaning that after using the model the users should be able to provide feedback so the model is optimized for their use.

6.4.2 Risk based decision making

The project is about making decision about lifetime impacts, however the requirements derived are about decision making models in asset management in general. This is because literature on lifetime impacts is limited. To create a more reliable research a wider perspective is taken by looking decision making at insurance companies. These companies have to manage long term uncertain risks, which are in some ways similar to lifetime impacts[11]. An extensive analysis of the research can be found in appendix IX. The result of the analysis is that they manage risks using well structured, extensive, and automated risk management systems. Additionally cost effectiveness is an important factor of risk management. Therefore the following requirement is added.

> Requirement 23: The decision making process should take the financial impacts of the lifetime impacts into account

6.4.3 Wishes from Liander

During the previously mentioned interviews, the following question was also asked: *“What are your criteria for the model?”*. The answers to this question can be found in Table 6-2 below and are the wishes from Liander that will be used to test the applicability of the model for Liander.

It is important to realise that the wishes originate from different policy advisers and members of the management team. And the visions on ALCP, and thus on a model can differ among the stakeholders. Therefore the model does not have to (and cannot) comply with all wishes. Especially when they contradict each other. For example, wishes W6 and W10. Or when they contradict with a requirement derived from science. So the wishes are not copied as a requirement for the final model, instead they are managed separately as discussed in section 7.3.

[11] Both long term and risks are parts of the definition of lifetime impacts as stated in section 5.2.

Table 6-2: Wishes of Liander derived from the interviews by asking the question: "What are criteria for the model?".

W#	Wishes from Liander
W1	The model should be easy to use and apply
W2	The model should exclude evaluation during the TECKO analysis
W3	The model should be able to improve itself over time
W4	The model should be transparent
W5	The model should be based on facts and not on opinions
W6	The model should eliminate aspects that are not an event or trend
W7	The model should not hinder process of gathering lifetime impacts
W8	The model should extent the TECKO methodology over time
W9	The model should use the knowledge of policy advisers
W10	The model should implement scenarios
W11	The model should support decision making and not make the decisions
W12	The model should make use of multidisciplinary teams
W13	The model should focus only on the most important lifetime impacts
W14	The model should allow to make no regret decisions
W15	The model should focus only on the most important lifetime impacts

Not all wishes are clear and therefore are W11, W14 and W15 will be elaborated on. Wish W11 states that: “The model should support decision making and not make the actual decisions”. With this wish Liander means that the final decision on what is the most important is still an act of the policy adviser and/or the management team. The role of the model is to aid them in this process.

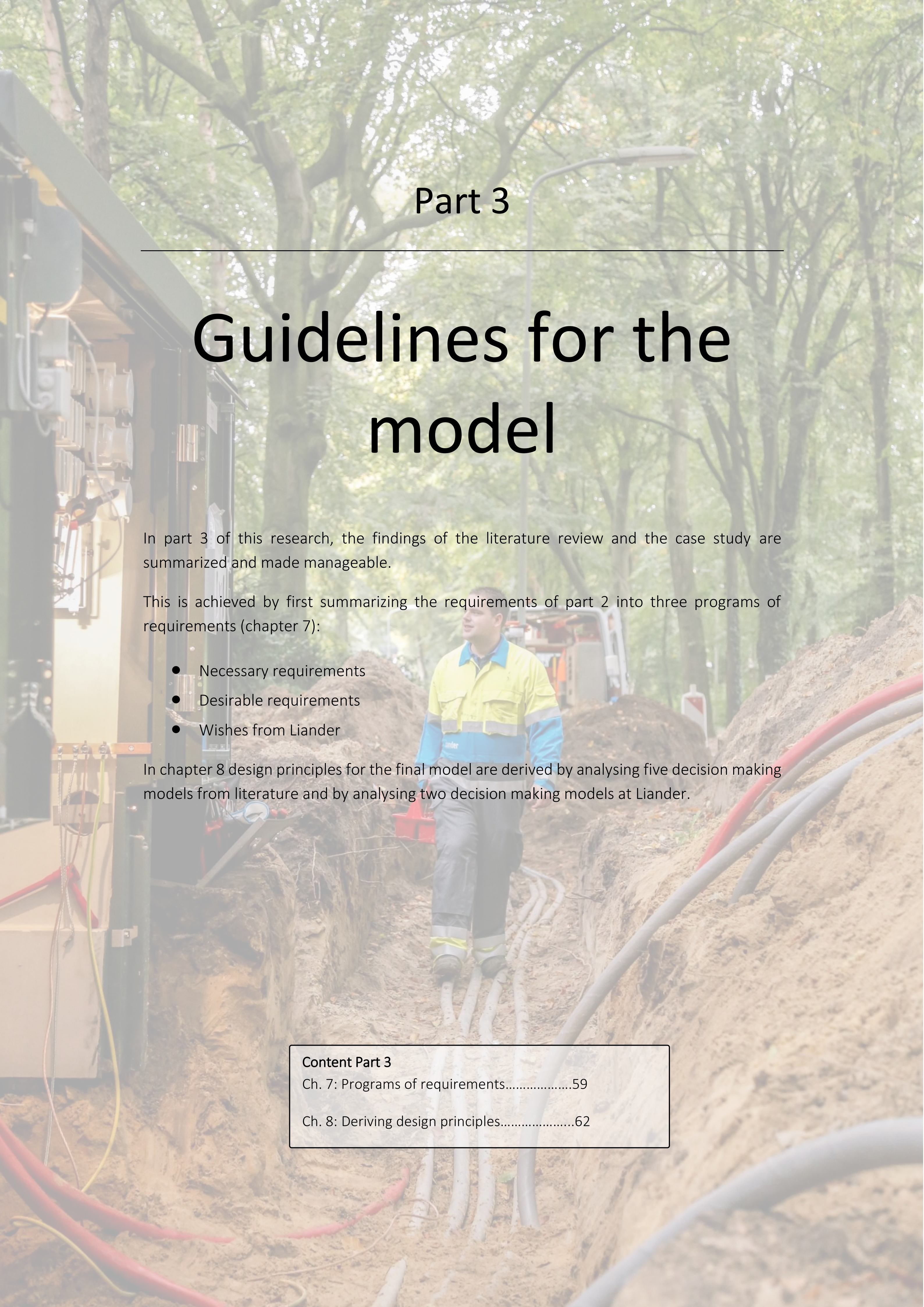
Wish W14 states: “The model should be able to assist in making no regret decisions”. At Liander a “no regret decisions” is a decision that has a positive outcome independent of the future scenario. So the wish does not mean that the model should make the decisions, but that the model can indicate which lifetime impacts will have an influence in all future scenarios.

Wish W15 states: “The model should focus only on the most important lifetime impacts”. Not all lifetime impacts are equally important, therefore the model should funnel all lifetime impacts and analyse the most important more extensive than the less important.

6.5 Conclusion

Chapter 6 first discusses the current decision making process of selecting the lifetime impacts at Liander. Hereafter it focusses on why a structured process is necessary and what this decision making process should do. The main conclusion of the part is that to improve the decision making process a new decision making model should be created. So the goal state is "a structured and transparent decision making model to select the most important lifetime impacts". This chapter also adds new requirements from analysing decision making processes. A final overview of all requirements can be found below. The requirements that are mentioned earlier in the research are eliminated from this list, but indicated in Table 6-1 with an asterisk.

Requirement 16	The decision making process should use the knowledge and experience of experts at the company
Requirement 17	Different users of the decision making process should get comparable results
Requirement 18	The decision making process should be structured and transparent
Requirement 19	The decision making process should be generalizable for various environments
Requirement 20	The decision making process should use the policy and strategy of the company as input
Requirement 21	The decision making process should involve multiple steps
Requirement 22	The decision making process should use both human judgment and data
Requirement 23	The decision making process should take the financial impacts of the lifetime impacts into account
Requirement 24	The decision making process should be able to cope with (future) uncertainties
Requirement 25	The decision making process should be usable without having prior knowledge
Requirement 26	The decision making process should be able to deal with qualitative and quantitative input
Requirement 27	The decision making process should be able to improve over time
Requirement 28	Users should get similar results when using the decision making model more than once



Part 3

Guidelines for the model

In part 3 of this research, the findings of the literature review and the case study are summarized and made manageable.

This is achieved by first summarizing the requirements of part 2 into three programs of requirements (chapter 7):

- Necessary requirements
- Desirable requirements
- Wishes from Liander

In chapter 8 design principles for the final model are derived by analysing five decision making models from literature and by analysing two decision making models at Liander.

Content Part 3

7. Programs of Requirements

Chapter 7 discusses the requirements that are derived in the previous three chapters. During these chapters 28 requirements for the model are derived. However not all of these requirements are applicable for a model that should categorize and prioritize lifetime impacts. These requirements have to be converted. For example, “Requirement 3: The decision making process should focus on the intermediate and long term” is converted to “The decision making process should be able to select intermediate and long term lifetime impacts”.

Additionally not all lifetime impacts are equally important and therefore a distinction between the lifetime impacts is made. This is done by splitting them into necessary requirements (section 7.1) and desirable requirements (section 7.2). The wishes of Liander as stated in the previous section are listed in section 7.3. The wishes that are already mentioned as a requirement are removed and the corresponding requirements are indicated with an asterisk.

All necessary and desirable requirements are derived from literature, ensuring the scientific rigour of this research. Additionally most requirements are also derived from the case study at Liander, either explicitly and implicitly mentioned in part 2.

7.1 Necessary requirements

The necessary requirements are listed in Table 7-1 below. They are split into the three categories of the research: decision making, lifetime impacts, and Asset Life Cycle Plans. Providing an overview of the origin of the requirements which makes testing and using them easier. The necessary requirements are selected because they are regarded to be the most important and concrete requirements. Furthermore, they are “must have” requirements meaning that the model must fulfil them and are therefore used to create the model.

Table 7-1: Necessary requirements and their origin in the research. Requirements with an asterisk are also a wish from Liander as identified in table 6.2.

	Decision Making
N1	The model should be able to deal with multiple and possibly conflicting criteria
N2	The model should use the knowledge and experience of experts at the company as input to make decisions*
N3	The model should be structured and transparent*
N4	The model should use multiple steps to prioritize the lifetime impacts
N5	The decision making process should be generalizable for various environments
	Lifetime Impacts
N6	The model should be able to deal with a large number of lifetime impacts
N7	The model should be able to deal with different lifetime impacts
N8	The model should be able to select the lifetime impact that influences the remaining useful lifetime of the asset population the most
N9	Different users of the model should get comparable results
	Asset Life Cycle Plans
N10	The output of the model should be strategic lifetime impacts
N11	The output of the model should be easy to use in an ALCP

7.2 Desirable requirements

The desirable requirements are listed in Table 7-2 below in a similar structure as the necessary requirements. The desirable requirements are the remaining requirements after the necessary requirements are separated. The requirements can be characterized as "should have". So the model would improve if it fulfils them, but it is not necessary. Therefore these requirements are mainly used to test the model.

Table 7-2: Desirable requirements and their origin in the research. Requirements with an asterisk are also a wish from Liander as stated in section 6.2.

	Decision Making
D1	The model should be able to cope with (future) uncertainties
D3	The model should be able to improve over time*
D4	The model should be able to deal with qualitative and quantitative lifetime impacts as input
D5	The model should be usable without having prior knowledge
D6	The model should use the policy and strategy of the company as input to make a decision
D7	The model should take the financial impact of the lifetime impacts into account to make a decision
D8	The model should use both human judgment and data to make a decision
	Lifetime Impacts
D9	The model should be able to select the intermediate and long term lifetime impacts
D10	The model should be able to deal with both threats and opportunities as input
D11	The model should exclude evaluation during the expert session*
D12	The process should be able to deal with tacit and non-tacit knowledge
	Asset Life Cycle Plans
D13	The model should be able to deal with lifetime impacts from the whole lifecycle as input
D14	The model should involve management to make a decision
D15	The model should involve different divisions to make a decision
D16	The decision making process should aid in improving ALCPs by being able to determine what is important to take into account and what not.
D17	The model should be able to provide information for multiple stakeholders

7.3 Wishes from Liander

The wishes from Liander are listed in Table 7-3 below and are derived from Table 6-2 in section 6.4.3. The wishes are regarded as "would have" requirements and are used to test the usability of the model for Liander.

Table 7-3: Remaining wishes from Liander derived during the interviews

	Wishes from Liander
W1	The model should be easy to use and apply
W2	The model should support decision making and not make the actual decisions
W3	The model should use facts to make decisions
W4	The model should be able to select events and/or trends
W5	The model should not hinder process of acquiring lifetime impacts
W6	The model should be able to provide input for new expert sessions
W7	The model should use the future scenarios and be able to make no regret decisions based on these scenarios
W8	The model should focus only on the most important lifetime impacts

7.4 Conclusion

Chapter 7 discusses the requirements for the model to categorize and prioritize lifetime impacts. These requirements are derived from the part "Theoretical background". There are a large number of requirements and wishes and not all are equally relevant. Therefore the requirements are split into three categories; necessary requirements, desirable requirements, and wishes from Liander. Each category has a different purpose in creating the model, but all categories will be used to evaluate the final model. Since all requirements are derived from both science and Liander are they a good method to evaluate the scientific and practical rigour of the model. Additionally, the wishes of Liander are evaluated and these can provide an indication of the practical relevance of the model when evaluating it.

When testing to the requirement it is important to realise that a necessary requirement is more important than a desirable requirement or a wish. So when a conflict arises the necessary requirement has the preference and hereafter the desirable requirements.

8. Deriving design principles

The theoretical background showed that it is necessary to create a model to improve the decision making process for lifetime impacts in ALCPs. To be able to create such a model, numerous existing decision making models in literature and at Liander are analysed. The purpose is to derive design principles which will help to fulfil the criteria in the previous chapter. The chapter will first discuss the design principles derived from five methods from science in section 8.1. Hereafter the design principles derived from two methods from Liander are inspected in section 8.2.

8.1 Decision making methods in science

Numerous decision making models are available in asset management literature. However not all models can be researched because not all can provide added value to this research. Therefore a shortlist is created based on the following three criteria.

1. Applicable in asset management
2. Capable to rank risks (for reasons mentioned in section 5.2.4)
3. Proven in practice and in literature

Using these criteria, several models are selected. After a quick analysis of these models a shortlist of six models remained. These are: Multi Criteria Decision Model, Reliability Centred Maintenance, Hierarchical Holographic Modelling, AHP & TOPSIS, Fuzzy logic, and Bow-Tie. The first five will be elaborated on in the following five sections and a more extensive analyses of the models can be found in appendix X. The concept of Bow-Tie is not discussed because none of these design principles are used in the final model.

The explanation shows an overview of the working principle of the model, the derived design principle, and how it is used as input for the final model. Additionally, the models have been assessed using the requirements for decision making in asset management. This showed that each model has its strengths and weaknesses and that a combination of multiple models will be necessary to create the solution.

8.1.1 Multi Criteria Decision Models

Multi Criteria Decision Models (MCDM) is a method that selects an alternative using multiple (possibly conflicting) criteria. The combination of an alternative and a criterion is called a consequence. The consequences of each alternative can subsequently be evaluated to determine the best (Brugha, 2004). The most common form of an MCDM is a matrix format (Kiker, Bridges, Varghese, Seager, & Linkov, 2005).

The design principle derived from MCDM it is a powerful tool for decision making with multiple (possibly conflicting) criteria by structuring the problem is a structured way.

This design principle has been applied to the prioritization part of the model (section 9.5), which uses multiple criteria and alternatives (lifetime impacts) to determine the priority.

8.1.2 Reliability Centred Maintenance

Reliability Centred Maintenance (RCM) is a widely used and popular maintenance concept (Ruitenburg et al., 2014). RCM deals with identification and prioritization of failure modes (Smith & Hinchcliffe, 2003). This is done using a Failure Mode and Effect Analysis (FMEA), which uses linguistic values to score a failure mode on severity, occurrence, and likelihood. The results is a Risk Priority Number (RPN) that is used to assess each failure mode and select the worst (Moubray, 1997).

The design principle from RCM is that a combination of three criteria can result in a number which allows for mutual comparison. Additionally, RCM has proven that a combination of linguistic terms and corresponding numerical values are a good method to score and compare alternatives.

RCM is used as building block to prioritize the lifetime impacts, which is also done using linguistic values with a corresponding numerical value (section 9.5.2). Furthermore the structured method that RCM proposes to identify and select the most important failure modes is used as inspiration for the outline of the model (section 9.2).

8.1.3 Hierarchical Holographic Modelling

Hierarchical Holographic Modelling (HHM) is a methodology that is used to identify and manage sources of risk in complex systems (Lambert, Haimes, Li, Schooff, & Tulsiani, 2001). The principle uses different structured steps that first identifies over a thousand risks. And hereafter different processes are used to reduce the number of risks and to select the most important (Lambert et al., 2001).

The design principle derived from HHM is that when multiple and structured steps are used, a large number of risks can be reduced and the most important can be selected.

Different aspects of HHM are used as inspiration for the model. First the filtering step in the model is based on selecting the right risks using scope and level of decision making in HMM (section 9.3). Furthermore, clustering and standardizing the lifetime impacts in the categorization step of the model are based on similar steps in HHM (section 9.4.3). Finally, the overall structure of the model is influenced by the multiple step structure of HHM (section 9.2).

8.1.4 Analytical Hierarchy Process and Technique for Order Preference by Similarity of an Ideal Solution

Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity of an Ideal Solution (TOPSIS) are two decision methods that are often combined (Chamoli, 2015; Torfi, Farahani, & Rezapour, 2010). AHP determines priorities between different criteria (Saaty, 1990). And TOPSIS is used to select the best among alternatives (Hwang & Yoon, 1981). Together they can weigh criteria and rank alternatives.

The design principle that different criteria can have a different importance and thus weighting factor is derived from AHP and TOPSIS.

This design principle has been used to prioritize the lifetime impacts (section 9.5). Different criteria can have a different importance for Liander or other company. Therefore a weighting factor is introduced.

8.1.5 Fuzzy logic

Fuzzy logic, founded by Lofti Zadeh at UC Berkeley, is a method that converts linguistic terms into fuzzy numerical values (Zadeh, 1965). This enables decision making based on vague, uncertain, and qualitative information (Evans, Lohse, & Summers, 2013). However, fuzzy logic is not a decision making method on its own. Instead it can improve other methods. For example Fuzzy FMEA (Jamshidi, Rahimi, Ait-kadi, & Ruiz, 2015), Fuzzy AHP, Fuzzy TOPSIS (Chamoli, 2015; Mokhtari, Ren, Roberts, & Wang, 2011; Torfi et al., 2010), etc.

Fuzzy logic mainly shows that a numerical value should be fuzzy to represent the vagueness of the linguistic terms.

The design principle has not been used in the model because it was not within the capabilities of the researcher to implement it. However, it is recommended that further research is conducted on it (section 13.1.2).

8.2 Decision making methods at Liander

Numerous decision making models were encountered at Liander by the researcher. Two of those models are used as building blocks for the final model. The working principle, design principles, and how these used are discussed briefly in the sections below. A more extensive review of each of the models can be found in appendix X.

8.2.1 Integrative Net Planning process

The Integrative Net Planning (INP) process is a widely known process within Asset Management to identify, evaluate, and mitigate risks at Liander. The process identifies potential risks as bottlenecks (knelpunten). The bottlenecks are classified using a risk matrix which uses the company values to determine the importance of each risk.

The design principle derived from the INP process is that a combination of the impact on the company values and certainty of impact can be used to evaluate each risk.

Because Liander is highly familiar with this process, are the company values also used to prioritize the lifetime impacts (section 9.5). Furthermore, the filtering step is influenced by the filtering step in the INP process (section 9.3).

8.2.2 Innovation funnel

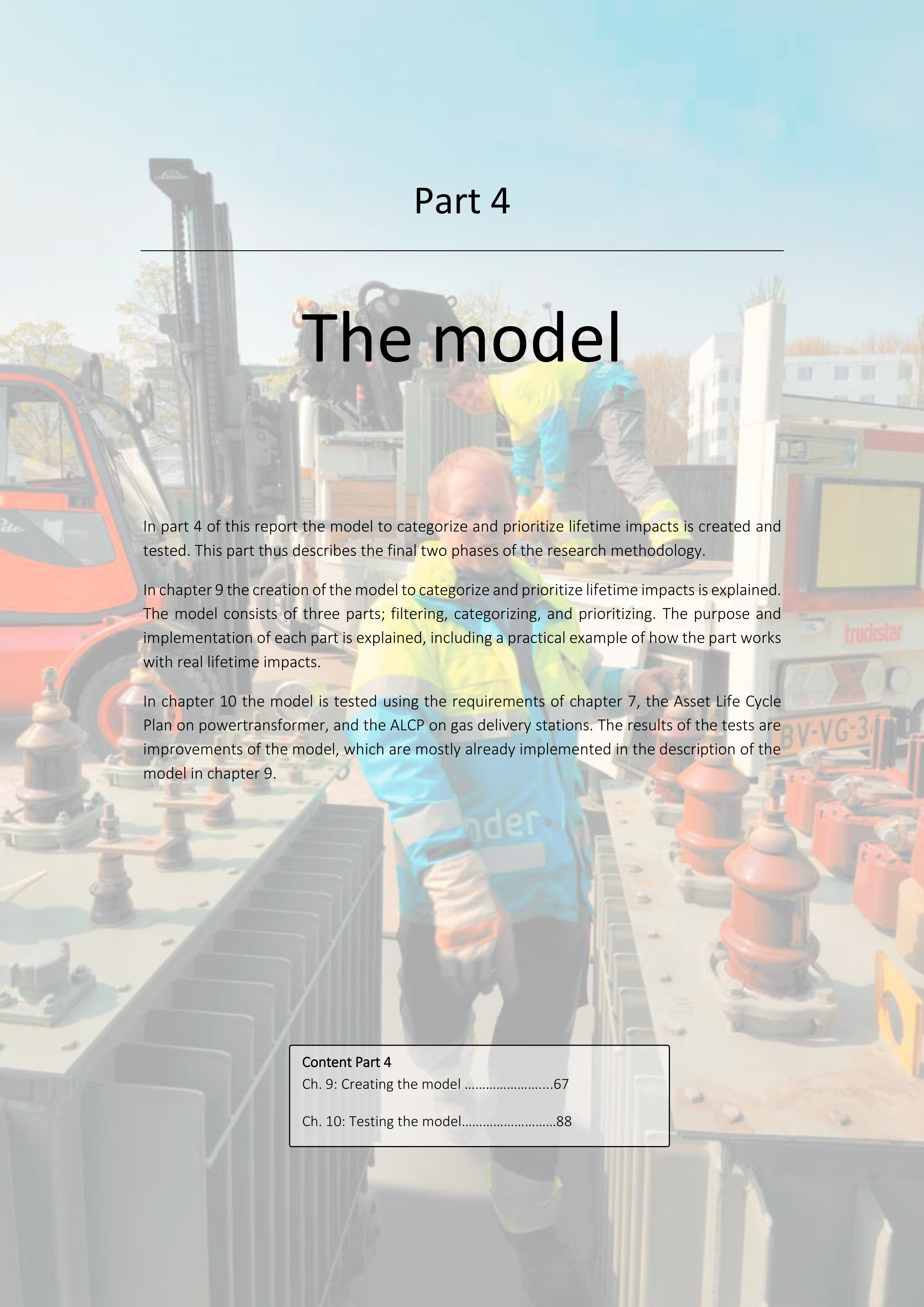
The innovation funnel is a process used to streamline the selection which idea of a large number of ideas should be developed into a practical innovation. The process consists out of five phases; idea, business case, proof of concept, development, and implementation. Each idea has to pass each phase, which is done by means of a discussion by the management team or the PIB (Project Investment Board).

The innovation funnel shows that a process with clear decision moments between different phases can streamline the process of reducing a large number of ideas.

The design principles of the innovation funnel are used to implement multiple users in when prioritizing the lifetime impacts (section 9.5.5). And to add the discussion step after all lifetime impacts are prioritized (section 9.5.6).

8.3 Conclusion

Chapter 8 shows and examines different decision making models in asset management and at Liander. The analyses shows that one specific model is not suitable to solve the problem, but instead a combination of models have to be used. Design principles are derived from different models to understand what can be used from each model. And the parts that are influenced by the principles are indicated. In the next part these design principles will be mentioned implicit and explicit to base decisions for the model to categorize and prioritize lifetime impacts.



Part 4

The model

In part 4 of this report the model to categorize and prioritize lifetime impacts is created and tested. This part thus describes the final two phases of the research methodology.

In chapter 9 the creation of the model to categorize and prioritize lifetime impacts is explained. The model consists of three parts; filtering, categorizing, and prioritizing. The purpose and implementation of each part is explained, including a practical example of how the part works with real lifetime impacts.

In chapter 10 the model is tested using the requirements of chapter 7, the Asset Life Cycle Plan on powertransformer, and the ALCP on gas delivery stations. The results of the tests are improvements of the model, which are mostly already implemented in the description of the model in chapter 9.

Content Part 4

9. Creating the model

Chapter 9 describes the actual model to categorize and prioritize lifetime impacts and shows all the considerations and decisions that have been made. The chapter starts with a description of the process how the model has been created (section 9.1). Hereafter a general description of the method is given in section 9.2. Providing an overview that can be used to understand the larger picture when discussing the details. The different details of the model are described in section 9.3 up to 9.5. Finally, in section 9.6 the model in practice is shown and discussed.

9.1 The process of creating the model

The research is based on design science and the model is also created using this methodology. The methodology implies that the artefact should be created using a cycle of testing and adjusting, as can be seen in Figure 3-1. To get a start, first a concept model is created. This has been achieved by structuring the lifetime impacts from the expert session for the ALCP on power transformers, while using the necessary requirements and the design principles as guidelines. The result is a concept model that shows the general idea and that can be discussed and adapted easily. In later stages the details are added to the model.

The concept model was first discussed with the supervisor Richard Ruitenburg. The discussion led to new ideas and improvements which were implemented in the model. Hereafter, the process repeated itself fourteen times by discussing the model with different experts and stakeholders of ALCPs at Liander and the University of Twente. After each discussion the model was optimized using their feedback. After the fourth iteration step the outline of the model (the steps filtering, categorizing, and prioritizing) was fixed. Hereafter the model was optimized by discussing smaller and larger details until the model was regarded to be finished. The discussions were with the experts and stakeholders in chronological order as seen in Table 9-1.

Table 9-1: Description of the experts that helped in creating the model

#	Description of expert or stakeholder
1	Supervisor of the project
2	Senior Consultant at Policy and Standardization & member of the management team
3	Senior Policy Adviser & Stakeholder of the ALCP project at Liander
4	Senior Policy Adviser Transformers & Creator of ALCP on powertransformers
5	Senior Netarchitect
6	Manager of Policy and Standardization Gas department
7	Senior Policy Adviser Gas & Creator of ALCP on gas delivery stations
8	Junior Policy Adviser Gas & Creator of ALCP on gas delivery stations
9	Senior Consultant Risk & Opportunities
10	Assistant professor in the chair Maintenance Engineering & Secondary supervisor of the project
11	Senior Policy Adviser Switch Gears & Creator of two ALCPs

12	Senior Consultant & Creator of ALCP on powertransformers
13	Manager of Policy and Standardization Electricity department & member of the management team
14	Manager of Policy & Standardization and member of the management team
15	Manager Strategy & Stakeholder of the ALCP project at Liander

The model discussed in this chapter is the final model after the fifteen steps and it includes the optimizations discovered during testing it (as is described in the next chapter).

The nature of the study implies that the model for Liander is never finished since it will never correspond to the opinions of all relevant stakeholders. Mainly because it involves tacit knowledge in decision making and because ALCPs are still a new type of document at Liander as described in section 4.2. Therefore the described model is the best model according to the executed literature and the case study, in the opinion of the researcher, and given the available time.

9.2 General description of the model

The function of the model is to “Make the lifetime impacts from the expert session usable for an ALCP” and is depicted in Figure 9-1. So the input of the model are non-modified lifetime impacts gathered during an expert session. These are acquired from the proceedings and other media[12] of the meeting. This decision is deliberately made because the expert session is outside the research scope and requirement D11 explicitly states that decision making during the expert session is not preferable. This decision resulted in the assumption that everything mentioned during an expert session is in some manner relevant (but not always for an ALCP).

The output of the model is a list of lifetime impacts prioritized on their importance. This list is used help creating an ALCP.

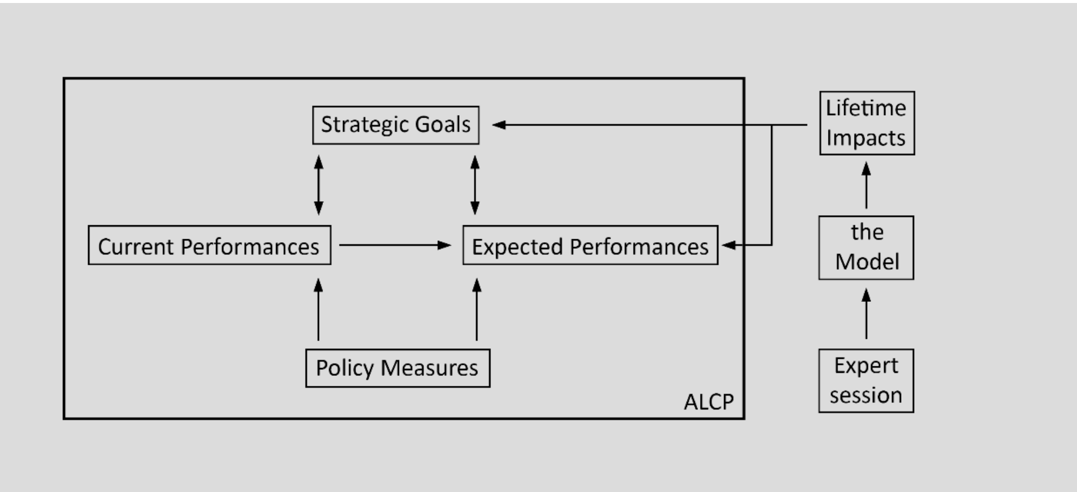


Figure 9-1: Graphical representation of the purpose and context of the model.

[12] During one of the expert sessions the attendees were asked if they would individually write lifetime impacts on Post-it notes to ensure that everybody could mention their individual impacts. It is probable that future experts meeting at different companies use different methods to gather lifetime impacts. These methods are meant with other media.

To be able to understand the total model, a general description will first be discussed briefly. This includes an overview of which and how the necessary requirements are used to create the model. The brief explanation is supported by Figure 9-2 on the next page, which is a graphical representation of the model.

The model consists out of three steps (N4):

- Step 1: Filtering the lifetime impacts
- Step 2: Categorizing the lifetime impacts
- Step 3: Prioritizing the lifetime impacts

In the first step the large number of lifetime impacts (N6) are filtered on their suitability for an ALCP. Making sure that only strategic impacts are selected for further processing (N9) and that time is not wasted on them later in a later stage.

In the second step the lifetime impacts are categorized so a structured overview of all the impacts is created (N3). The categorization step also includes clustering and removing identical impacts, and rewriting the lifetime impacts using a standard format (N7).

The final step is to prioritize the lifetime impacts on their influence on the remaining useful lifetime (N8). This will help Liander in selecting the most important lifetime impact on which the ALCP should focus on (N10). Prioritizing is done using multiple criteria and the most important lifetime impact has to be selected among many different alternatives (N11). Therefore a Multi Criteria Decision Model is used. The criteria of the MCDM are based on the company values, the certainty, and the effort (N5). Finally, all criteria are assessed by one or multiple experts on the topic of the ALCP (N2).

In the following three sections (9.3 – 9.5) each of the different steps of the model will be elaborated on. Discussing the criteria, considerations, and the implementation of the model at Liander. Each step is explained with a practical example using lifetime impacts for power transformers.

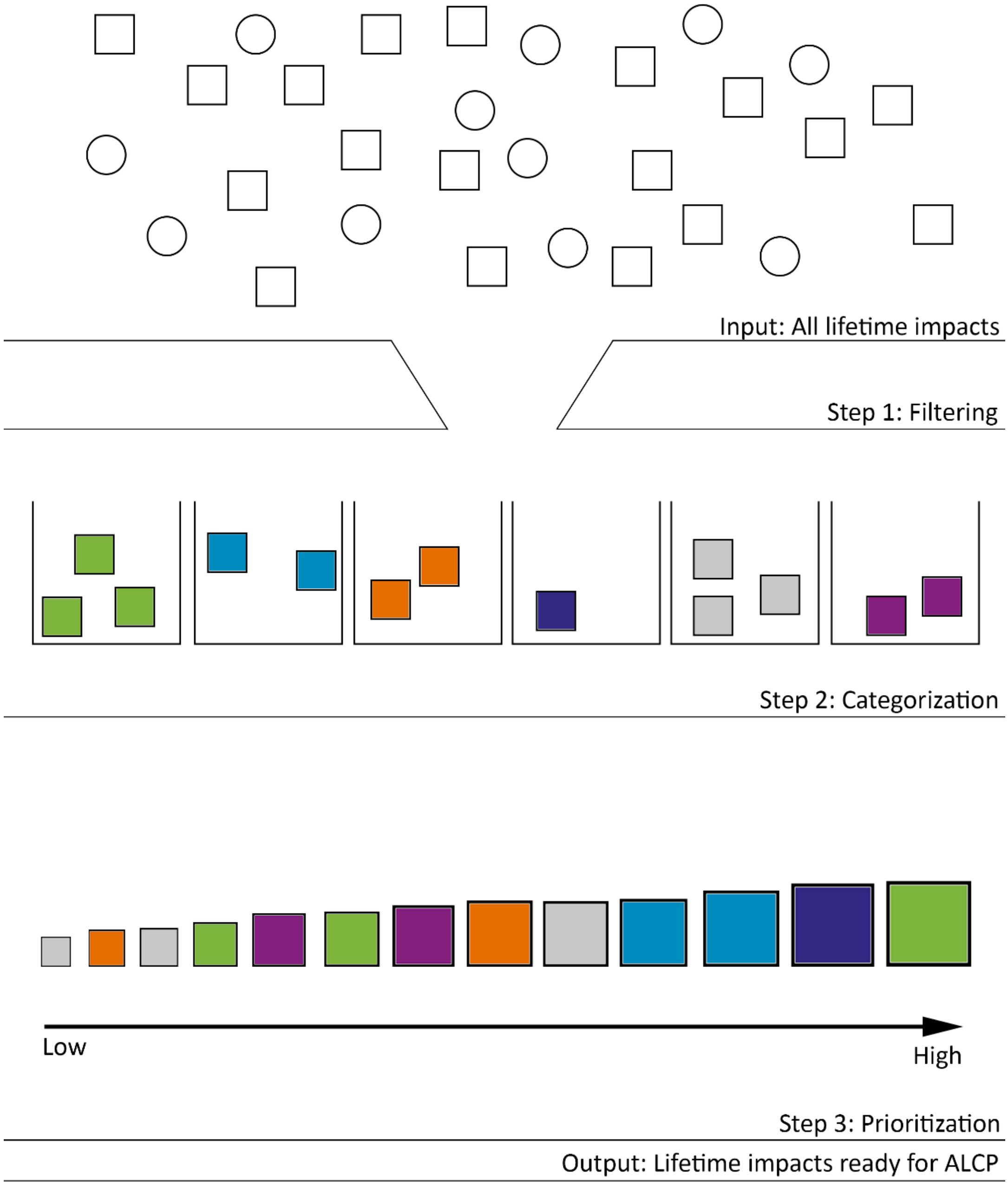


Figure 9-2: Graphical representation of the outline of the model. The unfiltered lifetime impacts are filtered, categorized, and prioritized. After this process lifetime impacts can be implemented in an ALCP.

9.3 Step 1: Filtering the lifetime impacts

The first step is to filter the proceedings of the expert session. The purpose filtering is to identify and remove impacts that are not a lifetime impact. Doing this ensures that effort and time in the two next steps of the model is not wasted on the wrong input. The step can be compared to determining the price range when buying a new car. Preventing that time and effort is wasted at determining the colour of a new Ferrari, since regardless the colour it is too expensive to buy. Do the things right instead of doing the right things (Woodhouse, 2005a).

The first step is necessary because the input of the model are raw impacts obtained during the brainstorm of the expert sessions. Not all of this input qualifies to the definition of lifetime impacts as stated in section 5.2 and therefore this step will refer to them as “input” or “impact” (without the prefix “lifetime”). To be able to select the lifetime impacts from the input it has to fulfil three criteria. These criteria are derived from the definition of lifetime impacts in section 5.2 and from the purpose of Asset Life Cycle Plans in section 4.2.1. Input that does not satisfy all three criteria will not be further processed in the model. An overview of the criteria and what to do when a lifetime impact does not qualify a criterion can be found in Table 9-2 and will be explained in more detail in the sections 9.3.1 up to 9.3.3.

Table 9-2: Criteria that are used to filter the lifetime impacts and an overview of what to do with a lifetime impact when it does not fulfil the criterion.

Criterion	Description	What to do when not fulfilled
Criterion 1	The impact should potentially influence the remaining useful lifetime of the asset population	Evaluate using a different process
Criterion 2	The impact should influence the remaining useful lifetime of the asset population in the intermediate or long term	Evaluate using the INP process
Criterion 3	The impact should be generic for the asset population	Use as input for a new expert session

9.3.1 Criterion 1: The impact should potentially influence the remaining useful lifetime of the asset population

The first criterion states that the input should influence the remaining useful lifetime of the asset population either positively or negatively. If the impact complies with this criterion it can continue to the next criterion. When the impact does not influence the remaining useful lifetime, the impact should not be disregarded immediately. Instead the user should determine if there is an underlying theme to the impact which does influence the remaining useful lifetime. If that is the case, the user should rewrite the impact in such way it does influence the remaining useful lifetime.

When the impact and underlying theme does not satisfy all criteria, it should not be processed further in the model. Instead the impact should be evaluated separately since there is a reason why it was mentioned during the expert session.

An example of this process is the impact: “The implementation department should have more responsibilities and possibilities so transformers are maintained faster and more efficient”. The impact as stated does not influence the RUL of the transformers. The overarching theme of this impact is that maintenance is not always executed efficient. This does influence the RUL of the transformers. Therefore the impact is rewritten to “Maintenance on transformers is currently executed inefficient”.

9.3.2 Criterion 2: The impact should influence the remaining useful lifetime of the asset population in the intermediate or long term

The second criterion is that an impact should influence the asset population in the intermediate or long term. There are two reasons for this, first because an ALCP focusses on the intermediate and long term. Second, short term impacts should be managed immediately. Waiting for the ALCP to finish before managing the impact, could result into substantial threats or missing great opportunities.

Impacts that influence the asset population on the short term should not be processed further in the model. Instead it should be managed using a different process. At Liander this should be the INP process discussed in section 8.2.1. The process is specialised in dealing with short term risks in a fast and effective manner. This includes a detailed planning of what risks to mitigate for the coming two years. Therefore the criterion is made more concrete for Liander by altering it in: “The impact should influence the remaining useful lifetime of the asset population in more than 2 years”. This alteration optimizes the model for Liander, but at different companies other suitable methods to handle short term impacts should be used. So the definition of short term should be determined depending on these methods. Regardless of how the short term impacts are managed, it is important for the creators of the ALCP to check if it is done properly.

9.3.3 Criterion 3: The impact should be generic for an asset population

Input from the expert sessions varies between generic impacts on the whole asset population, to specific impacts about the failure of an individual asset. However, an ALCP is a strategic document so impacts that influence an individual asset should not be included and not be processed further in the model.

It is important to acknowledge that a trend starts with a single incident. Therefore the eliminated impacts should be monitored regularly. This provides a company the possibility to spot and manage trends in an early stage. To be able to do this, the impacts that do not satisfy criterion 3 should be used as input for the next expert session.

9.3.4 Explanation by example

Table 9-3 below shows 12 impacts for power transformers. Using the three criteria, it appeared that impact 4, 6, and 10 are filtered.

Impact 4 is about an individual asset, in this case one in Apeldoorn, and does therefore not satisfy criterion 3. It is however possible to inspect if more backup power transformers are of poor quality and a trend can be identified.

Impact 6 mentions that the number of reserve power transformers is low. This impact currently influences the remaining useful lifetime of the asset and does therefore not satisfy criterion 2. So the impact should be managed using the INP process, the creator of the ALCP should inspect if the problem is solved after this.

Impact 10 is a statement that the condition of the power transformers can be determined using a risk score calculated by the probability and the impact of failure. This statement does not influence the remaining useful lifetime of power transformers. Additionally no overarching theme can be identified that does influence the remaining useful lifetime and therefore lifetime impact 10 is not processed further.

Table 9-3: Testing 12 impacts from the ALCP on power transformers to the three criteria of filtering. Impact 4, 6 and 10 are eliminated.

#	Description of the Lifetime Impact	#1	#2	#3
1	Secure data	✓	✓	✓
2	Extending outage information; professionalize central condition and outage registration	✓	✓	✓
3	Outages and revisions are increasing	✓	✓	✓
4	Backup power transformer in Apeldoorn is of lower quality	✓	✓	X
5	Procurement becomes more global, positive effect on EU-prices	✓	✓	✓
6	The number of reserve transformers is sometimes insufficient	✓	X	✓
7	Replacement wave?	✓	✓	✓
8	Conducting data analyses	✓	✓	✓
9	The introduction of 20kV as the new standard voltage demands a new standard transformer	✓	✓	✓
10	Condition --> probability of failure x impact = risk score	X	✓	✓
11	Reactive replacement of a failed transformers implies a 24/7 standby crew, which will not work on the long term. Exceeding the maximum working hours laws (which already happens)	✓	✓	✓
12	Joint procurement of power-transformers in the Netherlands. Equal to the distribution-transformers. Realising this is difficult because we have a different tendering process.	✓	✓	✓

9.3.5 Conclusion

The first step filters impacts that should not be included in an Asset Life Cycle Plan using three criteria. The impacts that do not satisfy all three criteria should be managed differently, depending on the criteria they fail to satisfy. From now on the remaining impacts can be regarded as lifetime impacts.

9.4 Step 2: Categorizing the lifetime impacts

The second step of the model is to categorize the lifetime impacts. This step has two purposes:

1. Remove double and cluster similar lifetime impacts
2. Ensure that lifetime impacts are prioritized from the same perspective

An analysis of different expert sessions showed that a large number of similar lifetime impacts are obtained. These should be clustered and removed. It is however difficult to remember a large number (100+) of lifetime impacts, while determining which lifetime impacts can be clustered and which not. This is explainable because humans can remember 7 (+/- 2) chunks of information (Miller, 1956). By categorizing the lifetime impacts in six categories, similar ones can be spotted more easily per category, making clustering easier to execute.

The second reason for clustering is that it is necessary for the experts to view the lifetime impacts from the same perspective when prioritizing them. By categorizing a lifetime impact in a certain category, different experts are forced to view the lifetime impact from the same perspective. For example a lifetime impacts for a car can be "increased tax for diesel fuelled cars". This can be a threat for a current car. On the other hand, it can be can be regarded as an opportunity to buy a petrol fuelled car. But when placed in the category "current threats" it is clear what the purpose of this lifetime impact is.

An additional benefit of categorization is that is aids in analysing the results from prioritization. The prioritized list itself shows which lifetime impacts are most important. Dividing them in categories shows which lifetime impacts are the most important per category, providing additional insight.

The final categorization model can be found in Figure 9-3 and is evaluated by first discussing the criteria to categorize the lifetime impacts (section 9.4.1). Hereafter the categorization itself is explained in section 9.4.2. And the process of removing double lifetime impacts is discussed 9.4.3. This section finalizes with a practical example that shows the implementation of categorization.

9.4.1 Determining the criteria to categorize

There are three criteria to determine the categories for the lifetime impacts.

- A category should provide added value so additional insight to the results of prioritization is gained
- A category should cause little to no discussion so the step is easy to execute and the result is unambiguous
- A category should be a Boolean[13] category and not a continuous scale,. This means that a lifetime impacts is either in category A or in category B and not partly in both.

[13] A Boolean data type is a data type that has two values, it is either true or false. So for this method it is referred to as a category that is either one or the other, or otherwise stated categories that are mutually exclusive (Boole, 1847).

Figure 9-3: The categorization model consisting of three categories. Each lifetime impact should be categorized in one of the six categories by first determining the lifecycle phase (horizontal axis) and then if it is a threat of opportunity (vertical axis).

9.4.2 Determining the categories

Using the criteria above, the categorization model which can be found in Figure 9-3 is created. The categories are derived from lifetime impacts, Asset Life Cycle Plans, and Asset Life Cycle Management.

Lifecycle phases

ALCPs and ALCM both advocate that an asset should be managed by looking at their whole lifecycle, which can also be found in requirement D13. And depending on the phase of a lifecycle (design, use, and disposal), a different method to manage a lifetime impact could be necessary. For example, research has shown that a major part of the lifecycle costs are determined in the design and development phase. So impacts that are stated here can be of higher importance (Blanchard & Fabrycky, 2010). When testing the lifecycle phases as a category to the three criteria it can thus be concluded that they provide added value. Furthermore they are clearly defined and the three phases are Boolean. Therefore the three lifecycle phases are selected as a category.

There is however one problem because Liander does not design new assets, but only procures and installs them. Therefore the phases cannot be copied one to one, but are slightly changed. The new categories are:

- New assets; lifetime impacts that mainly influences assets that are not yet in use (future assets)
- Installed base; lifetime impacts that mainly influences assets that are currently in use or in reserve

- Decommissioned asset; lifetime impacts that mainly influences assets that are not used anymore and that are not planned to be used again

Despite the clear definition between the three phases, it is still possible that a lifetime impact influences an asset in more than one phase. When this is the case, the user should determine in which phase the largest effect takes place. And in the case it is not possible to pick one phase, the lifetime impacts can return in multiple phases. This can also provide additional insight in the lifetime impact. For example, the increased speed limit on highways can influence both a persons' current car, as well as his selection for a new car.

Threat and opportunity
The second category is based on the definition of lifetime impacts in section 5.2. From this definition four options to categorize can be derived:

1. Probability
2. TECKO
3. Threat or opportunity
4. Intermediate or long term

Testing each option to the three stated criteria results that categorization by threat or opportunity is the only suitable option. The first option, "categorization by probability" is not suitable because probability is a continuous scale so the values are not mutually exclusive. "Categorization by TECKO" is also not suitable because a lifetime impact almost always influences more than one TECKO category. This was discovered after an attempt to allocate a lifetime impact to a certain TECKO category using an Ishikawa diagram[14]. The fourth option, "categorization using intermediate or long term" provides added value because it shows when the lifetime impact will have an impact and additionally it is a distinct category. However, discussions with different people at Liander showed that the interpretation of short, intermediate, and long term varies a lot. A quick survey using six stakeholders provided six different numerical interpretations for short, medium, and long term. So it is assumable that different users would use different criteria to categorize the lifetime impacts, which is not desirable.

The third option, "categorization by threat or opportunity" uses distinct (Boolean) categories since a lifetime impact is either a threat or an opportunity. It is assumed to cause little to no discussion. And it does provide additional insight into all lifetime impacts. Therefore this category is chosen as the second category for categorization.

Process
To determine the category of a lifetime impact, first the lifecycle phase should be determined and then if it is a threat or an opportunity. This order is important because a lifetime impact can be a threat for new assets but an opportunity for the installed base, and vice versa.

[14] Ishikawa diagram, better known as a fishbone diagram. These are normally used to determine the cause of a certain event. For this research the event was one of the six company values of Liander, and the causes were the lifetime impacts combined per TECKO category. By doing this is was discovered that a lifetime impact returned multiple times in different TECKO categories.

9.4.3 Standardizing lifetime impacts

One of the two purposes of categorisation is to cluster lifetime impacts per category. When doing this the lifetime impacts will most likely need to be rewritten. This provides the opportunity to standardize the format of a lifetime impact. The added value of doing this, is that it will help in interpreting the lifetime impact similarly by different people. Which is necessary because the next step prioritizes lifetime impacts using multiple persons.

Standardizing is accomplished by describing the cause and the effect of the lifetime impact. The cause is relative easy to describe, but the effect should be stated with caution by stating the effect for only the asset population and not for the whole network. Additionally, the effect should be listed as a generic effect and not specific. For example, the effect should not only focus on the financial impact.

9.4.4 Explanation by example

In Table 9-4 the remaining lifetime impacts from the previous section are categorized in one of the six categories as indicated in Figure 9-3. And in Table 9-5 the lifetime impacts are clustered and rewrtitten into four lifetime impacts.

Table 9-4: Categorizing the remaining lifetime impacts in one of the six categories.

#	Description of the Lifetime Impact	Category 1	Category 2
1	Secure data	Installed base	Opportunity
2	Extending outage information; professionalize central condition and outage registration	Installed base	Opportunity
3	Outages and revisions are increasing	Installed base	Threat
4	Procurement becomes more global, positive effect on EU-prices	New assets	Opportunity
5	Replacement wave?	Installed base	Threat
6	Conducting data analyses	Installed base	Opportunity
7	The introduction of 20kV as the new standard voltage demands a new standard transformer	New assets	Threat
8	Reactive replacement of a failed transformers implies a 24/7 stand-by crew, which will not work on the long term. Exceeding the maximum working hours laws (which already happens)	Installed base	Threat
9	Joint procurement of power-transformers in the Netherlands. Equal to the distribution-transformers. Realising this is difficult because we have a different tendering process.	New assets	Opportunity

Table 9-5: The remaining lifetime impacts clustered together to four lifetime impacts. The third column shows the origin of the lifetime impact in Table 9-4.

#	Lifetime Impact	Origin
1	By increasing data collection and improving the analysis of the data, the performance of the transformers can better be determined. Reducing the number of failures and making maintenance more effective.	1, 2, 6
2	The capacity and knowledge of maintenance teams has to increase, due to the increasing number of failures and revisions, and because manufacturers quit providing support.	3, 5, 7
3	The introduction of 20kV as the new standard voltage demands a new standard transformer	7
4	The procurement costs of power transformers can decrease because of cluster-, global-, and collective procurement.	4, 9

9.4.5 Conclusion

The second step categorizes lifetime impacts into one of six categories. This is done by first determining the lifecycle phase it has an impact in, and hereafter if the lifetime impact is a threat or an opportunity. After categorization the lifetime impacts can be clustered, providing the opportunity to standardize them by stating the cause and the effect of each lifetime impact. The result of the categorization step is a much shorter list of lifetime impacts which could already be used in an ALCP. To structure the ALCP and to focus on the most important lifetime impacts, the lifetime impacts will be prioritized in the following step.

9.5 Step 3: Prioritizing the lifetime impacts

The third and final step of the model is to prioritize the lifetime impacts. The reason for this step is that not all lifetime impacts can be inserted in an ALCP and not all lifetime impacts are equally important. The prioritization should score different lifetime impacts (alternatives) based on multiple criteria. Implying that a Multi Criteria Decision Model (MCDM) should be used. This section discusses the creation of this MCDM.

The design science methodology implies that a structured method should be used to create the artefact, and therefore the approach as proposed by Brugha will be used (Brugha, 2004). According to Brugha the most important aspect of a MCDM are the criteria, these will be obtained in section 9.5.1. Hereafter the method of scoring the criteria is discussed in 9.5.2, as well as the proposed numerical values in 9.5.3. The section closes with continuing the practical example and a conclusion.

9.5.1 Determining the criteria to prioritize

Brugha proposes the use of a decision tree to obtain the right criteria for the MCDM. The decision tree used for this model can be found in Figure 9-4. The tree consists of three stages, stage 1 the main questions, stage 2 the sub-questions, and stage 3 criteria to answers the sub-questions. The subdivision of the criteria (stage 4) will be explained later on.

The tree is constructed in such a way that each stage supports the previous stage. So scoring the criteria in stage 3 answers the sub-questions. And by answering the sub-questions the main question is answered. Meaning that selecting the criteria in stage 3 indirectly answers the main question. Therefore should these criteria be selected carefully, be understandable, and should have a relation with the topic of the decision tree. In this case lifetime impacts. Selecting the right criteria is done by filling in the decision tree from left to right, so first the main question will be determined.

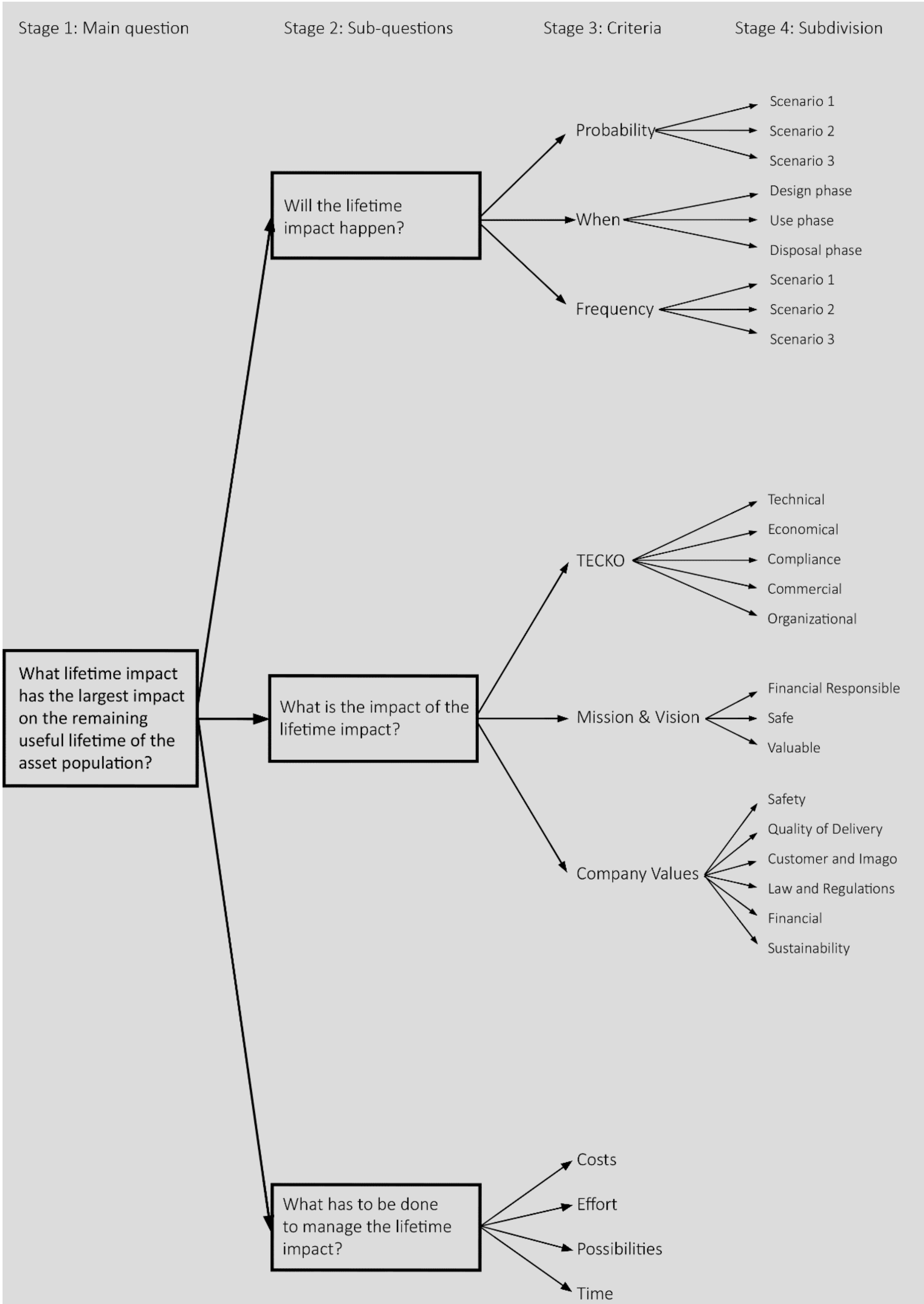


Figure 9-4: Decision tree used to create the MCDM to prioritize the lifetime impacts.

Main question: What lifetime impact has the largest influence on the RUL of the asset population
The main question in the decision tree is "What lifetime impact has the largest influence on the remaining useful lifetime of the asset population?", as is deduced from requirement N8. The main question is determined because the lifetime impact that has the largest influence on the RUL is regarded to most important (elaborated on in section 5.2.6).

The sub-questions are: "Will the lifetime impact happen?", "What is the impact of the lifetime impact?", and "What has to be done to manage the lifetime impact?". To answer these questions, ten criteria are selected (stage 4). However, using ten criteria to prioritize the lifetime impacts would demand for too much analysis. Therefore the most suitable criterion per sub-question is selected in the rest of this section. Doing this ensures that the main question is answered using a wide perspective while effort to use the model is reduced.

Sub-question 1: Will the lifetime impact happen?
The first sub-question can be answered using the criteria "certainty", "when", or "frequency". The criterion "when" is already used for categorization and will therefore not be used for prioritization. The criterion "frequency" is used by the INP process at Liander and is therefore a proven criterion. However, lifetime impacts are per definition future events and frequency is mostly determined by historical data. Still one could argue that the future frequency of a lifetime impact can be estimated. The final reason not to use frequency, is that some lifetime impacts occur only once, but still have a large influence. For example, the energy transition occurs only once so it would score low, but its impact is enormous.

The last possible criterion is probability. This criterion is often used in RCM/FMEA where the RPN score is calculated using probability, severity and detection (Moubray, 1997). So the criterion has proven itself and can be assumed that it is usable. Furthermore, scoring future events on their probability is regarded to provide additional insight on the importance of a lifetime impact. For example, scoring the probability the energy transition will have an impact on the asset population is a good indication of its importance.

The problem when using probability is that the lifetime impacts are by definition uncertain. On top of that is the future of the energy landscape highly uncertain as well (as stated in section 1.1). Therefore the criterion is further subdivided into scenarios, as can be seen in stage 4 of the decision tree. Research on scenario based strategy showed that uncertainty is reduced when using multiple scenarios (Linneman & Klein, 1985). So by added scenarios to the model, uncertainty is reducing. Implementing scenarios in the decision model means that scenarios should be available at the company and that they should cover the total future prospect. This is the case at Liander, but should be inspected when the model is implemented at different companies. Taking the above into account, the criterion is states as: "What is the probability the lifetime impact will happen in a specific future scenario?"

Sub-question 2: What is the impact of the lifetime impact?
The second sub-question asks for criteria to determine the actual impact of the lifetime impact. This can be done using three different criteria, impact on: "TECKO areas", "company values", or "mission and vision". All three criteria show a holistic and multidisciplinary overview of the impact so to be able to select one a closer look is taken at them. Firstly, the literature review showed that strategic asset management decisions should be in

correspondence with the company values (section 6.3.1) (Sun et al., 2012). Secondly, the five TECKO areas are already used to generate lifetime impacts. And thirdly, the mission and vision of a company is often a vague and abstract concept as can be seen in stage 4 of the decision tree, which shows the mission and vision of Alliander. These three findings led to the decision to use the company values as criterion. For Liander these are the ones mentioned depicted in appendix III and shown in stage 4. An additional benefit for Liander is that the company values are also used in the INP process and the users are thus familiar with using them to score alternatives. So the criterion is: "What is the impact of the lifetime impact on a specific company value?"

Sub-question 3: What has to be done to manage the lifetime impact?
The final sub-question deals with the effort to change a lifetime impact. If there are limited possibilities the effect on the lifetime impact will be larger than when there are a lot of possibilities. For example, a risk that needs 1000 FTE to mitigate has a higher priority than one that only needs 10 FTE to mitigate.

Numerous criteria can be used to determine the effort. However, for all possible criteria it is necessary to think about possible solutions. This is not desirable, because determining possible solutions for all lifetime impacts would significantly increase the time to use the MCDM. Additionally, creating solutions is beyond the scope of the model. After consultation with different policy advisers it was concluded that the effort can be estimated, but only as a rough estimation of the necessary costs. This is possible because policy advisers often take an estimation of the financial effect into account when making decisions in their daily activities. Therefore this criterion is stated as: "How much does it costs to mitigate the risk?" Or in case of an opportunity: "How much does it cost to benefit from the opportunity?". In both cases increased costs will have a negative effect on the RUL of the asset population.

It can be noticed that one of the company values is also financial impact. This is however the financial impact if nothing is done to prevent the lifetime impact. Whereas criterion 3 determines the financial consequences to prevent the lifetime impact. This does mean that financial impact plays a large role in prioritizing the lifetime impacts. However, literature states from multiple perspectives that finance is important in decision making in asset management (for example section 4.1, 4.2, 6.2.1, and 6.3.2).

9.5.2 Scoring the criteria

The next step in creating the MCDM is to determine the categories by which the criteria can be scored. The different categories should be measurable and meaningful to the decision maker (Brugha, 2004). Furthermore linguistic variables are selected, because experts are familiar with using them in the INP process, because it increases the usability and the reliability of decision making (Torfi et al., 2010), and it allows experts to reduce the uncertainty when making a decision (Evans et al., 2013). An example of this are the linguistic values used for the RPN (Bowles & Peláez, 1995). An overview of the resulting categories can be found in Table 9-6.

Table 9-6: The linguistic terms and their corresponding values of the criteria.

Certainty	Impact	Score	Effort	Score
Extremely unlikely	Very low	1	<500.000	1
Remote	Low	3	500K-5M	6
Occasional	Moderate	6	5M+	15
Reasonably	High	10		
Frequent	Very high	15		

Scoring probability

First the categories to score the probability of "What is the probability the lifetime impact will happen in a specific future scenario?" are determined. Looking at similar decision making models for inspirational purpose, the probability in determining the RPN score for FMEAs is selected. The categories for the RPN are: extremely unlikely, remote, occasional, reasonably, and frequent (Moubray, 1997)[15]. These values are usable for scoring lifetime impacts in the MCDM. Additionally the values have proven themselves to be suitable in practice in a similar situation. Therefore are these five categories selected to score the criteria "probability".

Scoring impact

Secondly, the categories to determine the impact on the company value are determined. For inspirational purposes a closer look at the risk matrix at Liander is taken. This matrix divided the effects of every company value into five categories; small, moderate, severe, serious and catastrophic. These are proven categories and could be usable. However, these categories only focus on threats while lifetime impacts are both threats and opportunities. And an opportunity with a catastrophic effect is illogic. Therefore a different division into five general effect indications is searched and found in the area of statistics. According to Hopkins there are six categories to determine the magnitude of a relationship; insubstantial, small, moderate, high, very high, and distinct (Hopkins, 1997). A distinct effect is not possible for a lifetime impact, leaving the first five categories. To optimize the model for Liander, the five categories can be substantiated with the description of the five categories used in the INP process, as is stated in appendix XI. In this case, the description for an opportunity should be read as what the lifetime impact can prevent. For example, preventing 10.000 SAIDI (SVBM) is an insubstantial impact.

Scoring effort

The final criteria is effort and is scored as a rough estimation using monetary values (see previous section). To do this a robust three step logarithmic scale is used. The numbers are based on the maximum costs of an investment proposal without having to be revised by the CEO of Liander, which is €500.000,- as a minimum value. The other scores are thus financial consequence of between €500.000,- and €5.000.000,- and more then €5.000.000,-. It is possible to use the same scale for all ALCPs because the replacement values of the different

[15] The definition of these categories are as follows: Extremely Unlikely (Virtually impossible the lifetime impact will occur); Remote (relatively possible that the lifetime impact will occur); Occasional (possible that the lifetime impact will occur); reasonably Possible (reasonably possible that the lifetime impact will occur failures); Frequent (lifetime impact is almost inevitable). These definition are derived from the definition of the RPN (Moubray, 1997).

asset populations at Liander is in the same order of magnitude. When implementing the model at different companies the monetary values might be different.

9.5.3 Determining the numerical values

To be able to compare the lifetime impacts, the linguistic criteria should have a numerical value as seen at determining the RPN. The selected values can be found in Table 9-6. The values are based on a scale where all categories are within the same order of magnitude. This is preferable in risk assessment when occurrence can be regarded as a percentage (certainty) and not as a frequency (occurrence) (Duijm, 2015)[16]. The other numerical values will therefore also be within one order of magnitude, otherwise the values would have a disproportional effect.

A method that uses scores within one order of magnitude is the RPN score, which uses steps of 1 per category. There are however two disadvantages to this scale. The first is that the number would result in a distorted risk matrix, as can be seen in Table 9-7. In this risk matrix the lower bound (green numbers) are spread across the table, instead of being gathered in the lower left corner. This is essential when developing a risk matrix (Duijm, 2015)[17]. Secondly, a sensitivity analysis showed that when using these numbers there are only 13 different totals as a final result (how the result is calculated can be seen in the next section). Resulting that the final scores of the lifetime impact are often similar. To solve both problems, the increasing sequence in Table 9-6 is selected between many different other sequences using trial and error and this sequence provided the best results. This is because the upper and lower bounds of the resulting risk matrix (Table 9-7) complies to the criteria stated by Duijm (Duijm, 2015). Secondly, using these numbers provides 28 different results, a substantial increase compared to the previously mentioned 13.

Table 9-7: Two risk matrices using two different sequences of numbers. The left matrix is not desirable because of the distribution of the "least important risks" in the lower left corner. The right matrix has a distribution as prescirbed by (Duijm, 2015) *and therefore is that sequence of number preferable.*

	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

	1	3	6	10	15
15	15	45	90	150	225
10	10	30	60	100	150
6	6	18	36	60	90
3	3	9	18	30	45
1	1	3	6	10	15

9.5.4 Determining the result of the model

This section discusses how the results of the MCDM model are shown. When doing this it is important to realize that there are two types of stakeholders of the model. Management, who desires a short and summarized result. And policy advisers, who desire an overview of all lifetime impacts that can be used to create the ALCP and to write a key message as explained in section 4.2.4. The overview is already obtained by consciously filling in the model. However, additional insight can be gained by depicting the right results for the right stakeholder.

[16] When using frequency a logarithmic scale is preferable
[17] Why this is important will be explained in the next section.

When looking in literature for inspiration on how to divide a result into two, a closer look at Impact Assessment Methods (IAM) and in special at the ReCiPe methodology is taken (Owsianiak, Laurent, Bjørn, & Hauschild, 2014)[18]. This methodology shows output for two types of stakeholders. Experts and users of the model on one hand and people who are only interested in the final result on the other hand. To be able to communicate with both stakeholders the method shows two types of results. Midpoints that provide useful background information and endpoints that show the final result. Important in the method is that the conclusion that can be drawn from the midpoints and the endpoints is identical to each other (Owsianiak et al., 2014). A similar structure can be used for the MCDM. Here the answers on the sub-questions in Figure 9-4 can be regarded as midpoints. Whereas the answer to the main question is the end point. Customizing the result to the desires of the different stakeholders.

Answering the first sub-question
The answer of the first sub-question is the total certainty, which is calculated using the following formula:

$$Total\ certainty\ (C) = \frac{\sum_{n=1}^{x}(CS_n * CW_n)}{\sum_{n=1}^{x}(CW_n)}$$

Where:

$\mathrm{n} = \mathrm{scenario}$
$\mathrm{x} = \mathrm{total\ number\ of\ scenarios}$
$\mathrm{CS_n} = \mathrm{the\ certainty\ of\ the\ lifetime\ impact\ in\ scenario\ n}$
$\mathrm{CW_n} = \mathrm{the\ weighting\ factor\ of\ scenario\ n}$

The total certainty is thus the average certainty, including a weighting factor. The weighting factor can be used to compensate for more plausible scenarios opposed to less plausible scenarios, derived from AHP (section 8.1.4). It is important that the weighting factor per scenario should be similar over all ALCPs to be able to compare the results with each other. Finally, the total certainty is normalized by dividing it with the sum of the weighting factors. The result is called “Total certainty = C”

Answering the second sub-question
The answer of the second sub-question is calculated by taking the average of the highest two impacts of the company values. This calculation is based on a combination of two principles, risk matrices and taking the average. A risk matrix only takes the highest impact of all company values into account. This has a major disadvantage, because there is no difference between a lifetime impact that scores maximum on all company values and a lifetime impact that scores maximum on only one company value (Duijm, 2015). On the other hand, averaging takes all lifetime impacts into account and thus prevents the previous situation. A disadvantage is when a lifetime impact scores high on only one impact. Then the total impact is negligible since it is averaged out. So by taking the average of the maximum two impacts, both disadvantages are overcome. Resulting that a reliable total impact can be calculated, called “Total impact = I”.

[18] IAMs are mostly known for their appliance in environmental Lifecycle Analyses. And the ReCiPe is a specific methods to conduct a Lifecycle Analysis.

Since all company values are considered to be equally important, there is no weighting factor included.

Answering the third sub-question
The third question only has one answer and will therefore be copied one to one as an end result, called “Total effort = E”.

So the result (midpoints) for the policy advisers is an overview of the total certainty, total impact, and total effort.

Answering the main question
The result for management summarizes the separate results a risk matrix category and a Lifetime Impact Priority Number (LIPN). The risk matrix category is calculated by multiplying the total certainty with the maximum impact value, as is usual with risk matrices (Duijm, 2015). The value is added because the management team is highly familiar with this principle. Furthermore it will only be calculated for lifetime impacts that are a threat, because it would be illogic to score an opportunity with a risk value.

The second result for management is the Lifetime Impact Priority Number (LIPN) and is calculated by the following formula:

$$LIPN = \frac{C * CW + I * IW + E * EW}{CW + IW + EW}$$

Where:

$\mathrm{C} = \text{Total certainty}$
$\mathrm{CW} = \text{Weighting factor of certainty}$
$\mathrm{I} = \text{Total Impact}$
$\mathrm{IW} = \text{Weighting factor of impact}$
$\mathrm{E} = \text{Total effort}$
$\mathrm{EW} = \text{Weighting factor of effort}$

So the LIPN is the sum of the three sub-questions, each multiplied with an individual weighting factor. The weighting factor is included to optimize the model when the company believes that one of the three categories is more important than the other. To be able to compare different ALCPs should the weighting factors be similar and is the LIPN standardized by dividing with the sum of the weighting factors. Finally, the LIPN is constructed such that a higher value mean that the lifetime impact is more important.

9.5.5 Implementing multiple users

To increase the reliability, the model should be used by multiple stakeholders as is discussed in section 4.2.4. The different stakeholders should be experts with a different background on the topic of the ALCP, creating a reliable and holistic image. Furthermore, at least one member of the management team should use the model. This will provide an additional perspective on the subject, as well as it will help in getting support from the management team for the results of the model (Ratcliffe, 2000). This can also be seen in the innovation funnel discussed in section 8.2.2.

9.5.6 Discussing the result

The final result of the model is an indication of the most important lifetime impacts. When testing the model it showed that different users still have a (slightly) different priority list (this will be discussed in section 10.3.3). However, the model makes the process that leads to the decision transparent, enabling that the different priority lists can be compared with each other. And a discussion can explain why the opinions of the stakeholders are different. So the final step in prioritizing the lifetime impacts is a discussion on the different priority lists of the different stakeholders.

9.5.7 Explanation by example

To get a better understanding of the model described above, the practical example is further developed by prioritizing the four remaining lifetime impacts. This process can be seen in tables 9-8 up to 9-11 below. The values for certainty, impact, and effort are the values as scored by an actual user of the ALCP on powertransformers. It can be noticed that the certainty depends on just one scenario. This is due to the fact that there were no usable scenarios for electricity (yet).

From the prioritization it can be concluded that lifetime impact #3 is the highest threat and lifetime impact #1 is the highest opportunity. But the LIPN scores of lifetime impact 2 and 3 are rather similar, so the discussion step should determine if one is actually more important than the other.

Table 9-8: The remaining lifetime impacts that will be prioritized.

#	Lifetime Impact
1	By increasing data collection and improving the analysis of the data, the performance of the transformers can better be determined. Reducing the number of failures and making maintenance more effective.
2	The capacity and knowledge of maintenance teams has to increase, due to the increasing number of failures and revisions, and because manufacturers quit providing support.
3	The introduction of 20kV as the new standard voltage demands a new standard transformer
4	The procurement costs of power transformers can decrease because of cluster-, global-, and collective procurement.

Table 9-9: Scoring the impact on the company values of each lifetime impact.

Lifetime Impact	Impact per company value					
	Safety	Quality of Delivery	Financial	Laws and Regulations	Customer and Imago	Sustainability
#1	Very low	Moderate	Low	Very low	Very low	Very low
#2	High	Low	Low	Very low	Low	Very low
#3	Very low	Moderate	High	Very low	Moderate	Very low
#4	Very low	Moderate	Moderate	Very low	Very low	Very low

Table 9-10: Scoring the probability and effort of the lifetime impacts.

Lifetime Impact	Certainty	Effort
#1	Occasional	5M+
#2	Reasonably	500K-5M
#3	Frequent	<500.000
#4	Reasonably	<500.000

Table 9-11: Result of prioritizing the lifetime impacts.

Lifetime Impact	Mid Result			End Result		Type
	Impact	Certainty	Effort	Risk Matrix	L.I.P.N	
#1	4.5	6	15		25.5	Opportunity
#2	6.5	10	6	Moderate	22.5	Threat
#3	8	15	1	High	24	Threat
#4	6	10	1		17	Opportunity

9.5.8 Conclusion

Section 9.5 discusses the prioritization process of the model to categorize and prioritize lifetime impacts. Prioritization is executed using a MCDM that uses three criteria which are derived from a decision tree. To make the model easy to use, the criteria will be scored by the users using linguistic terms while underlying numerical values make it possible to compare the lifetime impacts with each other. The result of this step is an indication of which lifetime impact is most important.

9.6 The model in practice

The model has been created as an Excel-sheet, so Liander can use the model. The result can be found in appendix XII. The sheet is also partly filled in to show how the model works in practice at Liander. Furthermore, a supporting document for the model has been created, so Liander can continue to use the model after the researcher is gone. This can be found in appendix XIII.

9.7 Conclusion

Chapter 9 shows the result of this study, which is a structured model that can categorize and prioritize lifetime impacts in three different steps. The input of the model comes directly from the proceedings of the expert meeting and is regarded as raw data. The first step is to analyse the raw data to identify and filter statements that are not a lifetime impact. The second step categorizes the lifetime impacts which helps in removing and clustering similar lifetime impacts. The categorization step also includes rewriting the lifetime impacts so each lifetime impact includes a cause and an effect. In the third step the lifetime impacts are prioritized by scoring them on different criteria. The results is in twofold and can therefore be presented to both the policy advisers and the management team.

Until so far the model is still theoretical and it usability should be proven in practice. This process will be discussed in the next chapter "Testing the model". Only when the model is tested it can be concluded if the process described is a structured process that is able to categorize and prioritize lifetime impacts. Furthermore during the development of the model several decisions have been made that influence the result. The influence of these decisions will be discussed in chapter 12.

10. Testing the model

Testing the model will show whether or not the model is usable at Liander and if it fulfils the requirements derived from literature. The process is not a part of the iterative process of discussing and adapting the model as was used in the previous chapter. Instead the possible improvements are implemented after the test with the ALCPs and hereafter the model is finalized.

Testing is divided into three parts, as is discussed in the methodology in section 3.1.5.

- Testing the model using the requirements in section 10.1
- Testing the model using the ALCP on powertransformers in section 10.2
- Testing the model using the ALCP on gas delivery station in section 10.3

10.1 Testing to the requirements

The first test is to test if the model complies with the necessary and desirable requirements and the wishes stated in chapter 7. The section is split into three parts, each discussing a different part of the requirements. To increase the reliability of the testing process, are all the requirements assessed by four persons: the researcher, one of the two creators of the Asset Life Cycle Plan on power transformers[19], and the two creators of the Asset Life Cycle Plan on gas delivery stations. All testers have actively used the whole model and it is regarded that they have thus sufficient background knowledge and experience. The test is conducted by providing a list of the requirements to the creators individually. They scored the requirements by determining in which extent the model fulfils the requirement. This is done using a 1-7 Likert scale for the desirable requirements and wishes, and a yes/no scale for the necessary requirements. After the creators filled the program of requirements the results were discussed briefly to determine if they had additional comments.

The tested model is the model described in the previous chapter. Possible optimizations from testing the model to the requirements are not implemented into the model. But these can be used for further research and to optimize the model by Liander self.

10.1.1 Testing to the necessary requirements

First the model is tested using the necessary requirements. The model is based on these requirements and should therefore fulfil them fully. Table 10-1 shows the results of the test.

From the table it can be concluded that the model fulfils all the necessary requirements. Not only from the perspective of the researcher, but also from the perspective of the three users of an ALCP. The fact that the model fulfils all requirements confirms that the model is based on them. The only exception is requirement N1, which should prove itself by testing the model in practice. This will be elaborated on in section 10.3.3.

[19] The other creator of the ALCP on power transformers was not able to test the model using the requirements due to time constraints.

Table 10-1: Result of testing the necessary requirements.

	Decision Making	Yes	No
N1	Different users should get comparable results from the model	-	-
N2	The model should use the input of experts at the company as input to make decisions	4	0
N3	The model should be structured and transparent	4	0
N4	The model should use multiple steps to prioritize the lifetime impacts	4	0
N5	The model should be specialized for each company	4	0
	Lifetime Impacts		
N6	The model should be able to process a large number of lifetime impacts	4	0
N7	The model should be able to process a variety of different types of lifetime impacts	4	0
N8	The model should be able to select the lifetime impact that influences the remaining useful lifetime of the asset population the most	4	0
	Asset Life Cycle Plans		
N9	The output of the model should be strategic lifetime impacts	4	0
N10	The output of the model should be easy to use in an ALCP	4	0
N11	The model should be able to deal with multiple and possibly conflicting criteria	4	0

10.1.2 Testing to the desirable requirements

The result of testing the model to the desirable requirements can be seen in Table 10-2, and it shows the average mark of the four testers. A more extensive table including the different individual scores can be found in appendix XIV.

Table 10-2: Result of testing the desirable requirements using a 1-7 scoring system. The bold requirements will be discussed in this section.

	Decision Making	1-7
D1	The model should be able to handle uncertainties	5.8
D2	The model should be able to improve over time	6.3
D3	The model should be able to deal with qualitative and quantitative lifetime impacts as input	5.0
D4	The model should be usable without having prior knowledge	3.5
D5	The model should use the policy and strategy of the company as input to make a decision	6.0
D6	The model should take the financial impact of the lifetime impacts into account to make a decision	6.5
D7	The model should make decisions using both data and human judgment	3.8
	Lifetime Impacts	
D8	The model should be able to select the intermediate and long term lifetime impacts	6.0
D9	The model should be able to deal with both threats and opportunities as input	6.0

D10	The model should exclude evaluation during the expert session	6.3
D11	The model should be able to deal with tacit knowledge as input to the model	5.8
	Asset Life Cycle Plans	
D12	The model should be able to deal with lifetime impacts from the whole lifecycle as input	6.5
D13	The model should involve management to make a decision	4.8
D14	The model should involve different divisions to make a decision	5.0
D15	The model should aid in improving ALCPs	5.5
D16	The model should be able to provide information for multiple stakeholders	5.3
D17	The model should not involve problem solving when making a decision	4.5

Testing the desirable requirements shows several remarkable outcomes. These are the highlighted requirements D4, D7, D13, D14, and D17. Requirement D4 states that the model should be usable without prior knowledge. This is not scored highly because knowledge about the INP process (risk matrix and company values) and about the future scenarios is necessary. The model also requires the ability to translate effort into financial impact, making the model more difficult to use for people who do not have experience in doing this. The problem can be solved by adding a supporting document to the model. This document could provide additional information about the risk matrix, the scenarios, and how to interpret the criteria[20].

Requirement D7 does not score high because the decision making in the model is mostly based on human judgment and not on data. This is partly due to the fact that lifetime impacts often regards tacit knowledge and determining the impact of each lifetime impact using data would demand for a large amount of analysis. And partly because there was no data available to base decisions on for the ALCP on gas delivery stations.

Requirements D13 and D14 both have a large difference in personal scores. This can be attributed to the fact that the ALCP on power transformers did not involve other users to use the prioritization model. While the creators of the ALCP on gas delivery stations did involve multiple individuals.

Finally, requirement D17 also has a large difference in individual scores. The policy advisers score this requirement highly, while the consultant who developed the ALCP on power transformers gives it a low score. The explanation is that the prioritization model requires an estimation of the costs of solving the lifetime impacts and the policy advisers are more used to estimating this value.

10.1.3 Testing to wishes of Liander

The method to test the wishes of Liander is similar to the method to test the desirable requirements. The scores of the wishes can be found in Table 10-3 below and in appendix XIV a more extensive table with the different opinions can be found. It is important to emphasize

[20] At the moment of testing this document was not created yet. But due to these results the document has been created and added in appendix XIII.

that these are wishes from individuals at Liander and they do not represent the overall quality, but show the quality of the model according to several individuals.

Table 10-3: Result of testing the wishes of Liander using a 1-7 scoring system. The bold wishes will be elaborated on.

	Wishes from Liander	1-7
W1	The model should be easy to use and apply	4.8
W2	The model should support decision making and not make the actual decisions	6.8
W3	The model should use facts to make decisions	2.0
W4	The model should be able to select events and/or trends	6.0
W5	The model should not hinder process of acquiring lifetime impacts	6.3
W6	The model should be able to provide input for new expert sessions	6.0
W7	The model should use the future scenarios and be able to make no regret decisions based on these scenarios	6.0
W8	The model should focus only on the most important lifetime impacts	4.3

From the table the highlighted wishes W3 and W8 are remarkable and therefore these will be discussed briefly.

Wish W3 has a very low score because scoring the lifetime impacts is by definition based on opinions. It is therefore determined that not complying this wish is not a problem for the model.

Wish W8 was scored very differently by the different persons, from a 1 up to a 5 and even a 6 (the 6 is scored by the researcher). After consultation with the person who scored it a 1, it appeared that the person believed that additional analysis should be conducted for the lifetime impacts that have the highest prioritization score. This is not implemented in the model, but can be recommended for further research. The other two users who scored it with 5 points mentioned that they believed that the filtering and categorization steps already ensure that the focus is mainly on the most important lifetime impacts.

10.1.4 Evaluation of testing

Testing the model using the program of requirements provides a good overview of the quality of the model according to the requirements. By involving the actual users of the model, their experience of using the model is documented. A drawback of this method is that some users had difficulty to score the requirements, so the researcher had to intervene introducing possible bias. Furthermore, only users of the model were asked to score the requirements. A more reliable perspective should be obtained if more and different stakeholder were asked to score them. Especially asking the management team could be of added value. Finally, the test mainly focusses on the determining how Liander experiences the model. While the scientific rigour was only tested by the researcher[21]. To increase the scientific reliability of the model, additional experts on decision making should have been involved.

[21] The score of the researcher can be found in appendix VII. To provide an indication, his average score of the desirable requirements was a 6.0 out 7.0. Indicating that the model does comply with the requirements from literature.

10.2 Testing the model using the Asset Life Cycle Plan power transformers

The second method of testing is by means of different Asset Life Cycle Plans. First the ALCP on power transformers is used. This plan was used to create the model, therefore the planning of the ALCP was ahead of the process of creating the model. As a consequence the test could only be used to test the usability of the model and not the reliability of the outcome.

10.2.1 Process of testing

The test was split into two parts.

- Part 1: Categorizing the lifetime impacts using the categorization model and an estimation of the importance of each lifetime impact without using a model.
- Part 2: Prioritizing the lifetime impacts using the prioritization model without scenarios[22], executed by one of the creators because the other one was not able to use the model in given time (explained in section 10.2.3).

The results of both parts are compared with each other to determine if the outcome of the prioritization model was similar to the estimated prioritization.

The filtering step of the model is excluded from this test, because the total model is created by attempting to structure the lifetime impacts on power transformers. Meaning that the input was already filtered from 124 to 34 lifetime impacts. These 34 lifetime impacts are the input of the categorization and prioritization model.

10.2.2 Results from testing

Part 1: Categorizing

Categorizing the lifetime impacts leads to clustering an additional three lifetime impacts. Showing that the categorization model leads to new insights. Furthermore the categorization model was experienced to be easy to use and to be a structured process. This also appears from the fact that the process took about 25 minutes, including the quick estimation of the priorities. Another observation is that little to no guidance was necessary to use the model and that the categorization caused little to no discussion. The only remark is that it was necessary to emphasize that the allocated lifecycle phase should be the phase in which the impact has the largest effect.

The result of the categorization can be found in Table 10-4. What can be noticed is that there are no lifetime impacts identified for the decommissioned assets.

Table 10-4: Categorization of the lifetime impacts of the ALCP on powertransformers.

Category	# of Lifetime Impacts
Threat for new assets	7
Opportunity for new assets	5
Threat for the installed base	15
Opportunity for the installed base	4
Threat for decommissioned assets	0
Opportunity for decommissioned assets	0

[22] At the moment of testing there were no usable scenarios available at Liander on the future of the electricity network

Part 2: Prioritizing

The second part is prioritizing the remaining 31 lifetime impacts. This part is executed by one of the two creators of the ALCP only (this will be elaborated on in section 10.2.3). Filling in the model took the users about 25 minutes which is experienced as a reasonable time period. However, all "insubstantial" impacts were left blank instead of filling in "insubstantial". This most likely reduced the required time to fill in the model, while it did not impact the final result[23]. Filling in the prioritization model was not experienced as unpleasant and it provided added value for him. Or as stated: "*Using the prioritization model is a useful process and should be conducted by multiple persons to get a more complete understanding*". Furthermore, the user realised that he did not have knowledge about all the lifetime impacts. However the model does not demand an exact value, so it is easy to estimate some impacts and probabilities. This ensured him of his opinion that the model should be used by multiple persons.

10.2.3 Evaluation of testing

The test is evaluated by comparing the initial expected priority (part 1) with the priority from the prioritization model (part 2). From the first estimation the following eight lifetime impacts were estimated to be most important (Table 10-5). And from the model is seen in Table 10-6.

Table 10-5: Preliminary estimation of the most important lifetime impacts using a short description of the real lifetime impact. The impacts are not stated in order of importance. The lifetime impacts with an asterisk is an opportunity.

#	Lifetime Impact
1	Capacity of implementation teams needs to increase
2	Introduction of 20 kV
3	Increase average age of powertransformers
4	Collection of data*
5	Increase of different suppliers for powertransformers
6	Rise of organizational costs when placing a new powertransformer
7	Long delivery time of electrical bushings
8	Implementing a decision tree to determine what to do with a powertransformer*

Table 10-6: Top 3 opportunities and top 5 threats from the prioritization model stated in order of importance.

#	Lifetime Impact
	Opportunity
1	Collection of data
2	Implementing a decision tree to determine what to do with a powertransformer
3	*Regenerate used oil*
	Threats
1	Introduction of 20 kV
2	Capacity of implementation teams needs to increase
3	*The number of assets increases*
4	Increase of different suppliers for powertransformers
5	*New transformers are less robust than before*

[23] To be able to calculate the final results the researcher filled all blank spaces with "insubstantial"

From the tables 10-5 and 10-6 it can be derived that the two opportunities that were identified as most important, also have the highest score in the prioritization model. Furthermore, three of the top five threats from the prioritization model are also mentioned earlier. After discussing the results with the user, the user recognized that threat #3 and #5 are also of high importance. And thereby he acknowledged the result of the model. But the user did mention that the three impacts from the initial estimation that do not return in the model, should also be taken into account. From this it can be concluded that the prioritization model (mostly) corresponds to the view of the expert. And that the model provides additional insight into the most important lifetime impact.

Reflection on testing

The prioritization model was only used by one person because the other creator of the ALCP had difficulty with the model. After two sessions of about 1.5 hours aiding the person to fill the model, only ten lifetime impacts were scored. Implying that the usability of the model is not very high, which is remarkable since other users had much less difficulty with the model. The main reason observed for this difficulty is that the model demands the users not to overthink each lifetime impact. Instead an indication of the impact, probability, and effort of each lifetime impact is required. When a user has difficulty doing this, the prioritization model becomes hard to use as occurred with the second creator of the ALCP on power transformers. Therefore the researcher has determined that using the model should take about 30 seconds per cell. Which is be indicated in the supporting document of the model.

Reliability of testing

The reliability of this test is not very high because the prioritization model is tested only by one person. To increase the reliability, the model should be used by multiple persons. This will be done in the ALCP for gas delivery stations.

10.3 Testing the model using the Asset Life Cycle Plan gas delivery stations

The final test is using the model for the Asset Life Cycle Plan on gas delivery stations. The planning of the ALCP was such that a developed concept version of the model was ready when the corresponding expert session was conducted, resulting that a full test could be performed. Furthermore, the results of the model are necessary to create the ALCP so both the usability and the reliability of the outcome of the model are tested.

10.3.1 Process of testing

The test consisted of three parts.

- Part 1: Filtering and categorizing the raw input from the expert session by two policy advisers.
- Part 2: Prioritizing the lifetime impacts using the prioritizing model by the two policy advisers, a senior network-strategist, and a product manager (all experts on gas delivery stations).
- Part 3: Prioritizing the lifetime impacts using the prioritizing model with slightly altered lifetime impacts by the two policy advisers, a senior network-architect, and the manager of the business unit policy and standardization gas (all experts on gas delivery stations).

The difference between part 2 and part 3 is that the cause and effect of the lifetime impacts were added to the description, as is discussed in section 9.4.3[24]. Additionally, part 3 involved a manager increasing the reliability of the test and the chance that the results are accepted (as stated in section 4.2.4).

10.3.2 Results from testing

The results of each part will be discussed separately.

Part 1: Filtering and categorizing the lifetime impacts

The first part had to handle 161 lifetime impacts. The exact process of this reduction has not been recorded by the policy advisers of the ALCP on gas delivery stations and the researcher did not have an advising role. Therefore only the result of this step can be shown, which are the 28 lifetime impacts categorized in Table 10-7. It can be noticed that there are no lifetime impacts identified in the decommissioned assets phase, which will be analysed in a later section. Evaluating the filtering and categorization step with the policy advisers showed that the large reduction could mainly be allocated to the large number of double lifetime impacts. This is because the expert session asks attendees to individually write a lifetime impact on Post-Its®, increasing the chance of double lifetime impacts. Furthermore, numerous solutions that could not be converted into a lifetime impact were identified during the expert session.

The process of filtering and categorizing was experienced as pleasant, transparent, and structured. It was also mentioned that it provided additional insight in identifying the actual problem. Other feedback was that it is necessary to regularly inspect the filtered lifetime impacts instead of eliminating them entirely[25]. The only difficulty experienced was categorizing the impacts in threats and opportunities, because it depends on the perspective at which the lifetime impact is perceived[26]. However, after further explanation it became more clear and easier to do.

Table 10-7: Categorization of the lifetime impacts of the ALCP on gas delivery stations.

Category	# of Lifetime Impacts
Threat for new assets	3
Opportunity for new assets	8
Threat for the installed base	14
Opportunity for the installed base	3
Threat for decommissioned assets	0
Opportunity for decommissioned assets	0

[24] The implementation of standardizing the lifetime impacts is a result of this test

[25] An aspect emphasized in the model due to this test result

[26] This test result caused a change in the categorization process that first the lifecycle stage should be determined and only then be categorized in a threat or an opportunity.

Part 2: Prioritizing the lifetime impacts (1)
The result of the second part were four filled in prioritization models and feedback from both policy advisers and the two other users. From this six observation are made.

The first observation is that knowledge about the risk matrix is of added value. One policy adviser and the network-strategist had this, while the other policy adviser and the product manager did not. This resulted that the latter two experienced more difficulty with determining the right values of the impact. This can be seen in the final result where the scores of the users without the knowledge was higher than the user with knowledge about the risk matrix. However, it could also be observed that the order of prioritization was similar between the four users. Showing that not the exact values, but the order of priority can be used to compare the results of different users.

Secondly, the users experienced difficulty with determining the effort. Or as one user stated: *"Determining the effort was only possible for very technical matters, but in most cases it was hard to imagine what the effort should be"*. After explaining that the purpose of determining the effort is an indication and not an exact value, the users indicated that this would have made it easier. But since it was mentioned after the model was filled in, it has not been tested.

Thirdly, the use of scenarios was experienced as useful and feedback was given that their implementation provides added value to both ALCPs and the scenarios in general. As one user stated: *"The usage of scenarios is very creative. It immediately provides an overview if an impact is scenario dependent or not"*.

Fourthly, feedback was given that the model is based on instinct and opinions and that this is inevitable because the lifetime impacts are mostly based on tacit knowledge. Furthermore they indicated that it is almost impossible to gather data to test the lifetime impacts on all criteria. However, by involving multiple experts with different backgrounds into the model the result was made more reliable and objective.

Fifthly, the model was experienced as a bit difficult to use, but after the first ten lifetime impacts it became easier. Showing that the users had to get into the right mind-set. Something that can be solved by including a document that supports the model.

Finally, it appeared that users had difficulty scoring the right impact of the lifetime impacts. Often the users scored the impact on the total gas network, instead of only on the gas delivery stations. To help the users in this, the cause and effect of the lifetime impacts on gas delivery stations was added to the description and tested in part 3 of the test.

Part 3: Prioritizing the lifetime impacts (2)
The third part of testing is almost similar to the second part, the only difference is the addition of the cause and effect to the description of the lifetime impacts. Here an additional four observations were made. First, is that the four main impacts identified in part 2 are also the four main impacts in this part, although not in the same order.

Secondly, the priority list of the two policy advisers are largely identical, showing that using the model more than once results in similar outcomes.

Thirdly, the feedback was similar to the feedback in step 2, with the main message that it is a good method to structure but sometimes hard to fill in.

Fourthly, explicitly adding the cause and effect of the lifetime impacts was experienced both as obstructive and helpful. Helpful because it provided guidance on how to interpret the lifetime impacts. Obstructive because the users did not always agree on the actual effect. Or as one user stated: *"Scoring the first several impacts was a hard job because I thought about everything and doubted the input. However after a while I realised that it not an exact science, and it is about my opinion on what is stated. After that realization the model was much easier and faster to use"*.

Discussion on the model
The model was mostly tested with the two policy advisers that created the ALCP. Therefore the whole model was evaluated in multiple non-formal conversations with them. The feedback returned during these conversation was that the model is a structured and transparent method to determine the most important lifetime impacts. And as much as the final prioritization is important, the process to determine the end results is equally beneficial. Since it makes one consciously think about the lifetime impacts instead of blindly copying them into an ALCP. Or as one stated: *"On first sight the list of 161 lifetime impacts appeared to indicate that there are a lot of problems with the gas delivery stations. But after using the model, all lifetime impacts were put into perspective and the situation is actually not that bad after all"*.

10.3.3 Evaluation of testing

The third test was extremely valuable to execute because it tested the whole model. Especially testing the prioritization part by different persons from different backgrounds was valuable. And using the model twice by the same policy advisers showed the reliability of the model. The test also showed that the model would benefit from a supporting document that guides the user by explaining each step and its purpose.

To further evaluate the test, the top four threats and opportunities of all four users of part 2 and part 3 are analysed. The priorities can be found in Table 10-8. The table shows that both parts did not identify four similar lifetime impacts. In part 2 seven different lifetime impacts are stated in the top four opportunities and ten different threats are identified. In part 3 five different opportunities and eleven different threats are identified. Especially the wide range in different threats shows that there is still disagreement on what the largest threat is. And that the model does not explicitly identify one lifetime impact as the most important. However, the model explicitly shows the different opinions providing a basis for discussion. And via the discussion a decision can be made on which lifetime impact is the most important. This is an improvement from the current process.

Finally, testing the model showed that the model is accepted at Liander. Not everybody agreed with every part of the model, but they do accept that it is the best solution. Acknowledging that it provides added value for ALCPs and multiple policy advisers have indicated to use the model for their (next) ALCP. So even though implementing the model is not a part of this research, major steps have been made while testing it. Additionally, the ALCP on gas delivery stations is accepted by PIB, while the ALCP is mostly based on the lifetime impacts processed using the model. Showing that there is support for the model in the multiple layers in the organization. So an elaborate implementation process might not be necessary, but this should be determined after the model is used more often.

Table 10-8: Overview of the top four opportunities and threats of part 2 and part 3 of testing using the ALCP on gas delivery stations.

Opportunities of part 2				
#	User 1	User 2	User 3	User 4
1	Change in design	New functionalities	New functionalities	New innovations
2	Gas for transportation	Gas for transportation	Gas for transportation	New gas types
3	Increased design restrictions	New innovations	Increased design restrictions	Gas for transportation
4	Changing customer demand	Change in design	Changing customer demand	New functionalities

Threats of part 2				
#	User 1	User 2	User 3	User 4
1	Knowledge decline	Knowledge decline	Decrease in suppliers	Higher safety demands
2	Decrease in gas demand	Higher safety demands	Increase land price	Increased functionalities
3	No spare parts plan	Decrease in gas demand	Decrease in gas demand	Decline in customers
4	EU based regulations	EU based regulations	Decline in customers	Wider span gas quality

Opportunities of part 3				
#	User 1	User 2	User 5	User 6
1	New functionalities	Gas for transportation	New innovations	Changing customer demand
2	New innovations	Change in design	Changing customer demand	Gas for transportation
3	Changing customer demand	New innovations	New functionalities	New innovations
4	Gas for transportation	Changing customer demand	Gas for transportation	Change in design

Threats of part 3				
#	User 1	User 2	User 5	User 6
1	Knowledge decline	Knowledge decline	Decrease in gas demand	Wider span gas quality
2	Decrease in suppliers	Higher safety demands	Decline in customers	Increase land price
3	Decrease in gas demand	Decrease in gas demand	Climate change	Increased functionalities
4	Wider span gas quality	Increased functionalities	Increased functionalities	Aging rubbers

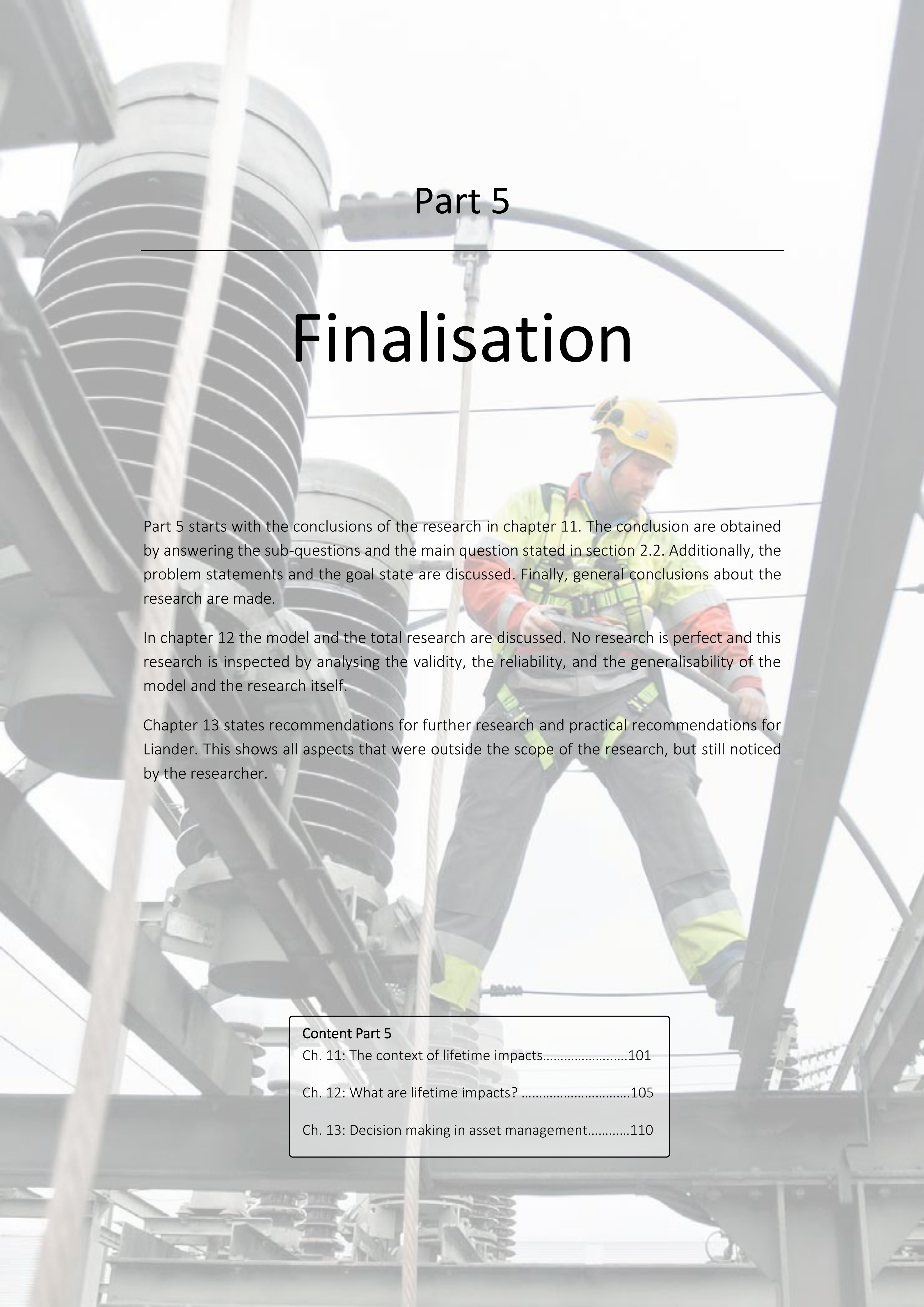
10.4 Conclusion

Testing the model with the program of requirements had a positive result. All necessary requirement are fulfilled and almost all of the desirable requirements and the wishes of Liander have a high score.

Testing the model in practice for the ALCP on power transformers and gas delivery stations tested the reliability and the usability of the model. The result is an overall positive review. Especially the process is experienced as structured, providing additional insight in the most important lifetime impacts. The positive experience also indicates that the model is accepted at Liander. Additionally, potential users have the intention to use the model for future ALCPs. Furthermore, testing resulted in useful feedback for further optimization.

However, the test with the ALCP on gas delivery stations also showed that there is still a wide range of different “most important” lifetime impacts. Showing either a large disagreement about the most important or that the model is not able of select it. On the other hand, the process of determining the most important lifetime impact is transparent and enables the policy advisers to discuss and come to an agreement.

A final conclusion is that both tests did not identify lifetime impacts that have an effect on decommissioned assets. This can be an incident and due to the chosen ALCPs. Or it could be possible that there are no lifetime impacts that have an effect on the decommissioned assets. But because the addition of decommissioned asset stimulates lifecycle thinking (an aspect also stimulated by Liander) it is not eliminated.



Part 5

Finalisation

Part 5 starts with the conclusions of the research in chapter 11. The conclusion are obtained by answering the sub-questions and the main question stated in section 2.2. Additionally, the problem statements and the goal state are discussed. Finally, general conclusions about the research are made.

In chapter 12 the model and the total research are discussed. No research is perfect and this research is inspected by analysing the validity, the reliability, and the generalisability of the model and the research itself.

Chapter 13 states recommendations for further research and practical recommendations for Liander. This shows all aspects that were outside the scope of the research, but still noticed by the researcher.

Content Part 5

11. Conclusions

Chapter 11 shows the conclusions of the research. First in section 11.1 by answering the five sub-questions as stated in section 2.2. Sub-questions 2 and 3, and sub-questions 4 and 5 are combined, because their answers are largely similar. Hereafter the main research question is answered in section 11.2. The chapter finalizes with overall conclusions regarding this research in section 11.3. The conclusions made in this chapter contain all the information from the separate conclusions of each chapter and is therefore thus a summary of the whole research.

11.1 Answering the sub-questions

Q1. What are lifetime impacts and how are they currently identified?

Lifetime impacts are: "*Probable (technical and non-technical) events or trends that may have a positive or negative influence on the remaining lifetime of the asset in the intermediate or long term*" (Ruitenburg et al., 2014). For science the lifetime impacts are used to determine what influences the remaining useful lifetime of an asset. Liander uses them to help determining the future performance of an asset.

For both science and Liander are the lifetime impacts used as input for an ALCP. An ALCP consists of four parts; current performances, strategic goals, expected performances, and policy measures. The lifetime impacts are used for the part "expected performances". The relation between the four parts is that the current performances should match the strategic goals and the expected performances. When this is not the case, appropriate policy measures should be created to bridge the difference.

The exact definition that Liander uses for ALCPs are: "*An Asset Life Cycle Plan combines all relevant information and developments of an asset population to create an integral overview of the asset population which is used to manage the asset population (if necessary) to accomplish certain objectives, eliminate threats, and seize opportunities. By doing this Liander becomes in control of the assets*" (Liander N.V., 2014a). Where the role of lifetime impacts is to determine the threats and the opportunities.

Lifetime impact are obtained by means of an expert session including multiple experts with different backgrounds. During the session an asset is analysed from the five TECKO perspectives; technical, economical, compliance, customer, and economical. The exact format of the expert session is still subject of change, but it is clear that it involves stakeholders from different backgrounds, lots of discussion, and that each session identifies numerous and very different lifetime impacts.

Q2 & Q3. How are lifetime impacts currently categorized and prioritized by Liander?

Interviews with policy advisers and the management team showed that the current method to select the most important lifetime impacts is not structured and transparent. Instead lifetime impacts are prioritized using a combination of expert knowledge, experience, and opinions. This is regarded as not sufficient for three reasons:

- The current method is not reliable, so different persons could have a different priority.
- The current method is not transparent, so it is hard to compare the different opinions with each other.
- Other decision making processes at Liander do have a structured method, so Liander is familiar with using them and recognizes the added value of one.

To further answer the sub-question, some of the previous mentioned decision making processes at Liander are analysed. The result are design principles which are used as guidelines to create the final model. Additionally, this prevents that the new model is developed from scratch and it shows the decision making processes Liander is familiar with. Finally, the wishes of Liander for the model are identified.

Q4 & Q5. How are lifetime impacts or comparable principles categorized and prioritized in other science disciplines?

Lifetime impacts are a relatively new concept in science and it was not possible to determine how they should be categorized and prioritized. Therefore a wider perspective is taken by looking at decision making (models) in asset management. The literature review showed that decision making in asset management needs a structured method because:

- The imprecision of human judgment; meaning that human tend to choose for the familiar.
- Difficulty of the decision making in asset management; decision making in asset management involves numerous criteria and an asset manager is not able to take all into account without using a structured method.

To research how this should be done, decision making in asset management is analysed more closely. This is done by researching what decision making is, as well as analysing five existing decision making models. The results are multiple requirements for the model to categorize and prioritize lifetime impacts and design principles for the new model. The requirements are split into necessary requirements which are essential to the model. And desirable requirements, which are used to test the model on its suitability according to literature (and Liander). The requirements state (among others) that the prioritization should be done in different steps using multiple criteria and input from multiple experts with different backgrounds. Furthermore the model should be structured and transparent, and optimized for the company where it is implemented. The design principles show elements of decisions making models that have proven themselves in theory and in practice.

11.2 Answering the research question

In this section first the main research question will be answered. Hereafter the problem statements and the goal situation is examined. The main research question of this research is:

How can lifetime impacts be categorized and prioritized?

The main question is answered by the model described in chapter 9. The model uses three steps (filtering, categorizing, and prioritizing) to convert the input into the expected output. The input of the model are a list of impacts that are derived from the proceedings of the associated expert session. The output is a prioritized list of the lifetime impacts.

In the first step, “filtering the impacts”, wrong input is filtered by testing the impacts to three criteria:

- Criterion 1: The impact should potentially influence the remaining useful lifetime of the asset population.
- Criterion 2: The impact should influence the remaining useful lifetime of the asset population in the intermediate or long term.
- Criterion 3: The impact should be generic for an asset population.

The second step is categorizing the remaining lifetime impacts. This is done to aid in clustering similar lifetime impacts and to ensure that different users view the lifetime impact from the same perspective. The second step also includes rewriting the lifetime impact in a standardized format so they all include the cause and effect of the lifetime impact. Categorization is based on the lifecycle phase of the lifetime impact and if it is a threat or opportunity.

The final step prioritizes lifetime impacts by answering the following questions about the lifetime impact:

- What is the probability the lifetime impact will happen in a specific future scenario?
- What is the impact of the lifetime impact on a specific company value?
- How much does it costs to mitigate the risk?” or “How much does it cost to benefit from the opportunity?

Different users will answer these questions using linguistic values which also have a numerical value. Hereby the different lifetime impacts can be compared to each other and a priority list is created. The different priority lists of the different users can subsequently be compared with each other and based on the outcome a discussion can lead to a finalized priority list.

The model described above is tested successfully using the previously mentioned requirements, and by means of two case studies in the form of an ALCP on power transformers and on gas delivery stations. This process can be found in chapter 10. Results from the test indicates that the users believe that the models provides added value for ALCP. Additionally Liander has the intention to implement the model.

11.2.1 Solving the problem statements

To determine the usefulness of the research, the problems statements mentioned in section 2.1 are analysed. The result can be found in Table 11-1 below and is briefly discussed.

Table 11-1: Overview of the situation of the in chapter 2 determined problems statements.

#	Problem statement	Origin	Solved
1	The absence of a structured decision making process to identify the most important lifetime impacts	Science	Yes
2	The absence of a structured decision making process to identify the most important lifetime impacts	Liander	Yes
3	The absence of a structured decision making process to provide an unambiguous view of the effects of future trends for all the assets	Liander	Yes

Problem statement 1 and 2 are solved by the result of this research for both science and for Liander by creating a structured decision making process that is able to identify the most important lifetime impacts. Furthermore, the process forces the user to think about the influence of each lifetime impact, creating awareness and helping to get an understanding of all lifetime impacts.

The third problem statement is also solved. The model provides a framework which enables different users to assess lifetime impacts in the same manner. However, testing the model showed that different priority lists of lifetime impacts differ from each other. For example; the top four priorities of eight different users of the model resulted into twelve different lifetime impacts. The model does make the motivation for their priority lists transparent, allowing for a comparison of the lists. And a discussion about the differences will enable the stakeholder to select the most important lifetime impact and create an unambiguous view. And hereby the problem statement is solved.

11.2.2 Improving the current situation

In section 6.1 the current state of categorizing and prioritizing lifetime impacts is determined as: “a decision making process that is not structured and transparent”. And the goal state as: “a structured and transparent decision making model to select the most important lifetime impacts”. It can be concluded that the model enables Liander to go from the current state to the desired goal state. Meaning that the problem is solved (Hevner et al., 2004).

11.3 General conclusions

Apart from the conclusions on the research, other conclusions for science and Liander can be drawn as well. First, it can be concluded the developed model is an improvement from the current situation by introducing structure and transparency. Additionally it helps Liander in their process of implementing ALCPs.

Secondly, it can be concluded that it is inevitable to use human judgement to categorize and prioritize the lifetime impacts. The result is that there is not one right or wrong answer on which lifetime impact is the most important. But what has been achieved is that the reasoning is made transparent.

Thirdly, it can be concluded that the implementation process of ALCPs is still ongoing. Meaning that the final content of the ALCPs still has to be determined. This also might have an effect on the model since a large change in the ALCP can demand for a different output of the model.

Fourthly, it can be concluded that implementing ALCPs requires a new way of thinking at Liander. Traditionally decisions are based on short term, economic, and certainty variables. ALCPs require to deal with long term and uncertain effects, as well as aspects other than technical and economic considerations have to be taken into account. This change needs time and flexibility, and the change has to be implemented into all levels of the Liander.

12. Discussion

In chapter 12 the final result of the research will be discussed. This will be done by looking at the validity, reliability, and generalisability of the research in section 12.1 up to 12.3.

12.1 Validity

Regarding the results of the research, the question can be asked how valid the final model is. This will be discussed by looking at the three separate steps of the model and at the model as a whole.

12.1.1 Validity of filtering

The filtering step is included to ensure that only lifetime impacts are processed by the following two steps of the model. It is however possible that during filtering lifetime impacts are eliminated which could be important in a later stage. Or that lifetime impacts are filtered that the user rather not mentions in an ALCP. Especially the first filtering criterion "*The impact should potentially influence the remaining useful lifetime of the asset population*" allows this. Excluding the filtering step could result that all lifetime impacts are processed in the model which would lead to a waste of valuable time. When evaluating the result of the filtering steps in the two conducted tests, it can be concluded that the filtering step is efficient. It is therefore important that the filtering step remains. But it should also be amplified that the filtered lifetime impacts are managed properly outside the scope of the ALCP.

12.1.2 Validity of categorization

Categorization is done using six categories which are based on the lifecycle phase and if it is a threat or an opportunity. Is it however possible to categorize all lifetime impacts in one of these six categories? Or would this derogate the multidisciplinary essence of a lifetime impact, especially because they are sometimes stated as very general impacts. This question suggest that other criteria might be used to categorize the lifetime impacts. For example, categories based on to what extent Liander can influence the lifetime impact. On the other hand, none of the users had any problems using these criteria after explaining them. So from that perspective the categories should not be changed.

12.1.3 Validity of prioritization

The prioritization is done by scoring different criteria with linguistic values. The selection of these criteria influence the final prioritization, meaning that other criteria might result in a different outcome. Especially determining the effort of managing a lifetime impact is a criteria that can be changed, for there are many methods to determine the effort (as discussed in section 9.5.1). For example, using the criterion "time"; a lifetime impact that takes up to ten years to manage and if its effect is noticeable in ten years should have a high priority because it should be managed immediately. For similar reasons is it possible to discuss the criteria "probability'" and "impact". So selecting different criteria could lead to a different and maybe better prioritization, making one wonder if the prioritization using the current methodology is the actual priority of the lifetime impacts.

Other aspects that influence the validity of prioritization are the numerical values of the linguistic categories and the formulas to calculate the final result. Numerical values make comparison between lifetime impacts easier, but is also makes the process less transparent. When different values or formulas are used, a similar input might lead to a different result. For example, using a logarithmic scale (opposed to a scale within one order of magnitude) would result that high impacts have a much larger influence.

Also the use of scenarios influences the validity of the prioritization model. Scoring the probability of the lifetime impacts over different scenarios can disguise a high probability in a highly probable scenario.

Another aspect that influences the validity of the prioritization model is the method by which the lifetime impacts are written down. This can be the Achilles heel of the model, since a wrong statement of the lifetime impact can result into a wrong prioritization. When the lifetime impacts are stated ambiguously, the different users will interpret it differently resulting in different scores. So it is essential for the model that the impacts are written down properly.

Finally, the lifetime impacts of the six different categories are scored using the same prioritization model. It is however hard to compare a threat and an opportunity with each other. This reduces the validity of the outcome, meaning that it might be better to create six different prioritization models for the six different categories.

Taken everything into account, the researcher still believes that the right method and criteria are selected to prioritize the lifetime impacts. This is mainly because the choices are made on an extensive literature and case study and because of the positive results of testing the model.

12.1.4 Validity of the total model

The total model consist of three steps to reduce and score the lifetime impacts. While it might be better to include more steps so the number of lifetime impacts is reduced more gradually and decision are made more consciously. But again the researcher believes that the right steps have been selected.

12.2 Reliability

The reliability of the research depends on if the results are replicable in future research. This differs for the methodology, the case study, and the literature review. Each element will be inspected in the following sections.

12.2.1 Reliability of the methodology

Design science a proven approach to conduct a research. To determine the reliability of the research method for this research, the seven guidelines of design science are analysed in Table 12-1 (Hevner et al., 2004). The analysis shows that all guidelines are followed, concluding that the research methodology is reliable.

Table 12-1: Overview of the situation of the design guidelines of design science.

Design science guideline	Implementation in the research
Guideline 1: Design as an artefact	The final model can be regarded as a viable artefact
Guideline 2: Problem relevance	The model is a solution for a relevant business problem at Liander
Guideline 3: Design evaluation	The model is properly tested by the researcher, the users, and by two different ALCPs
Guideline 4: Research contributions	The research provides a clear contribution to the scientific areas of Asset Life Cycle Plans and Management
Guideline 5: Research rigor	The method to construct the model via an iterative process, and the multiple tests of the model are both rigorous methods
Guideline 6: Design as a research process	Both a research process via literature as a case study at Liander have been conducted to reach the designed end
Guideline 7: Communication of research	The research is presented by means as a thesis for all audiences

There are however still four remarks that can be made regarding the reliability of the executed methodology. First, the research has been conducted in close collaboration with Liander which influenced the final result. For example, it is certain that the final model is suitable for Liander, but it is uncertain if the model is suitable for other companies (which will be discussed in the section 12.3).

Secondly, design science mainly focusses on designing and constructing an artefact and not on the implementation. This is solved by actively involving Liander into the process of creating and testing the model. Making future users familiar with the model and increasing the chance that the model is implemented by Liander. However, to properly implement the model at Liander another methodology should be used.

Thirdly, the methodology implies that the model is created using a case study, as well as a literature study. When just one of the two was selected, the result of the model could be more specialized for either Liander or science.

Finally, design science does not have a clear framework on how to execute a research. Therefore the methodology of analyzing, creating, and evaluating is implemented, which is not a proven methodology in a scientific research[27]. So a different method might have resulted into a different outcome. For example, creating and testing the model at the same time could result in a model that is more specialized to the tested ALCPs.

[27] As far as the author is aware.

12.2.2 Reliability of the case study

For the case study the decision was made to use interviews to obtain information about ALCPs and decision making at Liander. Another possibility would be to use a questionnaire. When using a questionnaire the results could have been easier to reproduce, since an interview is often subject to interpretation. However, using interviews was a fast method to obtain a lot of information and context about the problem. And it allowed the researcher to get familiar with everybody and their way of working.

The main subject of the case study was the asset group "power transformers". A subject the researcher did not have much experience with. Therefore it was sometimes difficult to correctly interpret the lifetime impacts. An aspect that was necessary because these lifetime impacts were used to create the final model. The result is that the meaning of some lifetime impacts are assumed. On the other hand the creator of the ALCP did approve the most important lifetime impacts, which showed that the assumptions were made correctly.

Finally, the model is tested using the input by four creators of ALCPs (all policy advisers), while the model is constructed for two types of stakeholders; policy advisors and the management team. So the opinion of the management team about the model is not obtained and the reliability of the model in the perspective of the management team cannot be verified.

12.2.3 Reliability of the literature review

Limited literature is available on lifetime impacts in asset management. All documents returned from Science Direct have been read for this research[28]. Also all documents on the topic of ALCPs have been read[29]. This implies that the literature review is highly reliable.

There are however numerous studies on decision making in asset management, topics related to lifetime impacts, and topics related to ALCPs. These studies have not all been analysed and not even all related topics have been inspected. This decreases the reliability, because it is possible to review other studies and draw other conclusions from these studies. To increase the reliability the most common decision making methods in asset management have been researched. So it is assumable that a new study would use similar studies as sources.

Finally, literature on using data in decision making was rather old. Taking the fast developments of information systems into account, it is possible that outdated sources are used with regard to use data in decision making. This is not a large part of this research, but additional research can be executed on the role of data and lifetime impacts.

[28] The phrase ("lifetime impact") and ("asset management") at sciencdirect.com returns two documents and both have been read for this research. (Derived in 2015)

[29] The phrase ("asset Life Cycle plans") at sciencedirect.com returns two document of which one actually has ALCPs as topic. (Derived in 2015)

12.3 Generalisability

To inspect the generalisability the scope of the research and the context of the model is analysed.

12.3.1 Discussing the scope of the research

The scope of the model can be viewed from the perspective time, company, and asset type. The model is made for the current situation at Liander, while there are many changes coming. For example, the energy transition and the ageing assets will have a large effect on the type of lifetime impacts identified. Other influences on the model is an increase in data storage and processing. This could result that the model should prioritize lifetime impacts using data instead of personal judgment. Additionally, there is a decrease in experienced employers due to an ageing workforce which might result in a reduction of available tacit knowledge.

The company scope of the research is Liander, which brings several restrictions to the research. For example, the energy market develops relative slow which makes future predictions easier. Furthermore, Liander does not have to be highly competitive so costs are less of a factor. Other companies might therefore have different requirements for the model, resulting that the model should be reconfigured. For example, a company that manufactures fast moving consumer goods has a shorter future image and has to be flexible to be competitive. So the majority of the lifetime impacts might be short term and uncertainty might be negligible.

The final perspective on the scope is the type of assets of this research; power transformers and gas delivery stations. Both types have a long lifetime, are relatively expensive, and are stationary. This scope is not a problem for Liander, because all assets have similar characteristics[30]. However, the type of asset might limit the results of the research for other companies with different types of assets. For example, the rolling stock of NedTrain is constantly moving so wear can be a large factor in determining the RUL.

12.3.2 Discussing the context of the model

The context of the research is Liander and this has several implications for the final result. For example, Liander uses future scenarios, has clear company values, uses a risk matrix, is able to score lifetime impacts on the amount of money it costs to manage them, and believes in implementing lifecycle thinking. It is important to inspect the context of a new company when the model is implemented there. If some of the previous mentioned aspects are not available, the model might need to be changed. If none of the above aspects are available, it might not even be possible to implement the model.

[30] This does not account for secondary assets which are sensors and other electronical equipment which have small lifespan.

13. Recommendations

Chapter 13 discusses the recommendations based on the research. These are split into two parts. First the recommendations for further research are made in section 13.1. Hereafter the overall recommendations are stated in section 13.2. The latter recommendations are not necessarily related to science or this research, but based on the experiences gained during the assignment.

13.1 Recommendations for further research

The recommendations for further research are split into three parts, research on the input of the model (expert sessions), the model to categorize and prioritize itself, and the output of the model. Finally, a recommendation to optimize the model using subpopulations is described.

13.1.1 Recommendations on the expert session

The model is based on the assumption that the raw output of the expert session is the input for the model. However, bad input often means bad output. Additionally, if an impact is not mentioned during the expert session, it will by definition not return in the ALCP. So it is important that the output of the expert session is complete and of high quality.

During the evaluation of the different expert sessions, it appeared that the exact format of the session has to be determined. Especially the consideration between obtaining as many lifetime impacts as possible, opposed to gathering high quality lifetime impacts has to be made. Also the background of the attendees of the expert session are changing, while standardizing this would most likely benefit the continuity.

Lastly, the expert meeting is based on a brainstorm using the five TECKO perspectives. It might be interesting to provide more structure to the brainstorm by implementing standard propositions or questions.

Taking these three aspects into account, it is recommendable to further research the format of the expert sessions.

13.1.2 Recommendations on categorizing and prioritizing

The model is created for Liander, but it is recommended to research the applicability of the model at other companies. Especially at companies that have different company activities than Liander has. This will increase the generalisability of the research in the scientific field of decision making in asset management. Additionally, it would improve the usability and the reliability of the model. It is recommended to do this using a quantitative study, so to test the model as often as possible at as many different companies as possible.

A second recommendation is to research how statistical data on future performances of the asset can be implemented in the model. Should it be another lifetime impact, or should it be managed outside the model? At this moment this is not a pressing matter because the available data is too fragmented and diverse in structure. However, data quality and availability are improving rapidly and it is assumable that other companies have more and reliable data available. Based on the researchers' experience, it is advisable to regard statistical data as a second pillar to determine the future performances. Where the first pillar is tacit knowledge from the expert session and structured using the proposed model. By combining the two pillars an exact, reliable, and complete estimation of the future performances of the asset population can be generated.

A third recommendation is to research the relation between different lifetime impacts. One lifetime impact that poses a threat could be solved by a lifetime impact that is an opportunity. Or two threats can intensify their impacts, resulting into a large unwanted effect. This has not been accounted for in the model, but it can have a large impact on the RUL. For example, the two lifetime impacts "reduction is experienced engineers" and "increase in the average age of the assets". Apart these two lifetime impact might not be very significant. Combined they can create a large threat.

A fourth recommendation is to research if there are lifetime impacts in the disposal phase of an asset. Since they are until so far not mentioned during an expert session.

Finally, it is recommended to research the possibilities of applying fuzzy numbers in the prioritization model. Fuzzy numbers are a proven and useful tool to manage uncertainties. Lifetime impacts have a high rate of uncertainty. So using fuzzy numbers will increase the reliability of the model. During this research the time and the required knowledge to implement them was not available and therefore they are not inspected more closely.

13.1.3 Recommendations on the output

Currently the model is able to prioritize each lifetime impact in relation to the other lifetime impacts. It is however not clear how to process the priority list in an ALCP. Especially the translation to the RUL is difficult to make. So it is recommended that future research determines how lifetime impacts are implemented in an ALCP.

13.1.4 Scoring per asset subpopulation

During the revision of the different ALCPs it appeared that the general message is often rather similar: *"There are no problems expected for the total population, however some subpopulations should be inspected more closely"*. This message is understandable when realizing that Asset Life Cycle Plans at Liander are created per asset group, a large number of assets. When the general condition of this large number of assets is poor, Liander would have a large problem. However, it is plausible (and assumable) that several subpopulations can be in a poor state while the majority is in a good condition. To take this into account the asset population can be divided into subpopulations and subsequently determining the impact per subpopulation. To keep the model easy to use, three categories are identified. A lifetime impact can have no impact (score 0), normal impact (score 1), or increased impact (score 2) on a subpopulation. The result is a number that indicates the total threat or total opportunity for that specific asset subpopulation. Where a higher score in both cases indicates that the RUL of that specific subpopulation is influenced more.

An additional benefit of implementing this principle is the possibility to use the model for the total gas or electricity network. Hereby the subpopulations should be replaced with asset groups and the lifetime impacts should have an influence on more than one asset group. This allows the users to compare the condition between different asset groups in the network.

$$Total\ Threat\ Subpopulation = \sum_{m=1}^{y} LIPN_m * S_m$$

$$Total\ Opportunity\ Subpopulation = \sum_{o=1}^{z} LIPN_o * S_o$$

Where:

m = Lifetime impact that is a threat
y = Total number of lifetime impacts that is are a threat
$LIPN_m$ = Lifetime Impact Priority Number of lifetime impact "m"
S_m = Impact of lifetime impact "m" on the subpopulation
o = Lifetime impact that are an opportunity
z = Total number of lifetime impacts that are an opportunity
$LIPN_o$ = Lifetime Impact Priority Number of lifetime impact "o"
S_o = Impact of lifetime impact "o" on the subpopulation

Table 13-1: Scoring method for the subpopulation.

Impact	Score
None	0
Normal	1
Extreme	2

It is recommended that adding subpopulations into the prioritization model is researched more.

13.2 Practical recommendations

In this section four practical recommendations regarding the research topic are stated. These recommendations are not directly beneficial for science, but more practical issues for Liander.

Firstly, the process of implementing ALCPs is still ongoing and there is currently not a similar view of the document by all stakeholders. The next steps in the implementation will most likely solve this problem. However, it is still recommended to clearly state the view of the management team and of the creators. This is necessary because the difference in opinion increase the necessary time to create an ALCP. And some did not regard the development of an ALCP as a pleasant experience. An example of the changes between the ALCPs is that the ALCP on powertransformers took about nine months to develop, included an elaborated data analysis and several rewritings. The ALCP on gas delivery stations on the other hand was finished within four months, did not include any data analysis, and the outline of the plan was first approved before a concept document was written.

Secondly, it can be recommended that the exact scope of an ALCP is inspected again. During the research it appeared that the current generic scope has several drawbacks. The main drawback is that the ALCP provides a very generic overview of the condition of the assets. Besides, the decision of making the ALCPs more generic was based on a more extensive type of ALCP. While the document has changed due to the Minto principle. So Liander has to determine whether they prefer details about the condition of the assets over the readability and time required per ALCP.

Implementing the gas scenarios in the model for the ALCP for gas delivery stations returned a lot of positive feedback. Feedback included that the scenarios provided grip on future events and how to score them. It is therefore recommended that Liander also clearly states and implements scenarios for electricity networks.

Finally, it is recommended that the prioritization model should be filled in by multiple persons, preferably the creators, an additional policy adviser, two experts who have a different perspective on the asset, and at least one member of the management team. This will make the outcome more reliable and it will help in creating support in the organization about the outcome of the ALCP.

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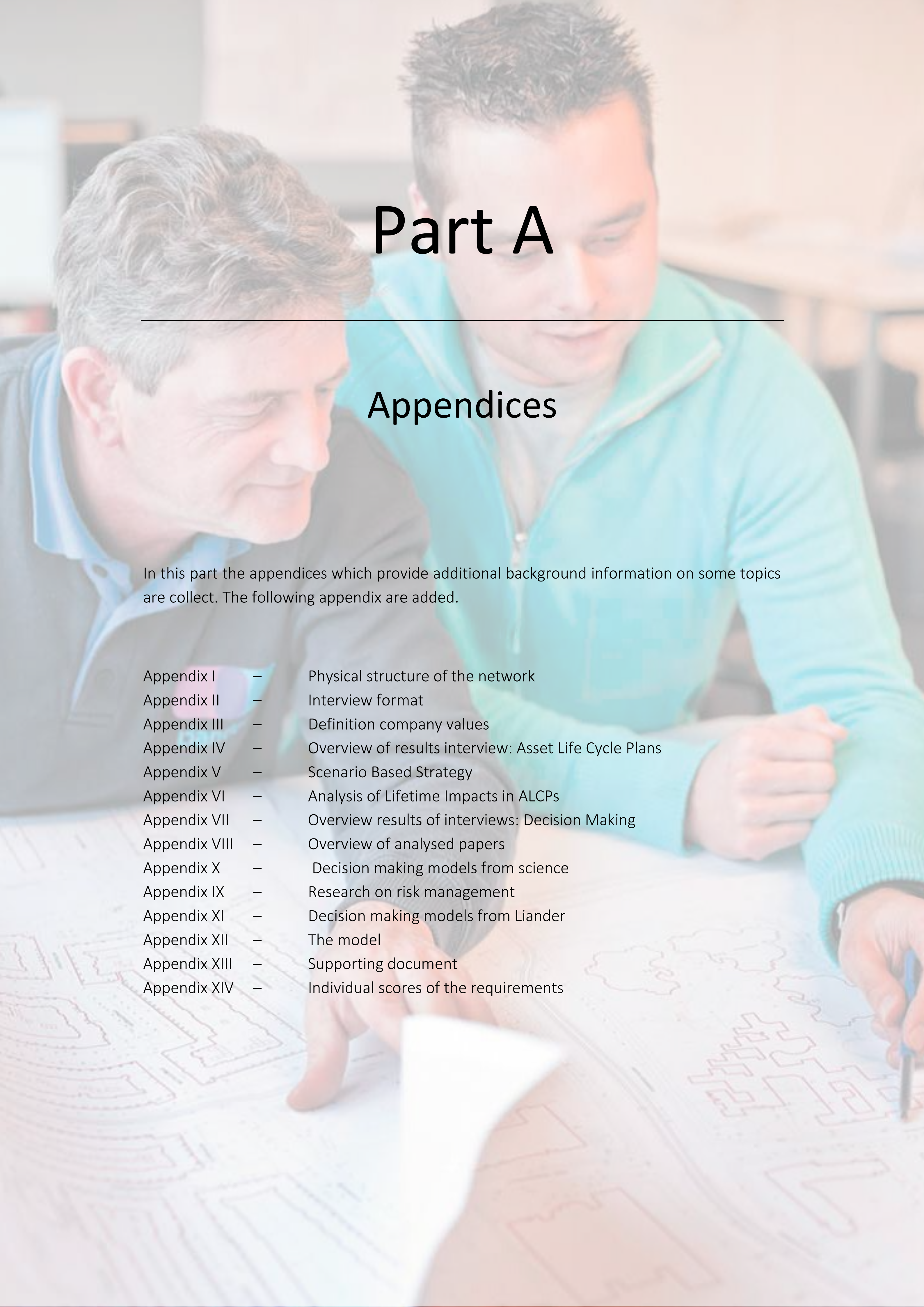


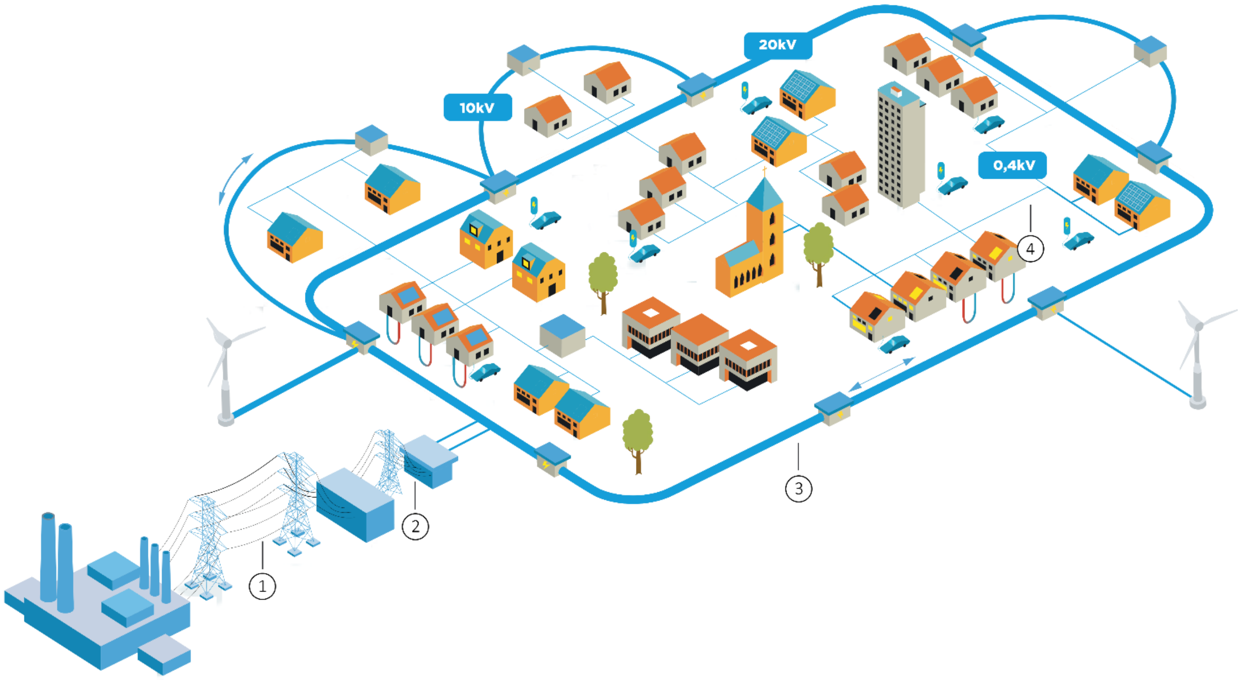
Part A

Appendices

In this part the appendices which provide additional background information on some topics are collect. The following appendix are added.

Appendix I	–	Physical structure of the network
Appendix II	–	Interview format
Appendix III	–	Definition company values
Appendix IV	–	Overview of results interview: Asset Life Cycle Plans
Appendix V	–	Scenario Based Strategy
Appendix VI	–	Analysis of Lifetime Impacts in ALCPs
Appendix VII	–	Overview results of interviews: Decision Making
Appendix VIII	–	Overview of analysed papers
Appendix X	–	Decision making models from science
Appendix IX	–	Research on risk management
Appendix XI	–	Decision making models from Liander
Appendix XII	–	The model
Appendix XIII	–	Supporting document
Appendix XIV	–	Individual scores of the requirements

Appendix I – Physical structure of the network



An overview of the electricity network of Liander. 1: Very high voltage supplied from TenneT. 2: High voltage of Liander for regional transportation. 3: Medium voltage for city transportation. 4: Low voltage for distribution to the customers (Alliander N.V., 2014).

An overview of the gas network of Liander. 1: High pressure supplied from GasUnie. 2: Medium pressure for regional transportation. 3: Low pressure for distribution to the customers (Alliander N.V., 2014).

Appendix II – Interview format

- Thank you for taking the time for an interview

Introduction

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.

Conversation

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?

………

………

………

Appendix III – Definition company values

Overview of the company values of Liander and their explanations, derived from a concept version of the ALCP on power transformers.

Company value	Goal(s)
Safety	Within the risk limits of safety, using and managing the asset may not result into unsafe situations for personnel and environment.
Quality of Delivery	Within the risk limits of quality, the asset should function without interruption, taking current redundancy, back-up assets, and delivery times into account.
Financial	The construction, repair, and maintenance costs should be optimal on both the short and long term.
Laws and Regulations	The asset should meet relevant laws and regulations
Customer and imago	The asset should not cause any impediment to customers (including noise disturbance) as a result of failures, construction, maintenance, and/or replacing the asset.
Sustainability	Circular and recyclable materials and components should be used The asset should have a low CO_2 footprint

Appendix IV – Overview of results interview: Asset Life Cycle Plans

Overview of the answer provided by Liander on the questions “What is your definition of an ALCP?” and “What is your vision on an ALCP?”. The interviews were conducted five members of the management team (MT) and ten policy advisers (PA). The last two column show how often the answer is given by each group.

Definition Asset Life Cycle Plan	MT	AM
An ALCP is a document that describes the future of an asset (group)	2	8
An ALCP is a document that determines the policy that should be executed	3	6
An ALCP is a document to communicate with the management team	3	1
An ALCP is a document that describes the current situation of an asset	2	1
An ALCP is a document that uses statistical models to predict the expected performances of an asset	2	0
An ALCP is a document that determines the expected performances of an asset	1	1
An ALCP is document that provides an overview and that does not make decisions	1	1
An ALCP is a document that optimizes the whole lifecycle of an asset	1	1
The ALCP is used to communicate within asset management	1	0
An ALCP has a supporting task	1	0
An ALCP determines how money is spend	1	0
An ALCP shows a wide perspective of influences on an asset	1	0
An ALCP creates multiple scenarios for the future of an asset and determines which one is best	1	0
An ALCP provides additional information on policy documents	1	0
An ALCP provides a total image of all bottlenecks (knelpunten)	1	0
ALCPs are used to implement ALCM at Liander	1	0
An ALCP puts information on an asset on paper (black on white)	0	1
An ALCP makes decisions on the future of an asset	0	1
An ALCP should show facts about the asset	0	1
An ALCP is a document that says something about an asset	0	1

Appendix V – Scenario Based Strategy

Research on Asset Life Cycle Plans is limited, so to conduct an objective research a wide perspective has to be obtained. Therefore another field of study is researched. The chosen field is scenario based strategy because it shows great similarities with ALCPs. But it is a more mature science and more research on the subject can be found (Linneman & Klein, 1985). This appendix first explains the discipline and shows the similarities with ALCP. Hereafter the relevant characteristics of scenario based strategy are determined, as well as how the model to prioritize and categorize the lifetime impacts can benefit from the findings.

Scenarios are possible sequences of events that depict a possible future state, or a range of possible future states and different conditions in either a qualitative or quantitative format (Linneman & Klein, 1985). Or according to Durance & Godet scenarios are means to clarify present actions in light of future occurrences (Durance & Godet, 2010). Among others, an ALCP determines what needs to be done to realize performance objectives in the coming years. Requiring the determination of a future state or future occurrences. This can be done in a qualitative format, with data analyses like Wei-bull curves, or in a quantitative format using tacit knowledge. Furthermore, scenarios are multidisciplinary and created using a collective group thinking process (Durance & Godet, 2010). Similar to ALCP which are also multidisciplinary and are created in a group expert session. Comparing both principles shows great similarities. Therefore scenarios are inspected more closely to determine how they select important future events, and how scenarios are implemented in an organization.

Six elements of scenario based strategy
By means of an analysis on scenario based strategy, six elements on determining possible future events are identified.

The first element is the combination of personal judgement of experienced employees and statistics (Durance & Godet, 2010). It is important not to rely on one of the two. Human judgment is often biased, as people have a distorted view of the future. Tending to see a future world that keeps on changing (Durance & Godet, 2010; Linneman & Klein, 1985; Ratcliffe, 2000). While using only statistics creates a false sense of certainty (Durance & Godet, 2010).

The second element is showing uncertainty. Future scenarios with even the most reliable elements can never eliminate all uncertainty. Therefore a scenario should show uncertainty instead of reducing or eliminating it. A good method of doing this is creating multiple scenarios showing multiple outcomes of uncertainties (Linneman & Klein, 1985).

The third element is to identify all possible future events is time. Time is necessary to conduct the required analyses, but also to enable the team to think about all the implications of the analyses (Durance & Godet, 2010). So the decision on which lifetime impact is most important should not be made too fast.

The fourth element to successfully determine the future events is support from the organization. A scenario is typically constructed for a period of five to seven years, so the future events should be true for this time period (Durance & Godet, 2010). This requires support from management, as well as support from the users of the scenarios. At Shell this problem is tackled by bringing all business entities together to create one common scenario. Preventing sudden shifts when a small group suddenly has a different opinion, but successful enough so Shell could deal with the oil shock is 1971-1972 (Wack, 1985a, 1985b).

This leads to the fifth element; determining future events is a group activity including top management (Ratcliffe, 2000). Involving top management by reviewing preliminary versions and demanding their input assures their acceptance of the scenario.

Finally the process of determining future events should be transparent and methodological. This enables them to be usable for a long period of time and helps building new scenarios (Durance & Godet, 2010). For example, using a simple matrix which allocates high, medium, and low scores to a key factor in a scenario (Ratcliffe, 2000).

Lifetime impacts

Scenario based strategy is at first hand very different from lifetime impacts. But by inspecting it more closely a better understanding of how to categorize and prioritize lifetime impacts can be obtained. The most important is that selecting the lifetime impacts should be executed by multiple persons involving different company divisions, as well as the management. This would improve the credibility of the decisions, making the ALCP more robust and accepted at a company. Furthermore the model should provide a structured and transparent method that shows uncertainty during decision making.

Appendix VI – Analysis of Lifetime Impacts in ALCPs

The tables below show an overview of the number lifetime impacts in each of the four analysed ALCPs indicated by type. By showing the number of lifetime impacts per version, the researcher spotted trends if the impacts grew or shrink in number.

Distribution Transformers	T	E	C	K	O
Version 1	8	4	1	2	3
Version 2	7	9	5	6	4
Version 3	4	7	4	4	5
Version 4	4	7	4	5	5

Switch gears	T	E	C	K	O
Version 1	3	2	1	1	1
Version 2	5	5	2	2	5
Version 3	8	6	2	2	5
Version 4	9	6	3	2	6
Version 5	13	5	1	2	8

Gas Delivery Stations	T	E	C	K	O
Version 1	7	7	3	6	5
Version 2	19	6	3	6	5
Version 3	25	9	6	8	7
Version 4	24	9	6	8	7

SVS - Switch gears	T	E	C	K	O
Version 1	14	14	14	14	14
Version 2	13	13	13	13	13
Version 3	8	8	8	8	8
Version 4	15	3	3	4	0
Version 5	11	4	2	1	0

Appendix VII – Overview results of interviews: Decision Making

Answers to the question “How does Liander currently make a decision between important and less important issues?”. Including the number of times the answer is provided.

Decision making at Liander	#
Decisions are made based on knowledge, experience, and opinions	8
Decisions are made based on emotions	3
Decisions are made based on external influences	2
Decisions are made in association with colleagues	2
Decisions are made in multidisciplinary group discussion	1
Decisions are made based on certainties	1
Decisions are made in consultation with suppliers	1
Decisions are made based on financial criteria	1
Decisions are made using the INP process	1

Appendix VIII – Overview of analysed papers

	A decision making model should be able to deal with multiple, conflicting criteria.	A decision making model requires the input of experts at the company.	A decision making model should be able to handle uncertainties.	A decision making model should be easy to use by all users without having prior	A decision making model should be able to deal with both qualitative and quantitative	A decision making model should not consider every aspect of the decision, but focus on	A decision making model should be transparent.	A decision making model should improve over time.	Different users should get similar results from a decision making model.	The decision making model should be flexible since every decision is different
(Evans et al., 2013)	x	x		x	x			x		x
(Chamoli, 2015)										
(Lambert et al., 2001)		x								
(Halmes, Kaplan, & Lambert, 2002)	x					x				
(Triantaphyllou & Chi-Tun, 1996)								x		
(Aqlan & Mustafa Ali, 2014)	x									
(Bowles & Peláez, 1995)									x	
(Jamshidi et al., 2015)	x	x	x	x						
(Cockshott, 2005)	x									
(Sun et al., 2012)	x	x		x	x	x	x			x
(Mokhtari et al., 2011)	x									
(Woodhouse, 2005b)	x					x				
(Geary, 2002)	x		x				x		x	
(Nordgård, 2012)	x	x	x				x			
(Nordgård, Sand, & Wangensteen, 2009)	x		x			x				
(Melchers, 2001)	x	x						x		
(Khan, Sadiq, & Haddara, 2004)		x	x		x			x	x	

(Pintelon & Gelders, 1992)	x		x	x	x					
(Woodhouse, 2005a)	x		x	x		x				
(Rommert Dekker & Scarf, 1998)				x			x			
(Lounis et al., 1998)	x						x			
(Jones-Lee & Aven, 2011)	x		x							
(Kiker et al., 2005)	x	x	x	x	x					
(Komonen et al., 2000)		x				x				
(Rogerson & Lambert, 2012)	x	x			x					
(Catrinu & Nordgård, 2011)	x	x	x	x	x	x	x			x
(Parada Puig, Basten, & van Dongen, 2013)		x		x	x					
(Langseth & Portinale, 2007)	x									
Total	20	12	10	9	9	7	6	4	3	3

Appendix IX – Research on risk management

To obtain an objective view on the subject, it is valuable to research lifetime impacts from different perspectives. However, research on lifetime impacts is limited in the field of asset management. To be able to take a wider view the definition of lifetime impacts is made more abstract. Resulting into: “Long term uncertain risks”. Looking from this perspective, numerous fields of study can be identified that are interesting to inspect. For example, insurance companies, long term planning, rental companies, or political decisions. So the research can be extended by analysing these fields of studies. To limit the scope of the research, the focus has been on just one topic, namely insurance companies.

During the last decade the main activity of insurance companies has changed to identifying risks. A change caused by several large unexpected events during the turn of the millennium (Mount, Pargeans, & Hansen, 2013). Making researching this field interesting, since the energy industry also faces big changes. Besides, insurance management can be regarded somewhat similar to asset management when regarding the different insurances as assets. Also the financial scale of operations is similar to asset management, handling billions of euros.

As risk management is their core business, a lot of development has been made during the last decade. The result is that the risks models have become increasingly complex, automated, and specialized. But also increasingly competitive and secret (Mount et al., 2013). Making it hard to identify requirements and trends. However, four characteristics for good risks management at insurance companies can be identified (Mount et al., 2013).

1. Superior management relative to the insurers risk profile based on the five risk types (credit, market, underwriting, operational, and strategic)
2. Superior capital management and financial flexibility to ensure costs effectiveness
3. Strong Enterprise Risk Management system
4. Strong economic capital modelling activities

Relation with lifetime impacts

Whereas identifying and managing risks is the core business of insurance companies, are lifetime impacts a part of the larger concept of asset management. So the attention it receives is not comparable and thus neither should their methodology be. So a complex, automated and specialized model is not per se required. But from the four characteristics it can be deduced that the model should look at all different types of lifetime impacts (operational and strategic). Should be specialized for every company. Ensure costs effectiveness when prioritizing lifetime impacts. And that the lifetime impacts should be handled using a structured model.

Appendix X – Decision making models from science

1: Multi Criteria Decision Model

Lifetime impacts, Asset Life Cycle Plans, and even Asset Life Cycle Management involves the use of multidisciplinary teams and knowledge. Especially since the lifetime impacts are multidisciplinary by nature, as can be concluded from the TECKO analysis. For that reason multi criteria decision models are analysed to discover if and how they can be useful for prioritizing the lifetime impacts.

Decision making in multi criteria decision model means choosing an alternative based on multiple criteria. The combination of an alternatives and criteria results in consequences, and these can be evaluated (Brugha, 2004). The most common type of MCDM is a matrix (Kiker et al., 2005). In the matrix alternatives (A_n), criteria (C_m) and the corresponding consequences (a_{nm}) are determined. Making MCDM a powerful tool for decision making with multiple (conflicting) criteria by structuring the problem in a systematic way (Chamoli, 2015; Pomerol & Romero, 2000). Essential for using MCDM is that the user has a set of values to identify each consequence. One of the most used method to do this is using the multi-attribute value function theory (Belton & Stewart, 2002). In this theory the user creates a value function $V(A_i)$ that is constructed by a comparison between the consequences of a criterion (scores) and a comparison of the criteria (weights). In its simplest form this can be written as seen in formula below. Where $v_k(a_{ik})$ are the scores and w_k are the weights. The value function is calculated for each alternative (A_n) and the highest score is the recommended decision (Catrinu & Nordgård, 2011).

$$V(A_i) = \sum_{k=1}^{n} w_k v_k(a_{ik})$$

A drawback of this method is when the decision is dealing with uncertainties, since the scores are then harder to quantify (Catrinu & Nordgård, 2011). This can be solved in several different ways, including making use of scenario's, fuzzy logic (will be discussed in later paragraph), multi-attribute utility theory (MAUT), and many others (Aqlan & Mustafa Ali, 2014; Catrinu & Nordgård, 2011; Figueira, Greco, & Ehrgott, 2005; Keeney & Raiffa, 1999). Making MCDM adaptable for different purposes and uses.

2: Reliability Centred Maintenance

Reliability Centred Maintenance (RCM) is a widely used and popular maintenance concept (Ruitenburg et al., 2014). The concept originates from the aviation industry, in the design project of the Boeing 747 (Jumbo Jet) (Moubray, 1997). RCM can be separated in four features:

1. Focus on preserving the asset function;

2. The identification of failure modes that would disrupt this function
3. The prioritization of these failure modes
4. The selection of appropriate maintenance tasks for the high priority failure modes (Smith & Hinchcliffe, 2003).

The third feature (prioritizing the failure modes) is relevant to analyse, since it represents the decision method in RCM and failure modes are in many ways similar to lifetime impacts.

Prioritizing the failure modes in RCM happens with the use of a Failure Mode and Effects Analysis (FMEA). In the FMEA the failure modes are modelled on their severity, occurrence, and likelihood (Moubray, 1997). Each failure receives a number from 1-10 for each factor. And the product of the factors determine the Risk Priority Number of a failure mode allowing the users to compare them. After determining the failure mode with the highest priority, appropriate measures can be selected. Using the RCM concept, this happens using a structured method in the form of a decision diagram. In this decision diagram the consequences, eventual preventive actions, and three standard questions are modelled. The result is an action that should be executed to mitigate the failure mode (Moubray, 1997).

Even though FMEA is an established and widely used method, there are several drawbacks. The largest of them are the shortcomings in the way the RPN can be interpreted. And that it is a time consuming model, especially when the number of failure modes increase (Bowles & Peláez, 1995).

3: Hierarchical Holographic Modelling

Hierarchical Holographic Modelling (HHM) is a methodology that is used to identify and manage sources of risk in complex systems (Lambert et al., 2001). In for example telecommunications, energy systems, and gas and oil systems more (Halmes et al., 2002). HHM identifies risks by parting the system into its main components and the sub(sub) components. A similar process as happens in systems engineering (Blanchard & Fabrycky, 2010). Hereafter a group of experts define multiple risks per component. The result is an extensive lists of risks (often in the thousands). The second step, managing the risks, systematically reduces the risks to several dozens. This should also be the case for the lifetime impacts.

There are several options to reduce the number of risks using HHM, for this section two different methods are discussed. In the first method individual analyst match the risks to the three most relevant areas of impact. These areas are predetermined and differ per company. The next step is to combine redundant sources of risk, creating a smaller list of risk categories. Finally, the remaining risk categories are ranked in low, medium, high impacts on different (predetermined) attributes. By assigning numerical values to the scores, the highest risks can be determined (Lambert et al., 2001). This method has been applied in identifying the most important sources of risk in the acquisition of a billion dollar software and database system (Lambert et al., 2001).

The second method is an eight phases plan called the Risk Filtering, Ranking and Management method (RFRM). The first phase is identifying all sources of risk. In the second phase the risks are judged on scope, temporal domain, and level of decision making. Eliminating the risks that are not within the right bounds. Phase three uses a risk matrix which determines the severity of a risk by its effect and likelihood. The risks with a high and extremely high severity are selected, eliminating the rest. The next step is multi-criteria evaluation, using predetermined criteria. By using numerical values the risk with the highest priority can be selected. The last step in prioritizing is using a risk matrix, where the likelihood is determined using Bayesian Networks (Langseth & Portinale, 2007). The final step of the method include selecting the proper mitigating actions and a feedback loop to improve the method. This method has been used in a case where the biggest risk for the US army in the Balkan are determined (Dombroski, Haimes, Lambert, Schlussel, & Sulcoski, 2002; Halmes et al., 2002).

The HMM method is a structured method to reduce the number of risks and select the most important. However, the largest drawback of HHM is that it is not an established method used in lots of researches.

4: AHP & TOPSIS

Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity of an Ideal Solution (TOPSIS) are two decision methods that are often combined. Creating the AHP and TOPSIS method (Chamoli, 2015; Torfi et al., 2010). Both methods use multiple criteria and are used for selecting the best alternative among many alternatives (Chamoli, 2015).

Analytical Hierarchy Process is a tool that can be used to determine the priorities between different criteria. This is done by comparing different alternatives pairwise over different criteria. The comparison is done with numerical values resulting in a ranking between different alternatives on which a decision is made. Important for the AHP process is determining a goal beforehand, since the criteria and the alternatives are all compared to their added value to the goal (Saaty, 1990).

Technique for Order Preference by Similarity of an Ideal Solution is a method that selects the best alternative amongst others. In TOPSIS the best alternative has the shortest distance to the positive-ideal solution and the longest distance to the negative-ideal solution (Hwang & Yoon, 1981). In which the positive-ideal solution is the highest possible rank for all criteria, including different weighting factors. The TOPSIS method is a compensatory model, allowing for a trade-off between different criteria (Greene, Luther, Devillers, & Eddy, 2010).

Combining the two methods combines the best of both world. The AHP weighs the different criteria and the TOPSIS ranks the alternatives, (Chamoli, 2015; Torfi et al., 2010). And is used in numerous researches[31].

AHP and TOPSIS have been criticized because of the large number of pairwise comparisons, taking a lot of time. Furthermore it has difficulty to deal with handle uncertainties (Jamshidi et al., 2015).

[31] *A search on sciencedirect.com using the search query: TITLE-ABSTR-KEY (AHP) and TITLE-ABSTR-KEY(TOPSIS) returns 137 results. (obtained in 2015)*

5: Fuzzy

It is often hard to assign a score to a criteria for a certain alternative. Mostly because it requires the transformation of qualitative data (predicted failure rates, current condition, preferences, and other factors that are often best guesses) into quantitative values (using a score between 1-10). For example, "What is the value of the impact of the *n*th alternative in terms of RUL extension?" (Triantaphyllou & Chi-Tun, 1996). The "hidden" transformation makes decisions often less precise and transparent then the quantitative (crisp) value appears to be. This would also be the case with lifetime impacts, since they include a lot of uncertainty (Bowles & Peláez, 1995).

Fuzzy logic, founded by Lofti Zadeh at UC Berkeley, is a method that converts linguistic terms into numerical values (Zadeh, 1965). This enables decision making based on vague, uncertain, and qualitative information (Evans et al., 2013). Besides, it converts crisp values (true or false) into fuzzy values that range between completely true and completely false (Arabacioglu, 2010). Further research on the topic by Dubois and Prade have converted fuzzy logic into fuzzy operations, making them useful in decision making (Dubois & Prade, 1979, 1980). However, it is still not a method that can be used to make decisions. But its ability is to improve other decision making methods. For example Fuzzy FMEA (Jamshidi et al., 2015), Fuzzy AHP, Fuzzy TOPSIS (Chamoli, 2015; Mokhtari et al., 2011; Torfi et al., 2010), etc.

A fuzzy number consist out of three components (a_1, a2, a3) that range between 0 and 1 as is depicted by figure X.1. This is the membership function and it represent the degree of truth for a certain variable, for example likelihood. The x-axis represents the scale of the variable. A predetermined allocation of linguistic terms to a certain fuzzy set of number, allows a user to determine the fuzzy number for a certain variable. Further explained in figure X.2 (Triantaphyllou & Chi-Tun, 1996).

Fuzzy received many criticism because it would not provide a representation of truth. However through the years it gained terrain, and it is currently widely used (Ross, 2010).

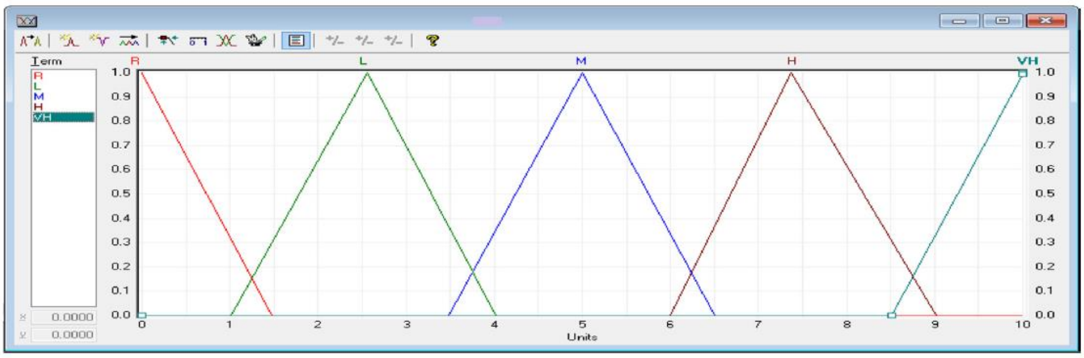


Figure X.1: Depiction of the constant scale of a fuzzy set (Jamshidi et al., 2015).

Rating	(O_1)		(O_2)	(O_3)	Fuzzy number
	Chance of failures	Corresponding *MTBF*	Corresponding time	Corresponding time	
Very high (VH)	Failure is almost inevitable	<3 months	Same failures in 3 months	It is not visible at all.	(8.5, 10, 10)
High (H)	Repeated failures	3–6 months	Same failures in 3–6 months	Visible while using the device	(6, 7.5, 9)
Moderate (M)	Occasional failures	6 months to 2 years	Same failures in 6–24 months	Visible between two inspection intervals	(3.5, 5, 6.5)
Low (L)	Relatively few failures	2–10 years	Same failures in 2–10 years	Visible while inspecting	(1, 2.5, 4)
Remote (R)	Failure is unlikely	>10 years	Failure is unlikely >10 years	Visible before an inspection	(0, 0, 1.5)

Figure X.2: Depiction of possible combinations of linguistic and fuzzy numbers (Jamshidi et al., 2015).

Appendix XI – Decision making models from Liander

1: Integrative Net Planning

The Integrative Net Planning (INP) process is a widely known process within Asset Management to identify, evaluate, and mitigate risks at Liander. The process first identifies potential risks as bottlenecks (knelpunten). The bottlenecks are examined by the preliminary filter in figure XI.1 which tests if they are suitable. If they are, the bottlenecks are evaluated using the risk matrix seen in figure XI.2. This matrix scores the bottlenecks on impact and probability of the six business values of Liander. Hereafter a panel of experts discuss and verify the output of the risk matrix. If the risk value is "very high" or "high", the risk is mitigated. Other risks are not immediately mitigated, but are analysed to determine the efficiency of the risk.

The three most important characteristics of the INP process are that everybody can provide a bottleneck as input to the process. Secondly, a standard and easy to use model (risk matrix) is used to evaluate all the risk using an identical method. Finally, all risks are discussed by a panel of experts from different backgrounds to verify the risk score and to prevent mistakes.

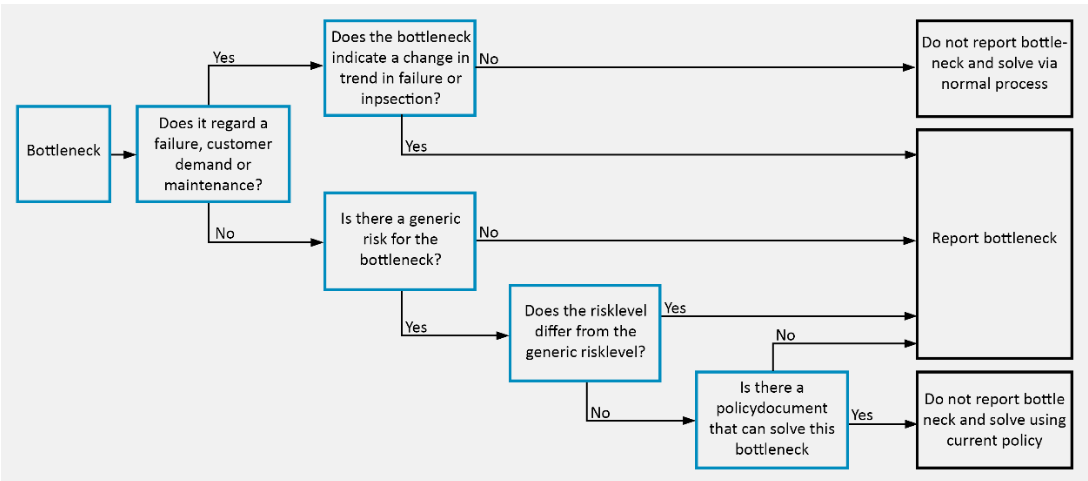


Figure XI.1: Process of determining if a bottleneck should be processed as a risk (Liander N.V., 2015b)

Riskmatrix Liander Assetmanagement											
							Probability of occurrence (per company value)				
Impact on company values							Possible	Probable	Regularly	Yearly	Montly
							Heard of in the industry	Multiple occurrences in the industry	Multiple occurrences at Liander	One to several times a year at Liander	One to several times a month at Liander
Category	Safety	Quality of Service	Customer and Imago	Laws and Regulations	Financial	Sustain-ability	Less than 1 time per 100 years	1 time per 10 to 100 years	1 time per 1 to 10 years	1 to 10 times a year	More than 10 tiems a year
Catastrophic	Multiple deaths	>10.000.000 SAIDI	Long-term widespread visibility in public domain	License revocation, accumulation of fines, criminal proceedings with jailtime, structur-al conflict with ACM	Damage of more than 10M Euro	Emmisions of more than 50kton CO_2	M	H	ZH	ZH	ZH
Serious	Accident with deadly result or serious injury	1.000.000 to 10.000.000 SAIDI	Short-term widespread visibility in the public domain	Administrative fine, fine category 4, 5, and 6; criminal pro-ceedings; conflict with ACM	Damage of 1M to 10M Euro	Emmisions of 50 to 500 kton CO_2	L	M	H	ZH	ZH
Severe	Accident with serious injury and non-attendence	100.000 to 1.000.000 SAIDI	Long-term small-scale visibility in the public domain	Cease and desist; fine category 2 and 3; law-suit 5000 customers; accumulation of inci-dents with ACM	Damages of 100K to 1M Euro	Emmisions of 5 to 50 kton CO_2	N	L	M	H	ZH
Moderate	Accident with injury and non-attendence	10.000 to 100.000 SAIDI	Short-term small-scale visibility in the public domain	Binding instruction; fine category 1; law-suit 500 customers; incident with ACM	Damage of 10K to 100K Euro	Emmisions of 0.5 to 5 kton CO_2	N	N	L	M	H
Small	Near-accident, accident with little injury, first aid	< 10.000 SAIDI	Little to no visibility in the public domain	Warning; lawsuit 50 customers; difference of opinion with ACM	Damages small-er than 10K Euro	Emmisions smaller than 0.5 kton CO_2	N	N	N	L	M

Figure XI.2: Risk matrix at Liander (Liander N.V., 2013)

2: Innovation funnel

The innovation department within asset management is responsible for developing innovations that can be used to optimize the energy network. There are numerous ideas that can potentially be used, but only a few will be developed into projects. To guide this process, the department uses the innovation funnel which can be seen in figure XI.4. The funnel consist out of five phases; idea, business case, proof of concept, development, and implementation. The selection of the ideas is based on an iterative process of developing the idea, and discussing it with either the management team or the PIB (Project Investment Board).

The most important characteristic of the decision method is the clear step-by-step process, and before the next step is taken the current one has to be approved by the management. This way the management is involved in the process and projects are eliminated in an early stage and not when they are fully developed.

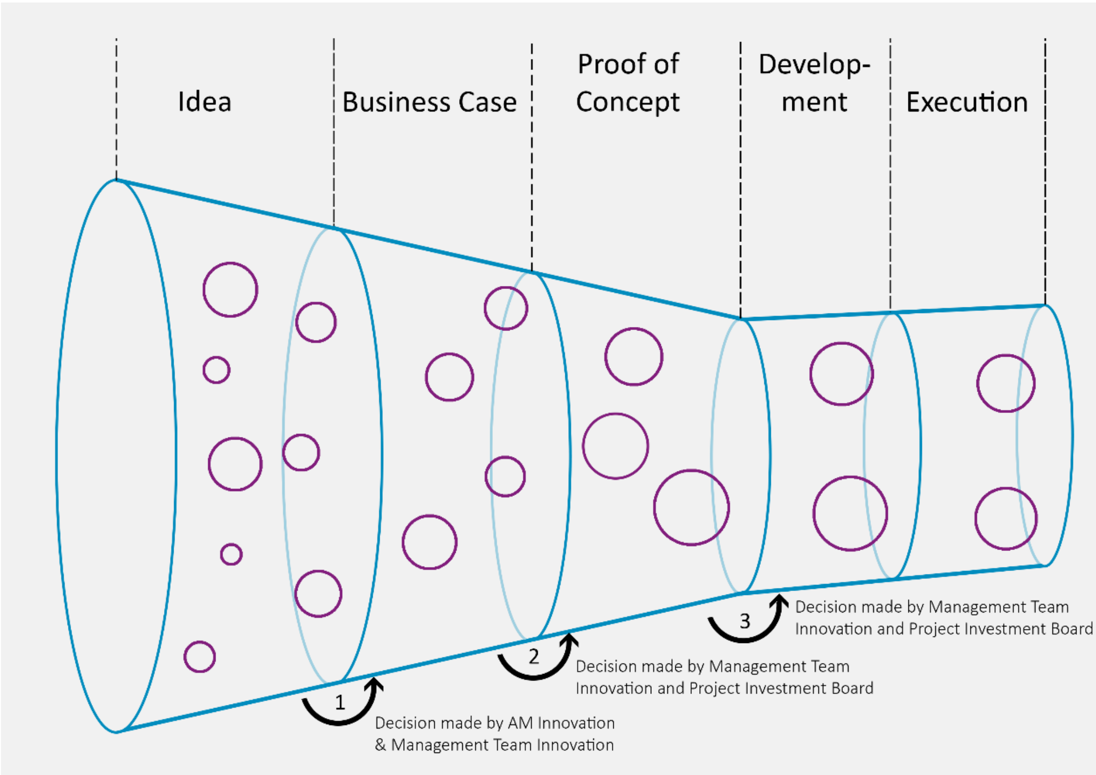
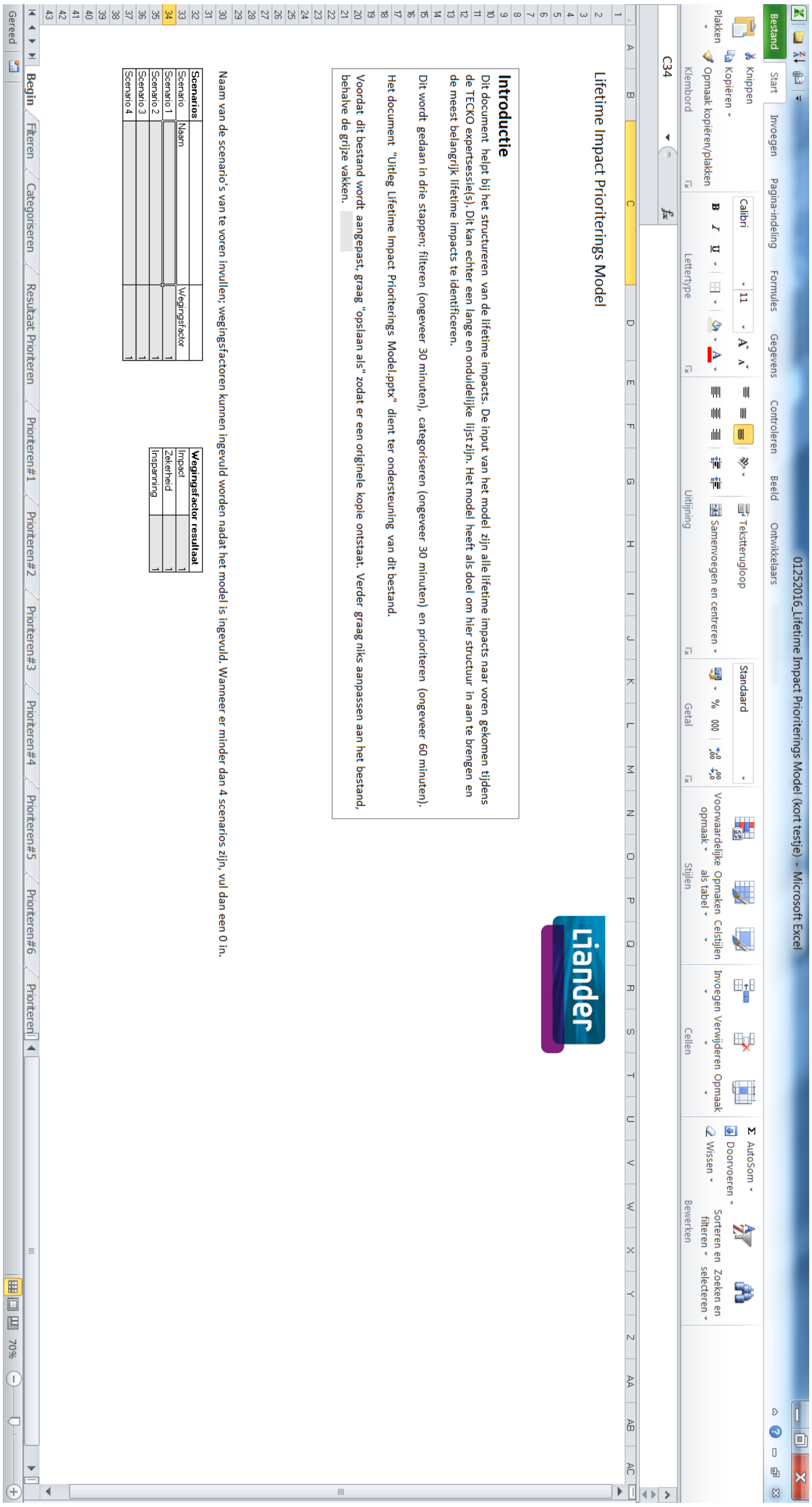
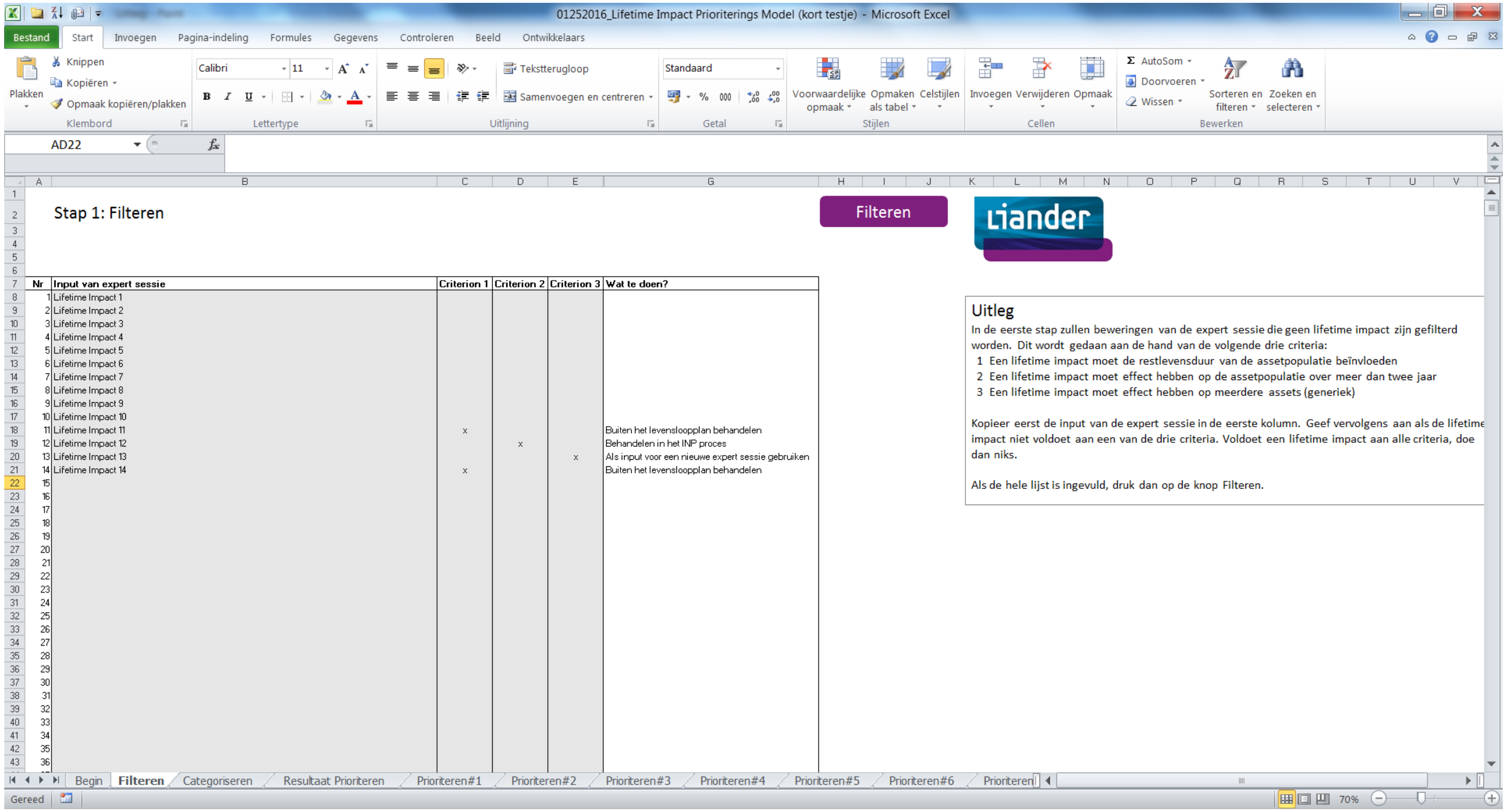


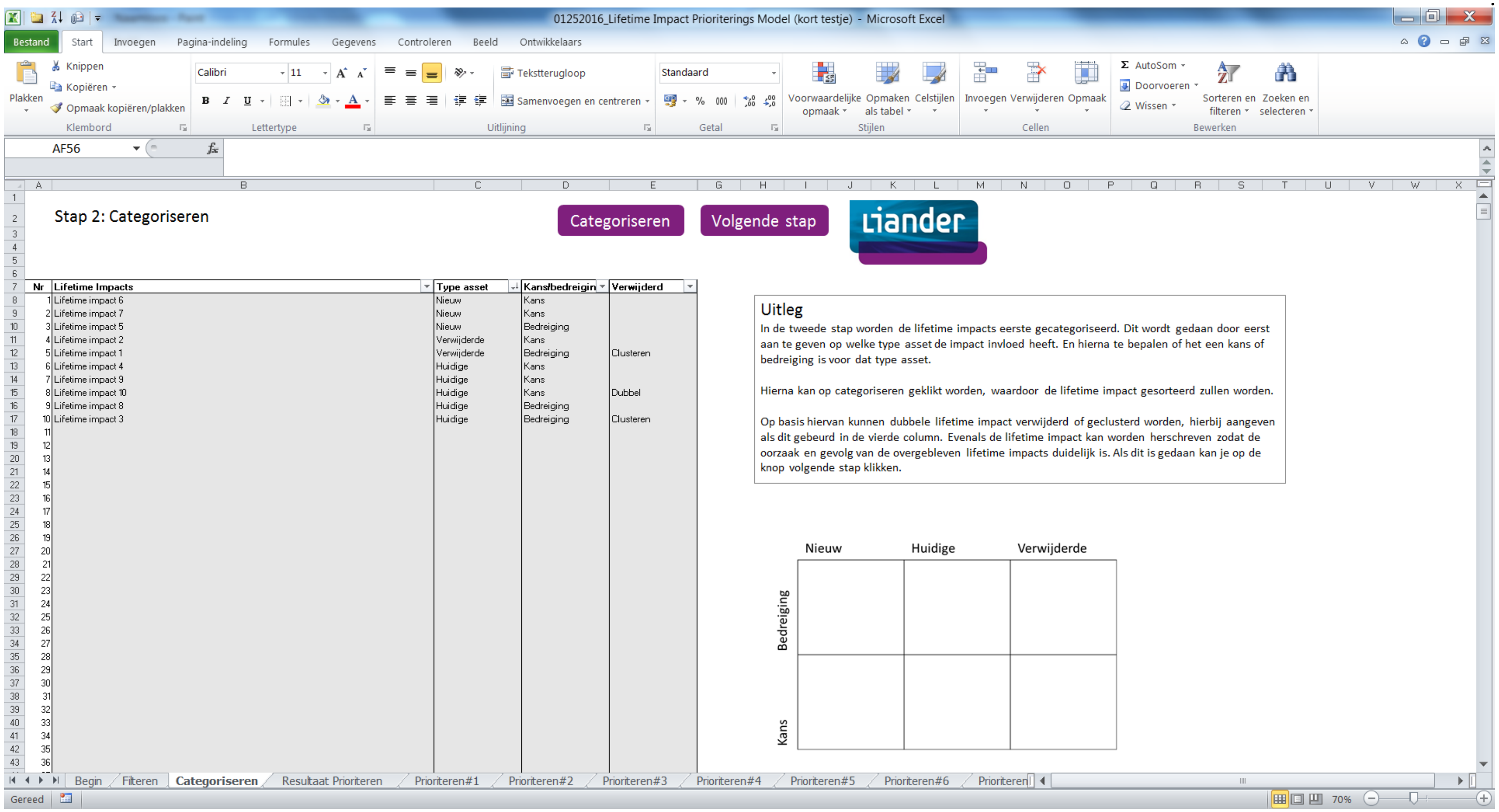
Figure XI.4: The five stages of the innovation funnel.

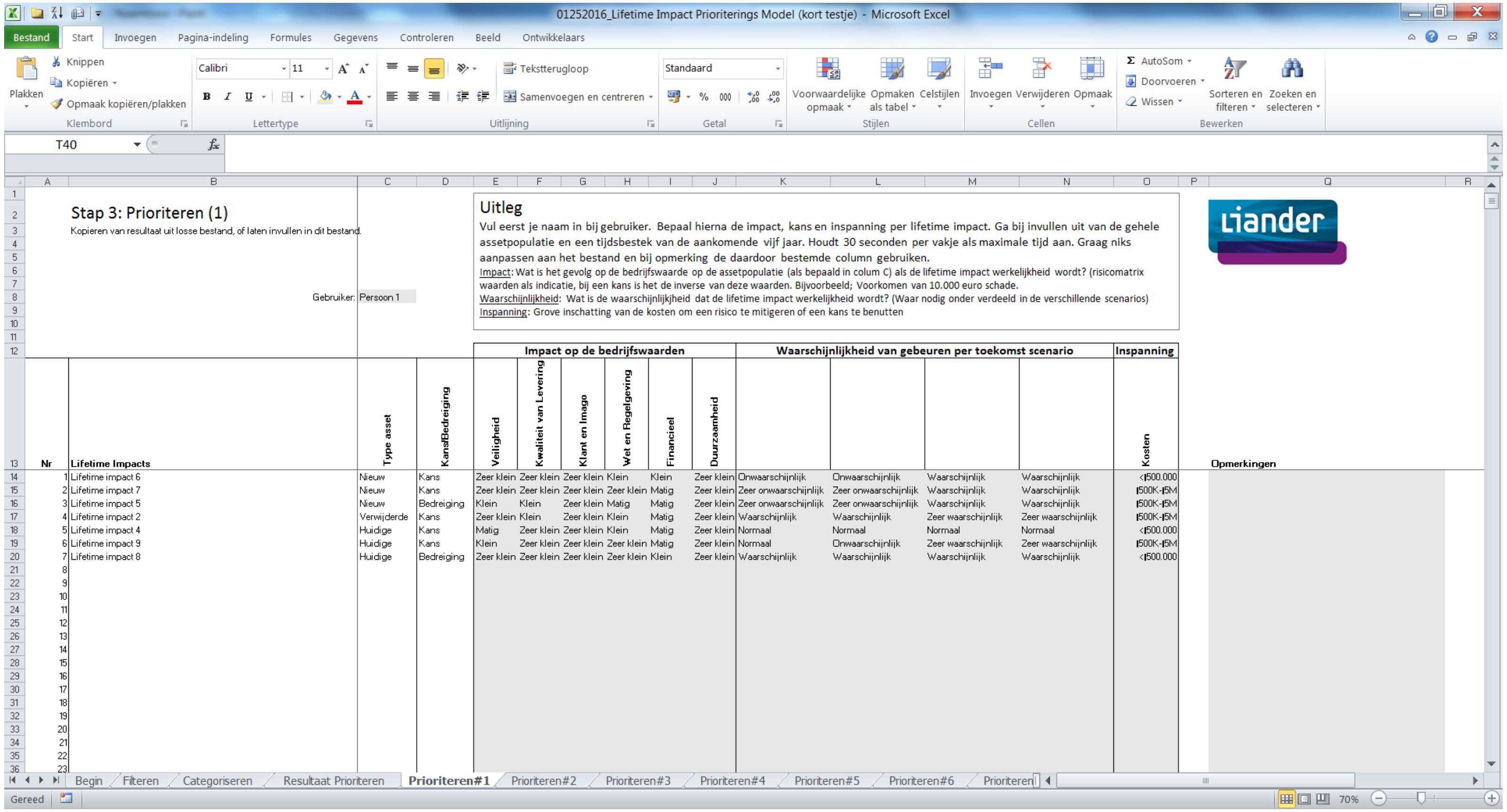
Appendix XII – the Model

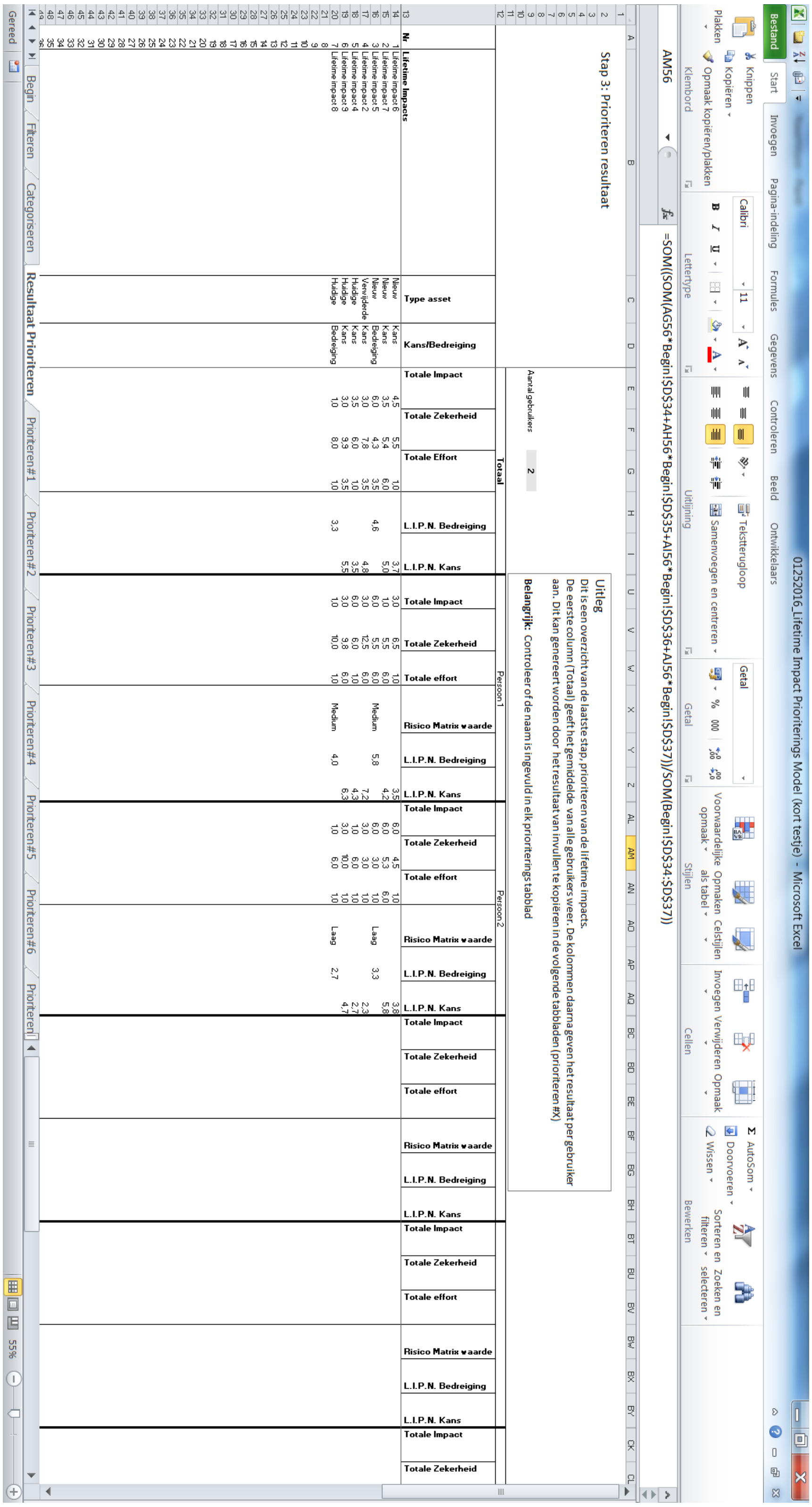
The screenshots below show the actual model made in Excel. If one desires to use the model, he/she can contact the researcher.




01252016_Lifetime Impact Prioriterings Model (kort testje) - Microsoft Excel
Stap 1: Filteren
Filteren
Liander
Nr | Input van expert sessie | Criterion 1 | Criterion 2 | Criterion 3 | Wat te doen?
1 Lifetime Impact 1
2 Lifetime Impact 2
3 Lifetime Impact 3
4 Lifetime Impact 4
5 Lifetime Impact 5
6 Lifetime Impact 6
7 Lifetime Impact 7
8 Lifetime Impact 8
9 Lifetime Impact 9
10 Lifetime Impact 10
11 Lifetime Impact 11 x Buiten het levensloopplan behandelen
12 Lifetime Impact 12 x Behandelen in het INP proces
13 Lifetime Impact 13 x Als input voor een nieuwe expert sessie gebruiken
14 Lifetime Impact 14 x Buiten het levensloopplan behandelen
Uitleg
In de eerste stap zullen beweringen van de expert sessie die geen lifetime impact zijn gefilterd worden. Dit wordt gedaan aan de hand van de volgende drie criteria:
1 Een lifetime impact moet de restlevensduur van de assetpopulatie beïnvloeden
2 Een lifetime impact moet effect hebben op de assetpopulatie over meer dan twee jaar
3 Een lifetime impact moet effect hebben op meerdere assets (generiek)
Kopieer eerst de input van de expert sessie in de eerste kolumn. Geef vervolgens aan als de lifetime impact niet voldoet aan een van de drie criteria. Voldoet een lifetime impact aan alle criteria, doe dan niks.
Als de hele lijst is ingevuld, druk dan op de knop Filteren.
Begin | Filteren | Categoriseren | Resultaat Prioriteren | Prioriteren#1 | Prioriteren#2 | Prioriteren#3 | Prioriteren#4 | Prioriteren#5 | Prioriteren#6


01252016_Lifetime Impact Prioriterings Model (kort testje) - Microsoft Excel
Stap 2: Categoriseren
Categoriseren
Volgende stap
Liander
Nr | Lifetime Impacts | Type asset | Kans/bedreigin | Verwijderd
1 Lifetime impact 6 Nieuw Kans
2 Lifetime impact 7 Nieuw Kans
3 Lifetime impact 5 Nieuw Bedreiging
4 Lifetime impact 2 Verwijderde Kans
5 Lifetime impact 1 Verwijderde Bedreiging Clusteren
6 Lifetime impact 4 Huidige Kans
7 Lifetime impact 9 Huidige Kans
8 Lifetime impact 10 Huidige Kans Dubbel
9 Lifetime impact 8 Huidige Bedreiging
10 Lifetime impact 3 Huidige Bedreiging Clusteren
Uitleg
In de tweede stap worden de lifetime impacts eerste gecategoriseerd. Dit wordt gedaan door eerst aan te geven op welke type asset de impact invloed heeft. En hierna te bepalen of het een kans of bedreiging is voor dat type asset.
Hierna kan op categoriseren geklikt worden, waardoor de lifetime impact gesorteerd zullen worden.
Op basis hiervan kunnen dubbele lifetime impact verwijderd of geclusterd worden, hierbij aangeven als dit gebeurd in de vierde column. Evenals de lifetime impact kan worden herschreven zodat de oorzaak en gevolg van de overgebleven lifetime impacts duidelijk is. Als dit is gedaan kan je op de knop volgende stap klikken.
Nieuw
Huidige
Verwijderde
Bedreiging
Kans
Begin
Filteren
Categoriseren
Resultaat Prioriteren
Prioriteren#1
Prioriteren#2
Prioriteren#3
Prioriteren#4
Prioriteren#5
Prioriteren#6
Gereed


01252016_Lifetime Impact Prioriterings Model (kort testje) - Microsoft Excel
Stap 3: Prioriteren (1)
Kopieren van resultaat uit losse bestand, of laten invullen in dit bestand.
Gebruiker: Persoon 1
Uitleg
Vul eerst je naam in bij gebruiker. Bepaal hierna de impact, kans en inspanning per lifetime impact. Ga bij invullen uit van de gehele assetpopulatie en een tijdsbestek van de aankomende vijf jaar. Houdt 30 seconden per vakje als maximale tijd aan. Graag niks aanpassen aan het bestand en bij opmerking de daardoor bestemde column gebruiken.
Impact: Wat is het gevolg op de bedrijfswaarde op de assetpopulatie (als bepaald in colum C) als de lifetime impact werkelijkheid wordt? (risicomatrix waarden als indicatie, bij een kans is het de inverse van deze waarden. Bijvoorbeeld; Voorkomen van 10.000 euro schade.
Waarschijnlijkheid: Wat is de waarschijnlijkheid dat de lifetime impact werkelijkheid wordt? (Waar nodig onder verdeeld in de verschillende scenarios)
Inspanning: Grove inschatting van de kosten om een risico te mitigeren of een kans te benutten
Liander
Impact op de bedrijfswaarden
Waarschijnlijkheid van gebeuren per toekomst scenario
Inspanning
Nr
Lifetime Impacts
Type asset
Kans/Bedreiging
Veiligheid
Kwaliteit van Levering
Klant en Imago
Wet en Regelgeving
Financieel
Duurzaamheid
Kosten
Opmerkingen
1 Lifetime impact 6 Nieuw Kans Zeer klein Zeer klein Zeer klein Klein Klein Zeer klein Onwaarschijnlijk Onwaarschijnlijk Waarschijnlijk Waarschijnlijk <€500.000
2 Lifetime impact 7 Nieuw Kans Zeer klein Zeer klein Zeer klein Zeer klein Matig Zeer klein Zeer onwaarschijnlijk Zeer onwaarschijnlijk Waarschijnlijk Waarschijnlijk €500K-€5M
3 Lifetime impact 5 Nieuw Bedreiging Klein Klein Zeer klein Matig Matig Zeer klein Zeer onwaarschijnlijk Zeer onwaarschijnlijk Waarschijnlijk Waarschijnlijk €500K-€5M
4 Lifetime impact 2 Verwijderde Kans Zeer klein Klein Zeer klein Klein Matig Zeer klein Waarschijnlijk Waarschijnlijk Zeer waarschijnlijk Zeer waarschijnlijk €500K-€5M
5 Lifetime impact 4 Huidige Kans Matig Zeer klein Zeer klein Klein Matig Zeer klein Normaal Normaal Normaal Normaal <€500.000
6 Lifetime impact 9 Huidige Kans Klein Zeer klein Zeer klein Zeer klein Matig Zeer klein Normaal Onwaarschijnlijk Zeer waarschijnlijk Zeer waarschijnlijk €500K-€5M
7 Lifetime impact 8 Huidige Bedreiging Zeer klein Zeer klein Zeer klein Zeer klein Klein Zeer klein Waarschijnlijk Waarschijnlijk Waarschijnlijk Waarschijnlijk <€500.000
Begin Filteren Categoriseren Resultaat Prioriteren Prioriteren#1 Prioriteren#2 Prioriteren#3 Prioriteren#4 Prioriteren#5 Prioriteren#6


0125016_Lifetime Impact Prioriterings Model (kort testje) - Microsoft Excel
Stap 3: Prioriteren resultaat
Uitleg

Appendix XIII – Supporting document

Uitleg prioritering model

Ter behoeve van lifetime impacts in levensloopplan

Concept V0.2
Tijmen van Diepen
Assetmanagement B&S

Beheert het netwerk voor gas en stroom

Inhoud

- Introductie
- Schematische weergave
- Filteren
- Categoriseren
- Prioriteren
- Vervolg

Deze presentatie is ondersteuning voor het Excel document “prioritering model.xslx”

Concept V0.2
Uitleg prioritering model

Introductie (1)

Het doel van dit document is om het excel document “Lifetime Impact Prioriterings Model.xslx” te ondersteunen.

De input van het model zijn alle lifetime impacts naar voren gekomen tijdens de TECKO expertsessie(s). Dit kan echter een lange en onduidelijke lijst zijn. Het model heeft als doel om hier structuur in aan te brengen en de meest belangrijk lifetime impacts te identificeren. Dit wordt gedaan in drie stappen;

- filteren (ongeveer 30 minuten)
- categoriseren (ongeveer 30 minuten)
- prioriteren (ongeveer 60 minuten)

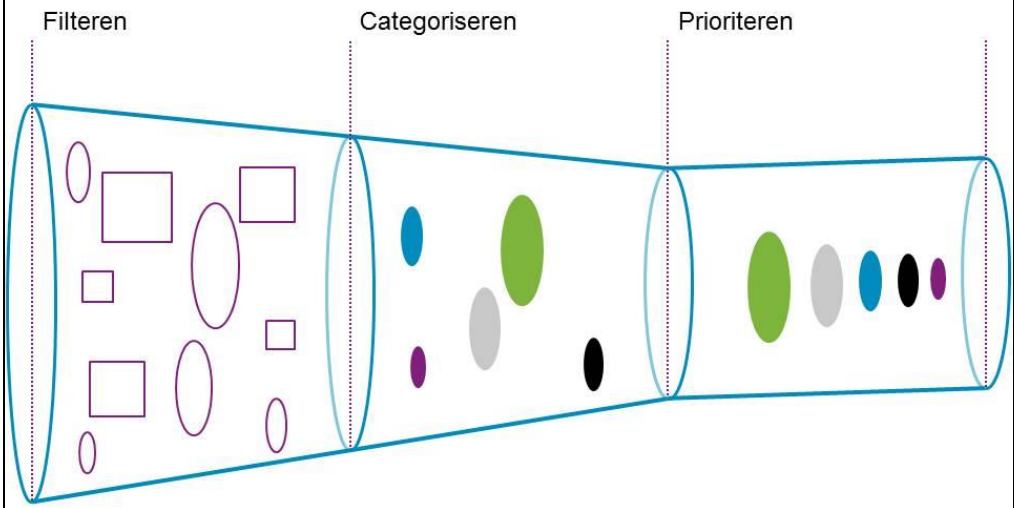
Voordat model ingevuld wordt, moet eerst aangegeven worden of de toekomstscenario’s zullen worden toegepast. Zo ja?, vul dan de naam van de scenario’s in op het tabblad “Begin”.

Introductie (2)

Belangrijk:

- Vul alleen cellen in die grijs gekleurd zijn
- Verwijder nooit rijen of kolommen
- Sla het bestand direct onder een unieke naam op zodat er altijd een niet ingevulde versie bestaat die anderen kunnen gebruiken

Schematische weergave



Concept V0.2
Uitleg prioritering model

Filteren (1)

Doel: Beweringen te filteren die geen lifetime impacts zijn

Wie: De makers van het levensloopplan

Hoe: Door middel van drie criteria

1. Een lifetime impact moet de restlevensduur van de assetpopulatie beïnvloeden
2. Een lifetime impact moet effect hebben op de assetpopulatie over meer dan twee jaar
3. Een lifetime impact moet effect hebben op meerdere assets binnen de asset populatie (generiek)

Praktijk: Tabblad “Filteren” in het excel bestand. Per lifetime impact aangeven als deze niet aan een van de drie criteria voldoet. Daarna kan naar het volgende tabblad gegaan worden.

Concept V0.2
Uitleg prioritering model

Filteren (2)

Wanneer een lifetime impact is gefilterd is het belangrijk deze niet te verwijderen. In plaats daarvan moet de lifetime impact:

Criterium 1: Buiten het levensloopplan behandelen

Criterium 2: Behandelen in het INP proces

Criterium 3: Als input voor een nieuwe expert sessie gebruiken

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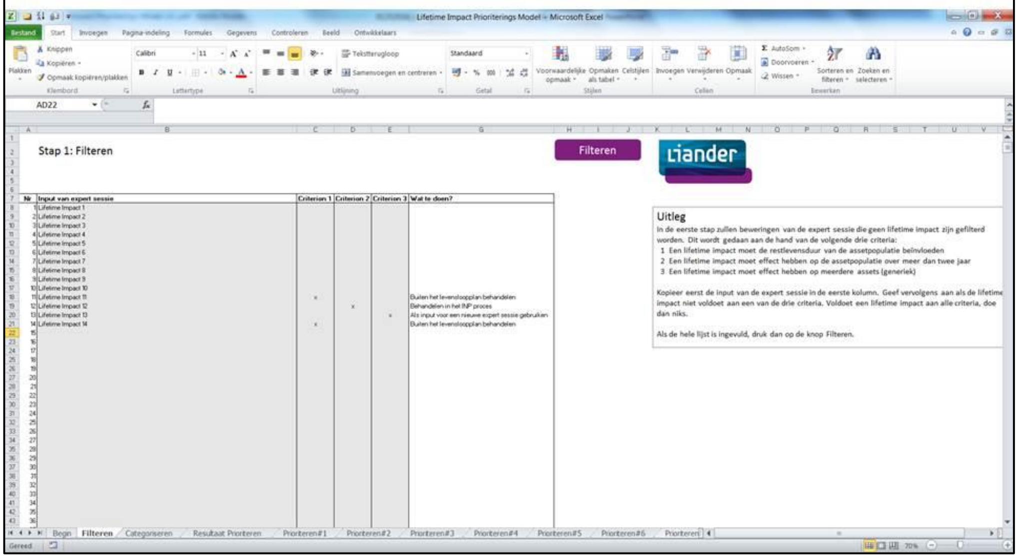
Uitleg prioritering model

Filteren - voorbeeld

Het voorbeeld beneden laat zien hoe filteren in het excel bestand werkt. Als de lifetime impact niet voldoet aan een van de 3 criteria, kan dit worden aangegeven door een “X”. Door op filteren te klikken worden de juiste lifetime impact automatisch naar de volgende tabblad gekopieerd.



Categoriseren (1)

Doel: - Lifetime impacts verdelen in een van de zes categorieën

- Clusteren en filteren van dubbele lifetime impacts

Wie: De makers van het levensloopplan

Hoe: In drie stappen

1. Bepalen op welk levensloopfase de lifetime impact het <u>grootste</u> effect heeft.
    a. Nieuwe assets (assets die nog niet in het net staan)
    b. Huidige assets (assets die in het net staan, of kunnen worden geplaatst)
    c. Verwijderde assets (assets die uit het net zijn gehaald en niet terug worden geplaatst)
2. Bepalen of de lifetime impact een kans of een bedreiging is.
3. Clusteren en filteren van dubbele lifetime impact per categorie (Handmatig doen)

	Nieuw	Huidige	Verwijderde
Bedreiging			
Kans			

Concept V0.2
Uitleg prioritering model

Categoriseren (2)

Praktijk: Tabblad "Categoriseren" in het excel bestand. Per lifetime impact eerst aangeven op welke levensloopfase de lifetime impact de grootste invloed heeft. Vervolgens bepalen of het een kans of bedreiging betreft op dat type asset. Door op de knop "categoriseren" te klikken worden de lifetime impacts automatisch gecategoriseerd.

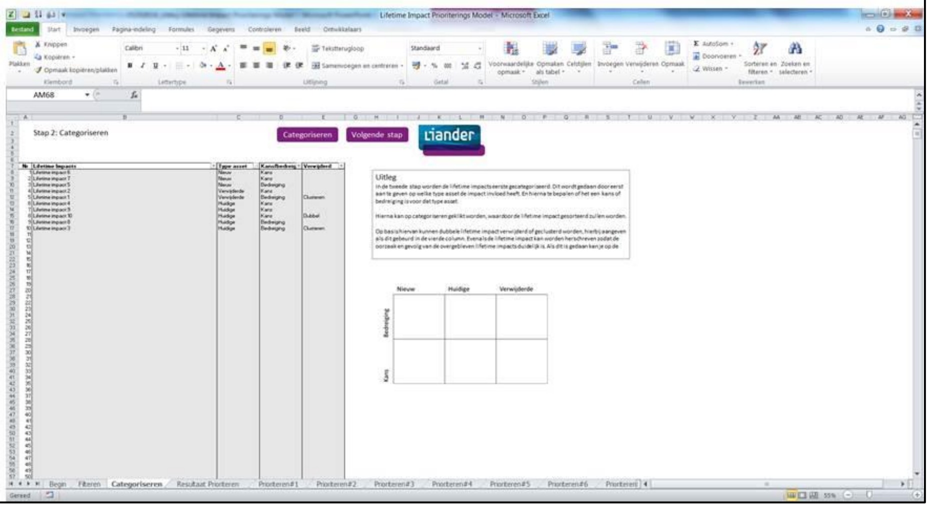
Op basis van de categorisatie de lifetime impacts clusteren en herschrijven zodat de oorzaak en gevolg van de impact duidelijk is.

De uiteindelijke lijst kopiëren naar tabblad "Prioriteren". Dit gebeurt automatisch door op de knop "volgende stap" de klikken.

Concept V0.2
Uitleg prioritering model

Categoriseren - voorbeeld

Het voorbeeld beneden laat zien hoe categoriseren in het excel bestand werkt. Eerst wordt column C ingevuld door de levensloopfase te bepalen. Vervolgens wordt bepaald of het een kans of bedreiging is. Hierna kan op de knop “categoriseren” geklikt worden, waardoor ze automatisch gecategoriseerd worden.
Vervolgens kunnen dubbele worden verwijderd door dit aan te geven in column E. En kunnen de lifetime impacts worden herschreven, dit moet handmatig gebeuren. Als alles gedaan is kan op de knop “volgende stap” geklikt worden.



Prioriteren (1)

Doel: Identificeren van de meest belangrijke lifetime impacts

Wie: - De makers van het levensloopplan

- Minimaal twee andere experts
- Minimaal een lid van het management team

Hoe: Door de lifetime impact te toetsen op drie criteria

1. Impact op de bedrijfswaarden
2. Waarschijnlijkheid van gebeuren per toekomst scenario (indien beschikbaar)
3. Inspanning nodig om de lifetime impact te mitigeren

Praktijk: Eerst bepalen wie gaat prioriteren en vervolgens het tabblad “Prioriteren” in laten vullen door de geselecteerde gebruikers. Doel is om per vakje maximaal 30 seconden te besteden.

Concept V0.2
Uitleg prioritering model

Prioriteren (2)

Impact op de bedrijfswaarden:

Voor elke lifetime impact bepalen “Wat is het gevolg op de bedrijfswaarde als de lifetime impact werkelijkheid wordt?” Waarbij de risicomatrixwaarden als leidraad gebruikt kunnen worden bij een risico. Als de lifetime impact een kans is, kan de inverse van deze waarde worden gebruikt; bijvoorbeeld voorkomen van €10.000,- schade.

Waarschijnlijkheid van gebeuren per toekomst scenario:

Voor elke lifetime impact bepalen: “Wat is de waarschijnlijkheid dat de lifetime impact werkelijkheid wordt?” En waar mogelijk kans bepalen per toekomst scenario. Deze scenarios zullen aangegeven worden in het tabblad “Begin”.

Concept V0.2
Uitleg prioritering model

Prioriteren (3)

Inspanning nodig om de lifetime impact te mitigeren

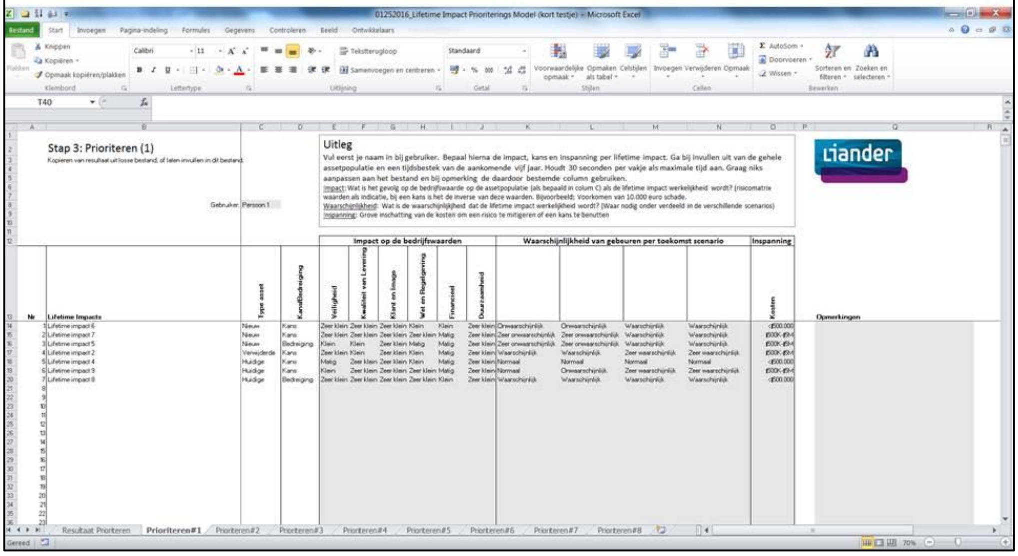
Voor elke lifetime impact een grove schatting geven van de inspanning door de benodigde kosten om een risico te mitigeren, of om de kans te benutten.

Let op: vul niet de kosten of opbrengsten van de impact in.

Concept V0.2
Uitleg prioritering model

Prioriteren - voorbeeld

Er zijn acht tabbladen die gebruikt kunnen worden om het resultaat van prioriteren van verschillende gebruikers in te vullen. Wanneer gebruikers in een apart bestand hebben ingevuld, kopieer dan alleen de grijze gedeelten. Belangrijk: vul de naam van de gebruiker in.



Resultaat prioriteren

Nadat de verschillende personen het prioriteringsmodel hebben ingevuld kunnen deze geplakt worden in de het excel bestand. Het tabblad “Resultaat prioriteren” zal vervolgens direct een overzicht tonen.

Om het resultaat te optimaliseren bestaat de mogelijkheid om twee wegingsfactoren toe te voegen in het tabblad “Begin”.

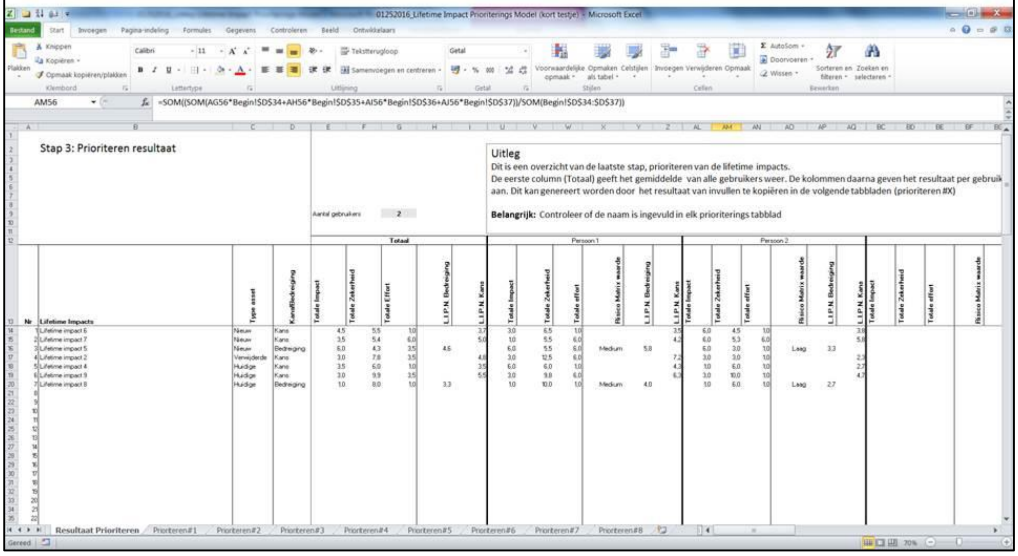
1. Wegingsfactor per toekomstscenario wanneer een scenario als zekerder wordt beschouwd dan een ander.
2. Wegingsfactor per criterium impact, zekerheid en inspanning voor als een van deze waarden belangrijker is dan een andere.

Het is belangrijk om het resultaat niet zomaar te accepteren, maar om de discussie te beginnen wanneer er een groot verschil is tussen de gebruikers.

Concept V0.2
Uitleg prioritering model

Resultaat prioriteren - voorbeeld

Onderstaande afbeeldingen geeft het resultaat van prioriteren weer. In column E – I een gemiddelde van alle gebruikers kan gevonden worden. In de kolommen ernaast kan het resultaat per gebruiker gevonden worden.
<u>Let op:</u> Vul het aantal gebruikers van het prioriteringsmodel in voor een bruikbaar resultaat.



				Totaal					Persoon 1						Persoon 2					
Nr	Lifetime Impacts	Type asset	Kans/Bedreiging	Totale Impact	Totale Zekerheid	Totale Effort	L.I.P.N. Bedreiging	L.I.P.N. Kans	Totale Impact	Totale Zekerheid	Totale effort	Risico Matrix waarde	L.I.P.N. Bedreiging	L.I.P.N. Kans	Totale Impact	Totale Zekerheid	Totale effort	Risico Matrix waarde	L.I.P.N. Bedreiging	L.I.P.N. Kans
1	Lifetime impact 6	Nieuw	Kans	4.5	5.5	1.0		3.7	3.0	6.5	1.0			3.5	6.0	4.5	1.0			3.8
2	Lifetime impact 7	Nieuw	Kans	3.5	5.4	6.0		5.0	1.0	5.5	6.0			4.2	6.0	5.3	6.0			5.8
3	Lifetime impact 5	Nieuw	Bedreiging	6.0	4.3	3.5	4.6		6.0	5.5	6.0	Medium	5.8		6.0	3.0	1.0	Laag	3.3	
4	Lifetime impact 2	Verwijderde	Kans	3.0	7.8	3.5		4.8	3.0	12.5	6.0			7.2	3.0	3.0	1.0			2.3
5	Lifetime impact 4	Huidige	Kans	3.5	6.0	1.0		3.5	6.0	6.0	1.0			4.3	1.0	6.0	1.0			2.7
6	Lifetime impact 9	Huidige	Kans	3.0	9.9	3.5		5.5	3.0	9.8	6.0			6.3	3.0	10.0	1.0			4.7
7	Lifetime impact 8	Huidige	Bedreiging	1.0	8.0	1.0	3.3		1.0	10.0	1.0	Medium	4.0		1.0	6.0	1.0	Laag	2.7	

Resultaat

Het resultaat is tweeledig, aan de ene kant extra inzicht over de lifetime impacts door er bewust mee bezig te zijn. Anderzijds een geprioriteerde lijst met lifetime impacts. Beide kunnen gebruikt worden om de uiteindelijk boodschap te creëren voor het levensloopplan.

Verder geeft het model inzicht in het proces wat gebruikt kan worden voor ondersteuning van het levensloopplan.

Als laatst moeten de gefilterde lifetime impacts in de eerste stap niet klakkeloos worden verwijderd. Controleer echter wat er met deze gedaan moet worden.

<u>Disclaimer:</u> Dit model structureert het proces, maar neem de prioriteiten niet zomaar over. Dit komt omdat een model is bij regel een simplificatie van de werkelijkheid.

Concept V0.2
Uitleg prioritering model

Appendix XIV – Individual scores of the requirements

The desirable requirements scored by the two creators of the ALCP on gas delivery stations (gas 1 & 2). By one creators of the ALCP on powertransformers (Trans). And by the researcher (Research). The scores are based on a 1-7 Likert scores system.

	Desirable requirements	**Gas 1**	**Gas 2**	**Trans**	**Research**	**Average**
D1	The model should be able to handle uncertainties	6	6	6	5	5,8
D2	The model should be able to improve over time	6	7	-	6	6
D3	The model should be able to deal with qualitative and quantitative lifetime impacts as input	5	6	3	6	4,8
D4	The model should be usable without having prior knowledge	3	4	3	4	3
D5	The model should use the policy and strategy of the company as input to make a decision	5	7	-	6	6
D6	The model should take the financial impact of the lifetime impacts into account to make a decision	4	6	6	7	5,8
D7	The model should make decisions using both data and human judgment	4	4	3	4	3,75
D8	The model should be able to select the intermediate and long term lifetime impacts	6	5	-	7	6
D9	The model should be able to deal with both risks and opportunities as input	6	5	6	7	6
D10	The model should exclude evaluation during the expert session	5	7	-	7	6
D11	The model should be able to deal with tacit knowledge as input to the model	6	7	7	6	6,2
D12	The model should be able to deal with lifetime impacts from the whole lifecycle as input	5	7	7	7	6
D13	The model should involve management to make a decision	4	6	2	7	4,6
D14	The model should involve different divisions to make a decision	4	6	3	7	5,2
D15	The model should aid in improving ALCPs	6	7	4	5	5,5
D16	The model should be able to provide information for multiple stakeholders	4	6	5	6	5,4
D17	The model should not involve problem solving when making a decision	5	7	2	4	4

The wishes of Liander scored by the two creators of the ALCP on gas delivery stations (gas 1 & 2). By one creators of the ALCP on powertransformers (Trans). And by the researcher (Research). The scores are based on a 1-7 Likert scores system.

	Wishes	Gas 1	Gas 2	Trans	Research	Average
W1	The model should be easy to use and apply	5	6	3	5	5,2
W2	The model should support decision making and not make the actual decisions	6	7	6	6	6,2
W3	The model should use facts to make decisions	4	1	1	2	2,4
W4	The model should be able to select events and/or trends	5	6	-	7	5,5
W5	The model should not hinder process of acquiring lifetime impacts	5	6	7	7	5,4
W6	The model should be able to provide input for new expert sessions	6	6	-	6	6
W7	The model should use the future scenarios and be able to make no regret decisions based on these scenarios	6	6	-	6	6
W8	The model should focus only on the most important lifetime impacts	5	1	5	6	4,6