Improvement in asset management using a lean perspective

The contribution of lean in the maturity models of asset management

T. A. van Nierop

Improvement in asset management using a lean perspective

The contribution of lean in the maturity models of asset management

by

T. A. van Nierop

to obtain the degree of Master of Science
at Delft University of Technology.

Thesis number:	2017.TIL.8169	
Student number:	4140834	
Project duration:	April, 2017 – October, 2017	
Thesis committee:	Dr. R. Negenborn,	TU Delft
	Dr. W. W. A. Beelaerts van Blokland,	TU Delft
	Ir. M. W. Ludema,	TU Delft
	M. Geerars,	Stork AMS
	A. Geelen,	Stork AMS

An electronic version of this thesis is available at `http://repository.tudelft.nl/`.

TU Delft

STORK
A Fluor Company

Preface

In this world, together we consume a lot of goods every day. From the food we eat, fuels we use and all products we use for all kind of activities. In the world with trends of globalization and specialization a lot of company's are fulfilling our daily demands. However, everyone uses these products less people know exactly how products are made. They do not know which machinery are used in the process and how many assets and people are involved. With this research I stepped into the new world (for me) of asset management.

This report is a result of a six month research into the world of asset management and the possibilities of lean in this field. This research is conducted at Stork Asset Management Solution, the consultancy department of Stork. This department has a lot of experience with asset management and uses lean to provide solutions in the maintenance of assets. Stork wanted to fill their knowledge gap about the possibilities of lean in asset management. In this research I researched to possibilities of improving asset management using a lean perspective. These improvement possibilities can be used as an addition to the current asset management maturity model. This report is my master thesis, with which I complete my master Transport, Infrastructure and Logistics at the Delft University of Technology.

I could not have completed this research without the help and support of others. Therefore, I would like to thank some people who were closely involved in this research. First I would like to thank Mark Geerars and Anouk Geelen for giving me the opportunity to perform this research. Thank you for helping me guiding to the world of asset management and being available for direct feedback. I would like to thank all employees of Stork AMS, which helped me with interviews and their knowledge. I would like to thank my daily supervisors, Marcel Ludema and Wouter Beelaerts van Blokland, for their review on my work and guiding me when I got lost in the world of asset management. I would like my professor Rudy Negenborn, for his useful and relevant feedback during the different meetings. At last I would like to thank my family and friends for always supporting me during this research and the rest of my study.

I hope you enjoy reading my thesis and should there be any clarity or question, do not hesitate contacting me.

T.A. van Nierop Delft, October 2017

Summary

We live in a consumer society with a great daily demand for products. Although raw materials are finite, consumers do not want to pay more for their products. Therefore, efficient use of resources is increasingly important for companies in the manufacturing and process sector. Machines, also called assets, need to be managed efficiently and effectively over their entire life cycle. In this asset life cycle, different sub-activities occur, such as engineering, operations, maintenance and disposal. To stimulate efficiency in the asset life cycle, asset management is necessary. Asset management concerns the coordination of the different sub-activities of the asset life cycle to improve the efficiency of the process (see figure 1). An international standard (ISO 55000) is available to define how asset management should be performed. Based on this performance, a maturity level is provided.

To become more efficient in asset management, the maturity and performance should be continuously

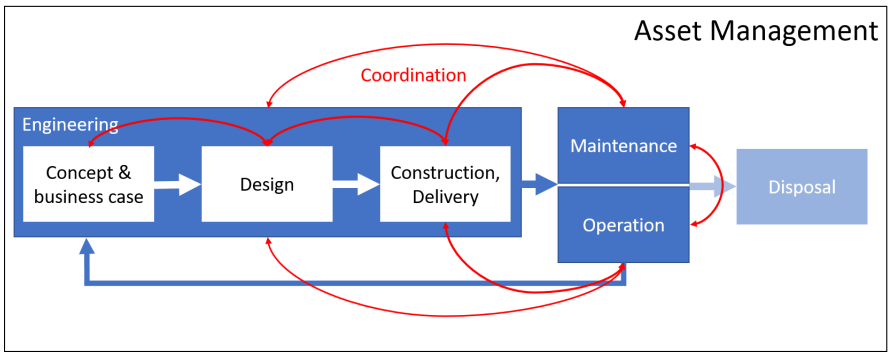


Figure 1: Scope research

improved. Currently, no sufficient models are available to provide direction for this improvement. In the literature, different optimisation methods are available. In this report, the possibility of using lean for this improvement is researched. Lean is a process optimisation method that has been successful in different industries and markets. Lean is best used in continuous or line-flow processes with a small deviation in products, which is the case in the process sector. Currently, it is unclear how asset management can be improved from a lean perspective. Therefore, the research question for this report was defined as follows:

How can asset management be improved using a lean approach and what is the impact of this lean approach on the asset management performance?

In this research, the focus is on the coordination of the different asset management sub-activities to improve the performance and maturity of the asset. This research does not focus on the maturity of the different sub-activities itself, nor does this research focus on the use of lean in the different sub-activities (engineering, maintenance and operations).

Asset management

First, asset management has been researched in both literature and practice. Asset management has been defined as *the coordinated activity of an organisation to realise value from assets in the asset life cycle.* The different sub-activities that need to be coordinated are engineering, operation, maintenance and dismantling. With such coordination, more value is created from the asset. This value needs to be defined by the asset owner, but is related to availability, occupancy rate and readiness.

Asset management is defined in the ISO 55000 standard. In this standard, asset management performance is based on the following seven aspects; organisation, leadership, AM plan, operations, evaluation, improvement and supporting facilities. These aspects vary from strategic to operational level. The maturity levels are based on the fulfilment of aspects' requirements.

There are four factors that influence asset management performance and maturity. First, the number of actors and companies involved in the asset management influences the ease of change. Second, the industry of the company influences the importance of asset management. In industries with dangerous goods, efficiency becomes less important. Third, the type of production process. Forth, the life span and cycle of the asset are important; in a shorter life span, dismantling becomes more important. The life cycle is important, because asset management is easier when it is considered in the design of the asset.

The current implementation in practice was researched in three case studies: A tank terminal, a brewery and a gas storage facility. Similar problems were found in each case study. These problems relate to analysing, implementation, improving and involving everybody in asset management. The two main problems in the current use of asset management are as follows:

- Analysing the problems in asset management.
- The structural method to continuously improve asset management.

Lean
Lean has been defined as *a management philosophy focussing on creating maximum customer value with minimum resources*. Lean consists of the following five steps: First, the value is defined. Then, the value stream is mapped. Third, flow is created. The forth step is creating a pull system. Finally, continuous improvement should be strived for. Lean has been successfully implemented in supply chains and different activities in the asset life-cycle.

Lean tools provide a way to implement lean. In total, more than thirty lean tools are available. Not all these tools can be used in an asset management context. Fifteen useful tools were selected, based on their capabilities of integrating sub-activities. These tools were divided into two groups: tools to analyse, and tools to improve. These groups are related to the two major problems in asset management.

Improvement cycle in asset management
Since world class performance cannot be reached in one step, an improvement cycle was developed, as illustrated in figure 2. This cycle illustrates how the current asset activities are placed in a continuous improvement environment. The cycle consists of five different steps that need to be performed. Two are existing steps and three steps need to be added to the current asset activities. These steps are:

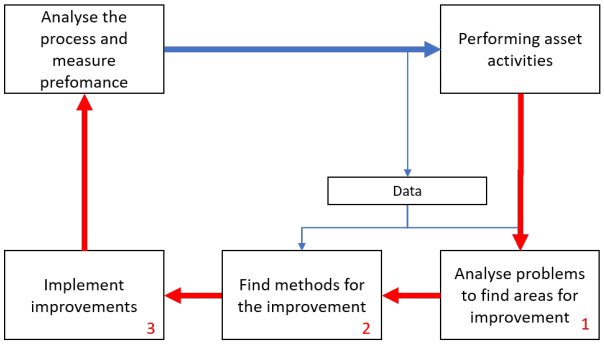


Figure 2: Improvement cycle for the implementation of continuous improvement in asset management (source: own author)

1. Areas for improvements are found. The reasons for value losses should be discovered. Asset management performance should be analysed to find areas for improvement. This analysis is done using lean tools.
2. Find methods to improve the coordination between the asset activities. Again, lean tools are used.
3. The improvement method should be implemented within the process. An implementation plan should be written based on the company characteristics.

Improvement method for asset management
To use different lean tools to analyse and improve the coordination of activities in the asset life cycle, an

improvement method was made. The method has three inputs; asset management performance, asset management maturity and lean tools. Based on these inputs, the correct lean tool is selected. The method consists of four different steps:

Step 1 The correct schedule should be selected based on the maturity level. These schedules are used in Step 3. Three different schedules have been made for the six maturity levels (schedule A, B and C). Each schedule is used for two different maturity levels.

Step 2 The asset management aspect to be improved should be selected. Based on the performance, one or two aspects should be selected for improvement

Step 3 Based on the previous steps, the correct tools need to be selected in the different schedules. First, a tool to analyse the problem should be selected, followed by a tool to improve asset management.

Step 4 Development of an custom made implementation plan based on the company characteristics.

With these different steps, one improvement cycle is fulfilled. The first improvement step, with the implementation of two lean tools, is established.

Validation and verification
The improvement method has been validated by different experts from Stork AMS. The verification of the method was done by using examples from practice and literature. In these examples the different lean tools were used successfully to coordinate two activities. Here, the lean tools led to an increased Overall Equipment Efficiency (OEE) and the reduction of waste in the system. In cases improvements of 10 % has been found.

The improvement cycle (figure 2) was implemented in one of the three case studies - the gas storage facility. The maturity level of asset management in this case study was low and therefore schedule A should be used. The aspects for improvement are; analysing and improve and operations. Following the improvement method, Root Cause Analysis (RCA) and Continuous Improvement (CI) should be implemented in this case. Improvements of 30 percent are expected in the OEE. This percentage is high, because the maturity is low and improvements are easily made.

Recommendations
From a scientific perspective, performing further research and implementing the improvement method in more case studies is recommended. A case study in the oil and gas sector with a significant maturity level should be performed first to measure the influence of the maturity level. Then case studies within other industries (manufacturing, process or chemicals) should be performed to measure the influence of this factor. Many different cases need to be studied with differences in the asset management maturity and industry. These case studies could prove whether the model is usable in all these situations.

For Stork AMS, it is recommended to write the proposition lean in asset management following the Stork format. Here the Stork asset management scan could be used to define the asset management maturity. A pilot study should be performed to create a validation based on actual data, which will strengthen the proposition. After a successful pilot study clients should be made aware of the new propositions, and the consultants from Stork AMS should be provided with internal training to update their skills. Currently, the proposition can be already performed at the different clients of Stork AMS.

Contents

List of Figures

List of Tables

1 Define Introduction

1.1. Context of this research

We live in a consumer society with a great daily demand for products. Although raw materials are finite, consumers do not want to pay more for their products. Therefore, the efficient use of resources is becoming increasingly important for companies in the manufacturing and process sector. Machines, also called assets, need to be managed efficiently and effectively over their entire life cycle. In this asset life cycle different sub-activities occur, such as engineering, operations, maintenance end disposal. To stimulate efficiency in the asset life cycle asset management is developed.

1.1.1. Introduction into asset management and lean

Asset management concerns the coordination of the different sub-activities in the asset life cycle to improve the efficiency of the process (Hastings, 2015) (see figure 1.1). These different sub-activities are difficult to integrate (ISO, 2014a), since these activities are mostly separated in different departments.

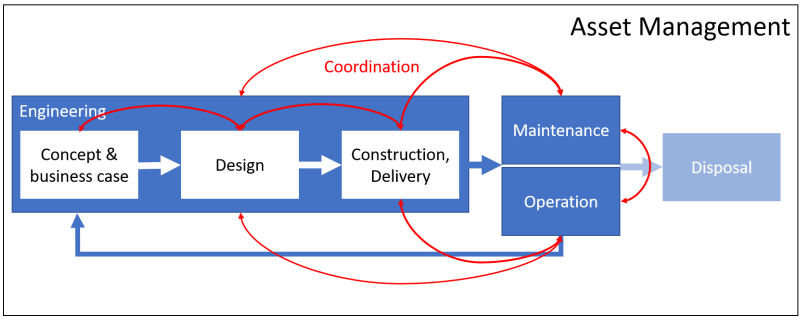


Figure 1.1: Scope asset management

An international standard (ISO 55000) is available to define how asset management should be performed. This standard also defines a method to measure the current asset management performance. Based on this performance a maturity level will be provided. Organisations want to improve this maturity level to become more efficient and effective. Currently, no sufficient method is available to provide direction for this improvement. In the literature different optimisations methods are available. In this research, the possibility of using the lean optimisation method for the improvement of asset management maturity is researched. Lean is best used in continuous or line-flow process with a small deviation in products, see figure 1.2. This relates to the process sector, which is researched. Lean is a management philosophy which optimises the production by focusing on maximising customer value (Womack and Jones, 2010). It is widely applied in the manufacturing

industry, where processes got more efficient and costs are reduced, even when this is not the main objective of lean manufacturing (Abdulmalek and Rajgopal, 2007) (Melton, 2005). Lean has already been applied in some sub-activities of asset management, but has not been implemented to coordinate the integration of all of these activities (Levitt, 2008)(McKone and Weiss, 1998).

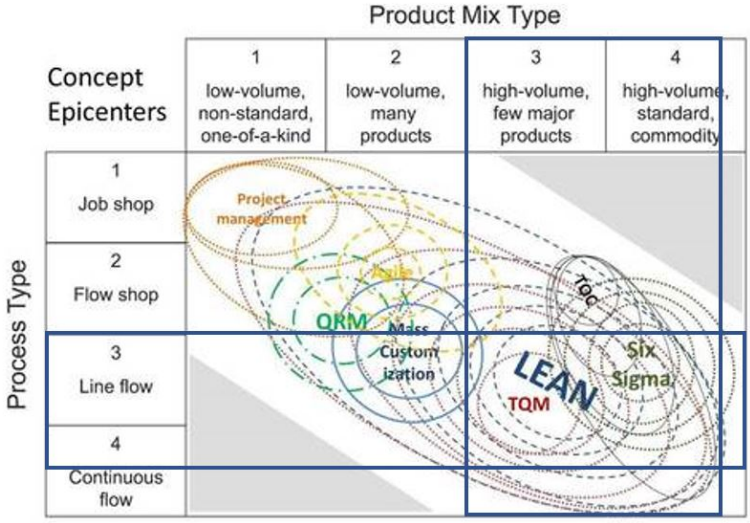


Figure 1.2: Optimization methods and their dimensions. (source: Adapted fromT. Netland www.better-operations.com/2014/01/17/concept-epicenters-lean-tqm-six-sigma)

1.2. Stork AMS

This master thesis is initiated by Stork Asset Management Solutions (Stork AMS), a department within a world wide company. Stork provides maintenance, modification and asset integrity services and is active in the sectors; oil & gas, chemicals & process, metals & mining, power and manufacturing industries. Stork Asset Management Solutions helps asset-intensive companies with connecting tangible asset management and performance solutions with a strategic vision for improvements. Since 2016, Stork is part of the Fluor Corporation, a global engineering and construction company. This gives Stork the position to deliver integrated solutions coverings the full asset life cycle, from design to the dismantling.

Stork provides their asset management solutions through propositions. One example of a proposition is Stork Lean in Maintenance. In this proposition, opportunities for clients using lean thinking in the maintenance of assets are established. The main focus in this proposition lies on increasing the availability of the assets. In practice this means that maintenance is avoid unless it is necessary. When it is performed, it should be as efficient as possible. This will be done by removing obstacles on the work floor together with the employees (Stork Consultancy, 2017).

Stork want to broaden their market and this research about the improvement of asset management with the use of a lean perspective is therefore a good possibility.

1.3. Problem definition

Asset management is used to become more efficient and effective by coordinating sub-activities in the asset life-cycle (Hastings, 2015). To measure the asset management performance, an international standard is written (ISO, 2014a). Within Stork AMS this standard is developed in a asset management performance scan (Stork Asset Management Solutions, 2016), but also guidelines in literature can be used to measure the asset management performance (ISO, 2014b), (ISO, 2014c). These methods relate the asset management performance to a benchmark level and assign a maturity level. Based on this information, companies would like to improve their asset management maturity. At this moment, a method for this improvement is not available.

The current methods are only benchmarking, but does not provide direction for improvement.

In the literature, different general optimisation methods are available. In the process sector, the lean optimisation method might be useful for the improvement of asset management performance. This is because, lean is suitable for line-flow or continuous processes with a small deviation in products. The application of a lean optimisation method for the improvement in asset management is not researched yet. The problem statement of this research is therefore;

It is insufficiently known how the asset management performance can be improved using a lean approach.

Currently the aspect of adding a lean perspective to asset management is unclear and there is limited information available on this aspect. Different companies use the concept 'lean in asset management' without any scientific fundamentals (Genesis Solutions, 2016) (Visser and Trip, 2016) (Reliable plant - Eric Luyer, 2016) (TMAC, 2016) (Whole Life Consultants LTD, 2016). These companies just aiming to use lean, but an overall vision of how to apply lean in asset management is still missing. It is unknown if an improvement method for asset management can be made from a lean perspective.

1.4. Relevance of this research

In this section the relevance of this research is discussed. A distinction is made between scientific and practical relevance. From a scientific point of view this research is relevant because it will develop a method to improve asset management. Currently, method is missing and no structure is available. The improvement method links the different lean tools to a maturity model. The link of lean tools to maturity models is also not researched yet. At the same time, this research will give a lean perspective to asset management. The lean point of view on asset management is not researched yet. This research will give a first indication of what the contribution of lean could be in the field of asset management.

The research also has practical relevance. The improvement method is designed for Stork AMS. This method can be used to improve effectiveness and efficiency of the management of asset at the clients of Stork AMS. This tool can be used to provide a way to improve the asset management maturity and become more efficient and effective. The use of lean in asset management is not research yet, the developed knowledge will provide Stork an advantage over other advising companies. This model can be used by other companies as well, which have large physical assets active in the oil &gas, process, metals & mining, power or manufacturing sector.

1.5. Scope

The scope of this research is visualised in figure 1.3. This research is focussing on improvement of maturity in asset management with a lean approach. With asset management as the coordination of the different sub-activities; engineering, maintenance and operations. This research does not focus on the use of lean in these different sub-activities nor does it focus on the maturity in these sub-activities. Both aspects have been research by different authors, also visualised in figure 1.3 (Baines et al., 2006) (Bate et al., 1995) (Levitt, 2008) (Hastings, 2015) (Chemweno et al., 2015) (Womack and Jones, 2010) (Shah and Ward, 2007) (Hujdurovic, 2008). These aspects will have influence on this research, for example it is likely to expect that the maturity in the sub-activities increases when the maturity in asset management increases. But these interfaces are not researched in this report.

The asset cycle has a relation to the supply chain cycle (see figure 1.4). In the supply chain cycle, lean has been used to integrate the different sub-activities. Also, inside the different sub-activities lean has been used to become more efficient and effective. In this research the supply chain is not taken into account. But the interface where production meets the operation and maintenance is important. The performing of the sub-activities depends on the production of the company. Also, the implementation of lean in the supply chain is relevant, since cases in asset management are not available.

The integration is scoped to brown field and the coordination of asset related activities at these plants. How can engineering maintenance, operations and dismantling be coordinated in existing plants. The case studies and implementation are therefore related to existing assets. However, the design of the asset is taken into account, since it will influence the performance of the asset management.

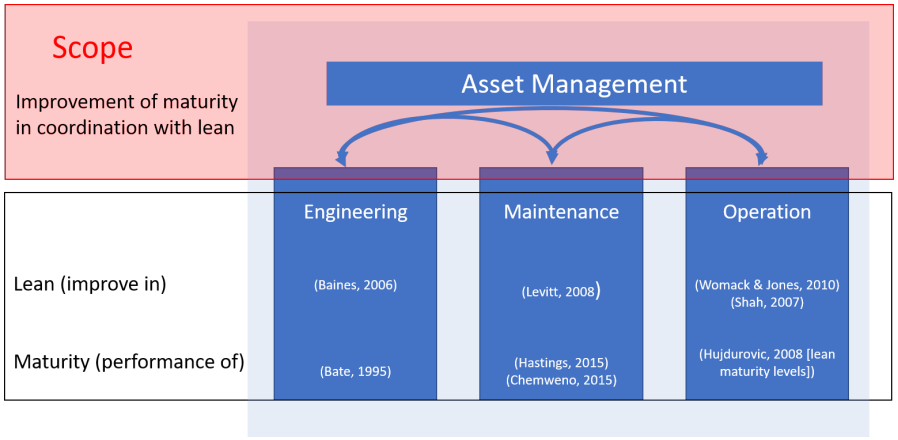


Figure 1.3: Scope research

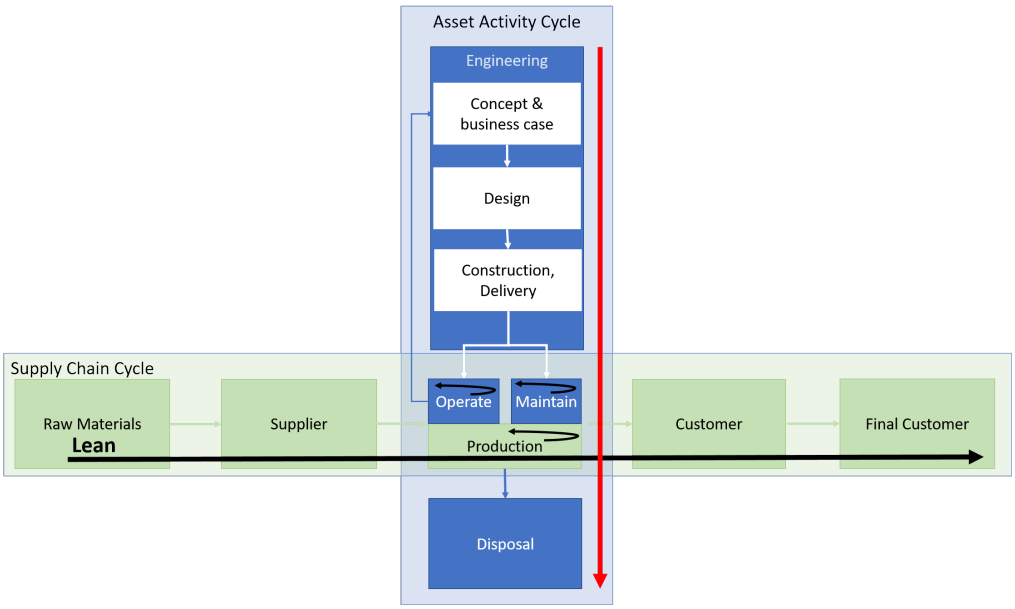


Figure 1.4: Relation asset life cycle and supply chain cycle

1.6. Research questions

From the problem description the following main research question and supporting sub-questions can be defined. These sub-question will help to answer the main research question and will solve the problem as stated before. Next to research questions, a design objective has been formulated. The research questions are as follows:

"How can the coordination between sub-activities in asset management be improved using a lean perspective and what is the impact of the lean perspective on the asset management performance?"

1. What is asset management and what are its main aspects?
2. What is the lean philosophy and what are its main aspects?
3. How is asset management currently implemented in related industries?
4. How can lean contribute in asset management?

5. What are the requirements for the contribution of lean in asset management?
6. What will be the influence of the lean perspective in asset management?

The design objective of this report is:

Develop a tool which will guide the improvement in asset management using a lean approach.

The relation between the different research question can be seen in figure 1.5

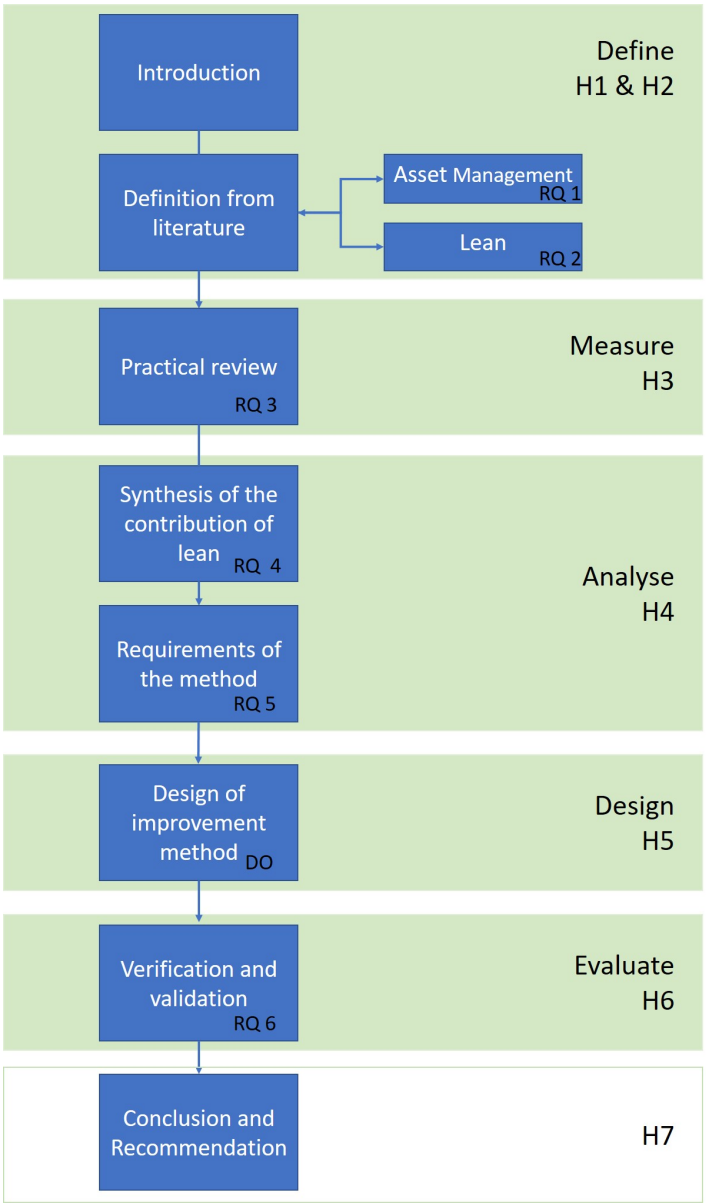


Figure 1.5: Research framework

1.7. Methods

In this section the research methods are explained. The research methodology ensures the answering of the research questions.

Different research methods are available, these methods can be used for different purposes. Here, some methods are explained and their usefulness in this research is discussed. To design engineering related products the engineering design method of Dym et al. (2009) can be used. For this research, this method is not sufficient. The method is specified for the design of products, while in this report a improvement method is developed. Another method that can be used, is the soft systems methodology (Checkland and Poulter, 2010). This method provides an approach and schematic techniques to model organizational processes. The soft systems methodology can be used for general problem analysis, synthesis and change management. This method does not have a design aspects and is therefore not suitable. For this research, the DMADE method is used. This method is based on the DMAIC method (Define, Measure, Analsye, Improve and Control). DMAIC originates from the Six Sigma optimisation philosophy. The DMAIC cycle is used to improve processes and find root causes and remove them from the process to increase the quality Lean Six Sigma (2005).

In this research an improvement method for asset management using a lean approach needs to be developed. To perform this research the problems in asset management need to be found and a quality improvement is needed. These steps are explained in the DMAIC cycle. However, the exact DMAIC cycle cannot be used, since it is designed for existing processes. In this research a new improvement method is developed and therefore the methodology is slightly adapted. The last two steps from the DMAIC cycle are replaced; Improvement by Design and Control by Evaluate. With these two changes, the methodology is suitable for making new designs. Therefore, the methods name is be adapted to DMADE; Define, Measure, Analyse, Design and Evaluate. This DMADE method is used to solve the main research question in this report.

Next the five steps of DMADE are explained in more detail . The relationship of the methodology related to the research questions and outline of this report can be seen in figure 1.5.

1.7.1. Define, H1&2

In the define step, the definition of the project is explained. The motivation for this research, the problem statement and research questions are defined. The define step is started in the introduction of this research. For this chapter, different interviews with experts in lean and asset management are held. Also some experts related to work flows and software are interviewed. Besides, research in literature is performed. Papers and books about lean and asset management are used to get insight in the existing problems and knowledge gaps. For this research data bases as Scopus and the TU Delft Library are used.

In the define step also the literature study is performed. To perform the literature study different scientific papers, books and standards that are available are reviewed. Based on this information, the concepts asset management and lean are be defined. Besides, the main aspects of both concepts are reviewed. The literature study gives different insights from different researchers, based on this information my own vision is created. Next to a literature review, some desk research and interviews are used. Based on company websites and experts in the field some other insights are collected. Concluding, the define part answers the first two research question: *RQ1: What is asset management and what are its main aspects?* and *RQ2: What is the lean philosophy and what are its main aspects?*

1.7.2. Measure, H3

In the measure step data is collected with case studies and desk research. In the analysis of these case studies different system analysis and observation methods are used. These are explained in the rest of this subsection. These methods help to answer the third research question: *RQ3: How is asset management currently implemented in related industries?*

Methods for system analysis

The system analysis is performed with process mapping tools. These give insight in the current performance of asset management and shows opportunities for improvement. To find methods for the system analysis, the most relevant tools from Damelio (2011) are selected. The tools that are selected give insight in the relationship between the different activities. These tools are:

- **Flowchart** – Shows Jobs/Performer
  A flowchart is a graphic representation of the sequence of work activities used to create, produce or

provide a single specific, unique output (Damelio (2011) p.8). A flowchart is ideal to map the process and to understand it. A method which uses flowcharts is Value Stream Mapping. This lean tool can be used to indicate waste in the process. More information about value stream mapping can be found in appendix E.

- **Swimlane** – Shows Process
  A swimlane analysis or cross-functional process map is a physical way to show responsibilities and job sharing for different process steps. In horizontal 'lanes' are the different organization parts shown, over which the different functions are divided. The swimlanes will show how the different activities are related and make interfaces visible.

- **Relationship map** – Shows Organization
  A relationship map visually depicts the parts of an organization and the internal or external supplier-customer relationships among those parts (Damelio (2011) p.4). This process map will show how the different part of the organizations are related and how they related in the bigger part of the organizations. In asset management some activities might be outsourced, while other are performed by the company itself. This will become visible in the relationship map.

Methods for observations

To get the right information from observations, a method and preparation is needed. In this research two observation methods are selected; interviews and visiting the asset. Interviews provide an easy way to collect information for different resources. In this research, this is necessary since actual data collection at the cases cannot be performed. The main disadvantage is the poor reproducibility. Visiting the asset provide a way to collect information from my own point of view.

- **Semi-structured interviews**
  In Soft Systems Methodology questions used to describe the problem are (Checkland and Poulter, 2010): What resources are deployed in what operational processes under what planning procedures within what structures, in what environments and wider systems, by whom? How is resource deployment monitored and controlled? These questions are used during the interviews. It provides a way to get insight in the asset, but still allows freedom during the interview. To make it easier the first question can be cut in different small questions, but at the end the answers to these to questions should be clear. To advanced of the semi structured interviews is that you ensure that you get the information you need, but enables the expert to elaborate on different aspects.

- **Visiting the asset**
  Besides the interviews and observations of managers, the asset will be visit. This provides insight in the actual process. During this visit it is important to look and ask questions to the people on the work floor. Do they find the standard proceedings clear and do they follow them. It is important to not be critical but observe the information.

1.7.3. Analyse, H4

The analysis is a synthesis of the define and measure phase. Here the aspects of lean and asset management are combined. Asset management will be approached from a lean perspective. Aspects of lean that are found in literature are explained in the asset management world. The results from literature review and practical review give insight in how lean can be used to improve asset management. The idea of the method is generated in this analysis step of the methodology. This idea follows from the conclusion of the synthesis. Another result of the synthesis are the requirements of the improvement method. These requirements follow from literature, case studies or will be determined by Stork AMS. Together these steps answer the following two research questions: *RQ4: How can lean contribute in asset management?* and *RQ5: What are the requirements for the contribution of lean in asset management?*

1.7.4. Design, H5

After the analysis an improvement method for asset management is designed. This design follows out of the requirements and lay-out that are specified in the previous step. The model is based on an input - output model that is made. The output is defined as the desired result from the model, this was the missing knowledge gap. The inputs are based on the information available and required. This model ensured a good layout

and structure. The different steps to implement the model are explained. All information and prescriptive decisions tools to implement the improvement method are explained. These are made based on the different requirements and constraints. Based on the exclude and combine theory the different lean tools are selected from a long list. The exclusion is based on the requirements and the clustering of lean tools is based on similarities.

This method step answers the design objective of this research: *DO: Develop a tool which will guide the implementation of lean in asset management.*

1.7.5. Evaluation, H6

The improvement method is verified and validated. This step is important since it shows the usefulness of the model. The verification consists of two different steps. First the method is checked based on the requirements that are set. In this check is analysed whether the requirements are met. The second step of validation consists of interviews with experts in the aspects lean and asset management. They are asked for the usefulness of the improvement method.

Validation of the improvement method is difficult, since the method cannot be implemented to check whether it leads to the desired outcomes. First a validation is performed based earlier implementation in case studies and literature. Different aspects of the improvement method have been implemented in comparable situations and this gives an indication of the potential of the method. Besides, a theoretical implementation in one the case studies is simulated. The gains of the improvement method are defined based on interviews with experts of the plant.
This step enables answering the last research question *RQ6: What will be the influence of the lean perspective in asset management?*

1.7.6. Conclusion, H7

This research ends in a conclusion followed by recommendations and limitations of this research. Finally, a reflection of my work is given in chapter 8.

2

Introduction on asset management and lean

This chapter presents background literature on asset management and lean. Both aspects are explained based on literature, and definitions for both aspects are given. First, the terms asset, management and asset management are defined. The implementations in literature and measurement methods of asset management are discussed and more explanation on the maturity levels in asset management is given (Section 2.1). Then a theoretic background of lean is given, where lean will be defined and explained. In this section also the lean implementation is explained (Section2.2). Finally, a conclusion of the literature review will be made (Section 2.3). The relationship between the different section in this chapter is shown in figure 2.1

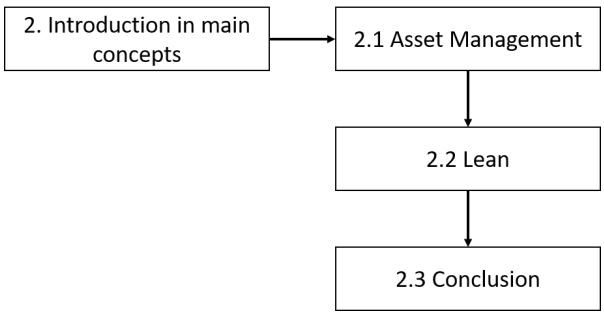


Figure 2.1: Chapter layout literature review

The research questions that are answered in this chapter are:

- What is asset management and what are its main aspects?
- What is the lean philosophy and what are its main aspects?

2.1. Asset management

Asset management is performed for as long as assets exists. But the term asset management originates from the financial world, firstly used by Banker's Magazine in 1930. In this sector, it relates to the outsourcing of the investment and management of financial assets (Oxford dictionary, 2016). Currently, the term asset management is used in a wide range of sectors with different industries and different definitions. Therefore, it is important to define asset management.

First, the terms asset (Section 2.1.1) and management (Section 2.1.2) are defined and discussed, followed by the definition of asset management (Section 2.1.3). The rest of the section implementation of asset management is discussed. The standards and norms (Section 2.1.4) and maturity (Section 2.1.5) are discussed. This

section is ended with a conclusion and main finding about asset management (Section 2.1.6).

To find literature and papers on asset management the terms asset management, physical asset management and engineering asset management are used. The books and papers of Hastings (2015), Amadi-Echendu et al. (2010) and Ouertani et al. (2008) are used to get more insight in asset management. Besides, the asset management standards ISO (2014a), (ISO, 2014b), (ISO, 2014c) and (BSI, 2004) are used.

2.1.1. Assets

In the Oxford dictionary an asset is defined as; *a useful or valuable thing or person.* In the ISO 55000, the asset management international standard, an asset is defined as; *an item, thing or entity that has potential or actual value to an organisation* (ISO, 2014a). Both definition contains the aspects that an asset is something with value to someone. The last definition of ISO will be used, since this one is more specified to physical assets which are researched.

Assets can be divided in different categories based on their appearance (Hastings, 2015):

- Physical Assets
- Financial Assets
- Human Assets
- Information Assets
- Intangible Assets

The physical assets are central in this research, these are the plants, machinery, buildings and other tangible assets. When different machines are performing in one line, these are all different assets performing in a asset system. Besides physical assets, there are multiple other types of assets. These asset support the management of the physical assets and are therefore also included in this research. These types assets and the relationship to physical assets is shown in figure 2.2. In this research the management of physical assets are central. But also the other assets are important, especially the human assets and the information assets. These two can be easily influenced by management. The financial and intangible asset are largely fixed and big changes cannot be made in short term.

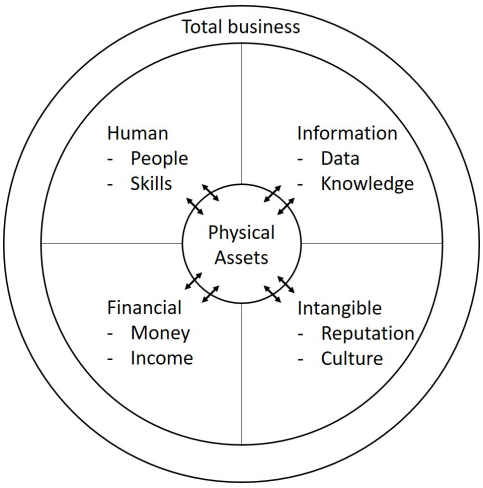


Figure 2.2: Different types of assets and their relation (adapted from (Woodhouse, 2004))

2.1.2. Management

In the previous section, the concept asset is defined and discussed. In this section the concept management is explained. Management can be defined as *The organisation and coordination of the activities of a business in order to achieve defined objectives* (Business Dictionary, 2017). There are different models on how management should be implemented and what aspects are included (Shenhar and Renier, 1996). One familiar way to describe management, is by including it in the production together with machine, materials and money. While other management models focuses on getting results through the work of others for the benefit of the

client. The functions of management are for example planning, organising, staffing, leading and controlling (Shenhar and Renier, 1996). In this research the definition as stated in the business dictionary is used.

2.1.3. Asset management

Now the concepts asset and management are defined and discussed. In this section these concepts are combined and asset management is discussed. In literature multiple definitions are used for asset management, a few important ones will be reviewed. In the ISO standard (ISO, 2014a) asset management is defined as: *The coordinated activity of an organisations to realise value from assets.* This definition is very wide at not specific. The PAS standard (BSI, 2004), the precursor of ISO, defines asset management as: *Systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organisational strategic plan.* This definition looks a lot like the definition of Hastings (2015): *Asset management is the set of activities associated with identifying what assets are needed, identifying funding requirements, acquiring assets, providing logistic and maintenance support for assets and deposing and renewing assets.*

Some aspects are similar in the different definitions. In the last two definitions the asset life cycle is taken into account. At the same time coordinated activities are a key factor in the different definitions. In asset management the different life cycle activities (engineering, operation, maintenance and dismantling) are managed together to maximise the value from the assets. Because the value is determined by the organisation, the management should follow the organisational strategic plan. Asset management does not only influence the work floor, but all layers in a company (Godau, 2007). It has influence on strategic, tactical an operational level in a company. To conclude, asset management will be defined as follow:

Asset management is the coordinated activity of an organisation to realise value from assets in the asset life cycle.

The last few years, there are terms created which separates asset management in the industrial sector from asset management in the financial sector, for example; physical asset management (Hastings, 2015), engineering asset management (Amadi-Echendu et al., 2010) and infrastructure asset management (IMESA, NAMS and Rowse, Nicholas and Naude, Leon and Byrne, Roger, 2012). Physical asset management focuses on the management of physical assets, like plants. Engineering asset management is a further specialisation of physical asset management, where the engineering activity is central. While, the infrastructure asset management focuses only on infrastructure project. In our research physical asset management is used, but the other asset aspects, as human assets and information assets, are also taken into account. Therefore, the term asset management is preferred for this research.

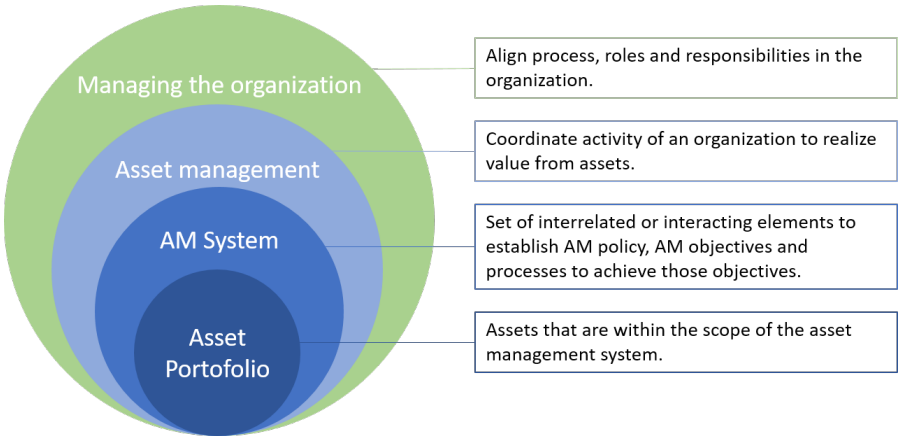


Figure 2.3: Asset management and relationship (source: adapted from ISO 55000 (ISO, 2014a))

The relationship between the asset and asset management is shown in figure 2.3. Asset management is aligned with the strategic goals of the company. To perform asset management the asset management system

is used, these are all interacting elements to realise and achieve the asset management policy and objectives. This system will affect the asset portfolio, which are all physical assets of the company.

Asset activities

Asset management is about the coordination of activities. The main asset activities are:

- Engineering
- Maintenance
- Operations
- Management

Besides these main activities there are different side activities and departments that are needed in asset management. For example; planning, logistics, human resource, finance, safety and purchasing. The activities are performed in sequence, first the asset sub-activities are performed, this performance is analysed. The analysis produces some data for the company (see figure 2.4).

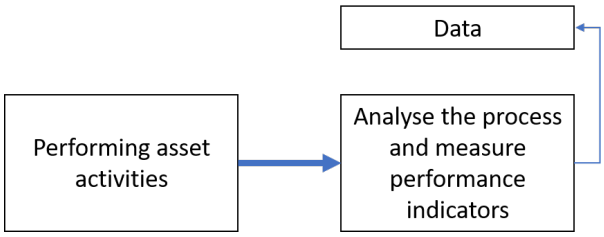


Figure 2.4: Asset activity

Asset value

The goal of asset management is to create value from the asset. The value of the asset is determined by the asset owner and stakeholders in accordance with the organisational objectives. These can be financial or non-financial, tangible or intangible. The value needs to defined since it influences the management of the asset and risks that can be taken. The indicators measure the value of asset management; availability, readiness and occupancy rate. The availability is the time that the asset can be used for production. The readiness defines the fact if the asset can be used when needed, this factor is relevant in non continuous flow productions. In these cases downtime is accepted, when the asset does not need to perform. The occupancy rate defines if the asset performs with the desired capacity.
This asset value can be measured with the overall equipment efficiency (OEE). The OEE shows how much time the asset is actually producing. The OEE can be calculated by multiplying the percentages of the availability, performance and quality of the production. The calculation is shown in equation 2.1 (Wireman, 2005) (Godfrey, 2002). In this case the availability can both be used as the value aspect availability and readiness as explained above. Another way to calculated the OEE, is by removing the different losses related to availability, performance and quality from 100%. Availability losses are defined as down time of the plant during the planned operating hours. Losses in the performance are speed losses or capacity losses, when the plant is not operating at the ideal speed. When the quality of the produced units is not good, this will cause quality losses and not all produced units can be used.

$$OEE[\%] = Availability * Performance * Quality \tag{2.1}$$

with

$$Availability = \frac{operating\,time}{schedulud\,time}$$

$$Performance = \frac{parts\,produced * ideal\,cycle\,time}{operating\,time}$$

$$Quality = \frac{units\,produced - defect\,units}{units\,produced}$$

Asset life cycle

Assets need to be managed in the asset life cycle. The different activities in the asset life cycle are given in figure 2.5. Ouertani et al. (2008) divided the life cycle in five stages, these are:

- Concept & Business Case
  The technical and financial analysis for the design, the planning and managing of the acquisition of the asset. Here the gap is knowledge and the potential value of the asset is defined.
- Design
  The design stage will define how the asset will be like and how it will be operated, maintained and dismantled. This stage will influence later stages in the asset cycle. At this moment, the requirements for the operations and maintenance should be clear.
- Construction & delivery
  The construction and delivery of the asset exist of the installation, testing and commissioning of the asset. In this stage it is very important that the settings are all correct and the starting mistakes are reduced to a minimum.
- Operate and Maintain
  In the operate and maintain stage the goal is to effectively ensure the asset availability, longevity and capability. The operation of the process are all activities related to the production. The operations is the activity which realises value out of the assets. The operators are close to the assets and work daily with the assets as designed by the engineers. Maintenance ensures the availability and reliability of the assets. There are different strategies to maintain assets. Companies can choose to not maintain assets or do corrective maintenance, repair when it breaks. But most companies strive to preventive maintenance, repair before it breaks. The chosen strategy depends on the strategy of the company and the asset value. To do the maintenance and operations, logistic support is needed. This logistic support will provide spare parts e.d. which are needed to maintain and operate the asset.
- Disposal
  During the production the asset is constant monitored and reviewed. This will review the fitness of the assets to the production. This might lead to the re-engineering of the assets or removal from the plant. After removal, the assets need to be disposed or recycled. Some parts of the assets might be re-used or sold. These final activities need to be taken into account when the assets are designed.

These five stages are used in most definition of the asset life cycle. Sometimes steps of Ouertani et al. (2008) are further divided. For example, in Hastings (2015) an eight step model is used. In this cycle the concept is divided in four steps; the business opportunities, gap analysis, pre-feasibility analysis and feasibility analysis. While at the operate and maintain stage a monitoring and review step is added. For this research the five stage model is significant to distinct the different activities. In this research the first three activities are called engineering and the operations and maintenance functions are split, figure 2.5.

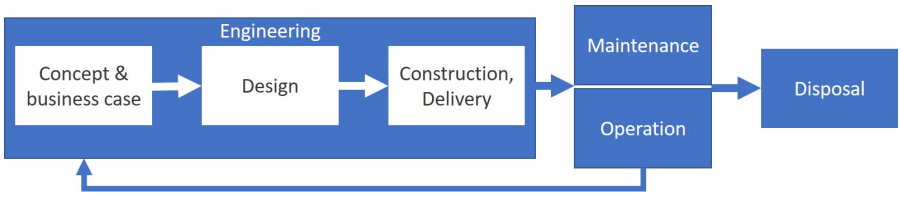


Figure 2.5: Asset life cycle (source: Adapted from Ouertani et al. (2008))

2.1.4. Standards and norms

In this section more information about the standard and norms of asset management are given. The first asset management standard is the British Publicly Available Specification (PAS 55). This standard is followed up by the International Organisation of Standardisation (ISO). They have defined three standards for asset management, these are currently used, the ISO 55000, IS 55001 and ISO 55002. The first is an overview of principles and terminology. The second and third one will give the requirements and guidance for implementation (ISO, 2014a)(ISO, 2014b)(ISO, 2014c). The requirements are related to the following six points;

- Organisation (Governance; Risk Management)
- Leadership (Policy & Strategy)
- AM Plan (Concept Management; Plan)
- Operation (Service Providing)
- Evaluation (Performance measurement)
- Improvement (Analyse & Improve)
- Supporting facilities (Organisation; People; Means)

The six points are split up in eleven points by Stork as shown behind the different points. A short explanation will be given, and in appendix D the full explanation is provided. The strategic asset management plan should be in line with the objectives of the organisation. The top management should support and commit to the asset management plan and a appropriate planning should be made. The resources (physical, human and information) should be available and employees should be aware of the importance of asset management. Then the operation should be performed following the plan, the performance needs to be evaluated and improvements should be proposed (ISO, 2014b). For each of them the ISO standard gives a detailed description how they should be fulfilled as shown in appendix D.

The ISO (2014a) has defined four fundamentals of asset management; value, alignment, leadership and assurance. Asset management wants to create value out the asset. The value has been defined in section 2.1.3. The asset management decisions are aligned with the organisational objectives and help to achieve these. All managerial levels should be committed to the changes. To create value, leadership and culture are very important, since it requires change management to implement asset management (Godau, 2007). At last, asset management will give assurance about the assets to the company.

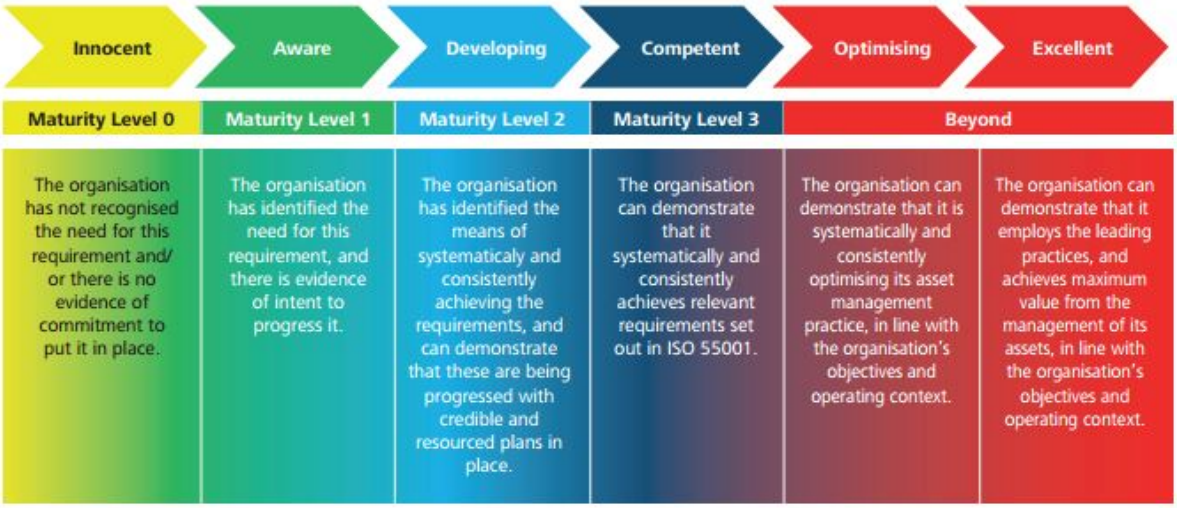


Figure 2.6: Different maturity levels in asset management (source: IAM from (The Institute of Asset management, 2015))

2.1.5. Maturity of asset management

In the ISO standard (ISO, 2014a) a maturity model for asset management is defined. The different levels are shown in figure 2.6. The scoring is done on the requirements of asset management and based on the fulfilment of the requirements by the company(The Institute of Asset management, 2015). A maturity model defines different maturity levels for the type of improvement. A maturity level can be defined as an evolutionary plateau of process improvement (Correia et al., 2017). Three different types of maturity models can be distinguished (Reefke et al., 2010a):

- A descriptive tool for the evaluation of strengths and weaknesses.
- A prescriptive instrument to help develop a guide for performance improvement.
- A comparative tool to evaluate the processes or organisation and compare it with standard and best practices from other organisations, thus enabling internal and external benchmarking.

The maturity model in asset management as defined by ISO (2014a) can be seen as a comparative tool, the third type. Based on the asset management standard and its requirements the performance can be indicated. This model gives an indication in the performance but do not guide the improvement. The asset management maturity model can be seen in figure 2.6 and is explained in appendix D.

Maturity models can have a different number of levels. The first developed maturity model, capability model, has five maturity levels and has been developed by Carnegie Mellon Correia et al. (2017). Yusuf et al. (2004) developed a three level model, which allows less precision and distinction. A four level model is proposed by Kurnia et al. (2014) with the levels unaware, unprepared, committed and advance. But the asset management maturity model has six levels similar to Reefke et al. (2010b). These levels are shown in figure 2.7. These six levels start with un-aware and ends with world class performance. In the model proposed by Reefke et al. (2010b) the levels are indicated from 1 to 6, while in the asset management maturity model the levels are indicated from 0 to 5, which does not differ but can be confusing. On one hand, level 0 for the lowest level is logical since it is non compliant, but on the other hand this confuses the amount of levels. In this report the levels as defined by the maturity model will be used.

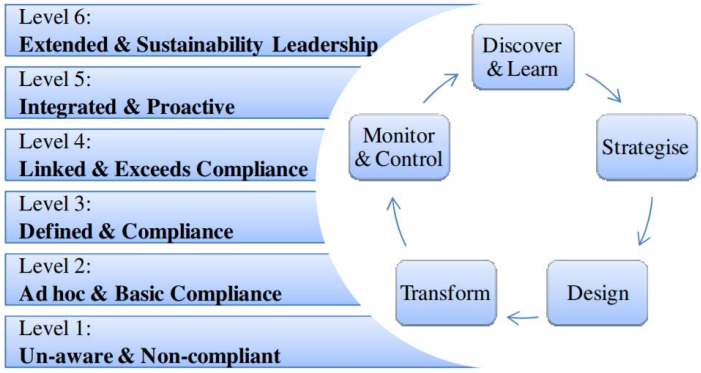


Figure 2.7: Layout of a six level maturity model (source: Reefke et al. (2010b)

As defined by Reefke et al. (2010b) and Correia et al. (2017), a maturity model helps to achieve goals and objectives. The model should provide a clear direction and a shared vision. To achieve the goals and objectives, guidelines should be available and it should help to define action plans. Since the asset management maturity model is a comparison model the last aspects are still missing.

2.1.6. Conclusion Asset Management

In this section asset, management, and asset management are defined and discussed. Asset management is the coordinated activity of an organisation to realise value from the asset in the asset life cycle. The main activities in asset management are engineering, operations and maintenance. The value of the asset is defined by the asset owner but related to availability, readiness and occupancy rate. Asset value is measured with the Overall Equipment Efficiency. Standards for asset management are developed and maturity levels are defined. The maturity model is a comparison model with 6 levels. This model analyses the performance and provides a maturity level but does not provide a way for improvement.

2.2. Lean

In the previous section, asset management has been explained. In this section the other main concept of this research will be introduced; Lean. First an introduction of lean is given (Section 2.2.1), then the history of lean is described (Section 2.2.2) followed by the fundamentals of lean (Section 2.2.3). The aspect of continuous improvement is further explained (Section 2.2.4) and the implementation of lean are given (Section 2.2.5). This section is ended with a conclusion (Section 2.2.7).

To perform this literature review on lean, first books about the basic principles are used, such as Womack et al. (1990), Womack and Jones (2010) and Liker (2004). Also some books about some specific aspects are

used, such as (Imai (1986) and Mann (2005)). Then papers are found with searching on the terms lean implementation and lean measurements.

2.2.1. Introduction on Lean

Lean Production of Lean Manufacturing is a way of process thinking where the customer value takes a central place. Customer value can be described as the aspects of a product, or service, where the customer wants to pay for. In lean the production steps should all contribute to the customer value, otherwise they are called waste and should be removed from the process. This removal of waste will reduce the complexity of the system and the lead time of products.
The most important principles of lean can be given in the house of lean, figure 2.8 (Stehn and Höök, 2008). The fundamental of the house is stability, the process should be stable and generate a predictable and reliable output. To reach stability standardisation is necessary, this is achieved by removing *Mudas*, waste, and *Kaizen*, continuous improvement. The roof stands on two pillars the left pillar is supported by *Heijunka*, level scheduling. This is needed to create *Just-in-Time* (JIT) delivery. The right pillar is supported by standard working to achieve *Jidoka*, automation. In between the pillars stands involvement, lean can only be implemented if all stakeholders and employees are involved. Finally, the roof of the house shows the ultimate goals of the company. JIT will decrease the delivery times and Jidoka will focus on the cost, when the overall goal of lean is to increase the quality of the products. This will lead to an increase in the customer value (Stehn and Höök, 2008). More explanation of the different concepts that are named can be found in appendix E.
To involve actors and employees the lean culture is created. This culture should be created next to the lean production (Stehn and Höök, 2008) (Blokland et al., 2008). This will ensure effective leadership and synchronisation of division. (Mann, 2005)

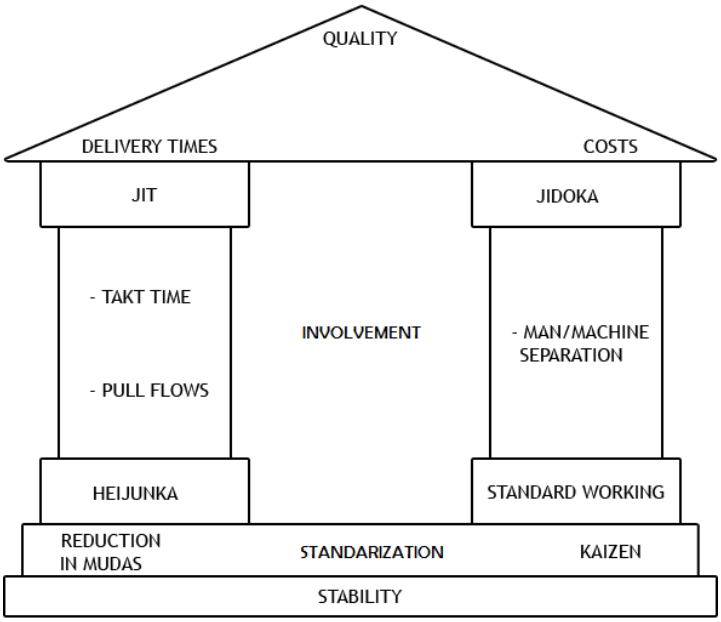


Figure 2.8: House of lean (source: adapted from http://www.managementtip.nl/lean-huis)

2.2.2. History of Lean

The term lean production is first used in 1988 by Krafcik in his article "Triumph of the lean production system" describing the difference between the Japanese and North American automotive industry (Krafcik, 1988). This article describes the Toyota's Production System (TPS). His research is continued and led to the book 'The Machine That Changed The World' by Womack, Jones and Roos which made lean production world famous.

TPS is inspired by the flow production system, developed by Henry Ford. The flow production uses moving

assembly lines to produce vehicles by introducing belt conveyors. This development made manufacturing simplistic and parts were made interchangeable, key factors for the successes of mass production (Womack et al., 1990). Toyota wanted to increase there productivity and looked at the successes of Ford. Due to the lack of financial and human resources and the changing market demand in product variability, Toyota had to develop his own production method. This became the Toyota Production System.

TPS can be concluded in 14 management principles, explained in appendix E. Different from mass production, Toyota implemented the Just-In-Time (JIT) principle, where parts are brought together when needed and inventories are minimised. TPS only works when the environment is good and created with the right philosophy and people of the organisation. Resulting in the 4P model, which can be used as follow (Liker, 2004):

- Philosophy – A company should have a long term philosophy. The goal should be sustainable growth achieved by focus on growth of the organisation, customers, the well-being of employees and society.
- Process – The production process should be optimised by reducing waste and creating flow in the value stream. To realise this, the process should be standardised, focus on quality and visually controlled.
- People & Partners – When applying lean, all employees and partners should be involved. A company needs to invest in trainings to learn the lean philosophy. An open culture should be created where ideas for continuous improvement can be initiated from everyone.
- Problem Solving – During the process time for reflection and continuous improvement is important. When making decisions, consensus should be made with the employees on the work floor. Problems can be solved with the Plan-Do-Check-Act cycle.

The implementation of TPS at Toyota led to great successes and Toyota became world leader in the automotive industry (Economist, 2005). Therefore, other companies in this industry also implemented lean production to create a more efficient process. These changes were noticed by other industries and currently lean is implemented in all kind of productions companies (Melton, 2005) (Buell et al., 2004), logistics companies (Abdulmalek and Rajgopal, 2007), construction companies (Stehn and Höök, 2008) and even service companies. In all these industries the focus on maximising customer value by removing waste in the process has shown to be valuable.

2.2.3. Fundamentals of Lean

To implement the lean philosophy five principles should be performed in sequence. To strive for continuous improvement the steps should be performed in a circle and will help to implement lean. The five principles are (Womack and Jones, 2010):

1. Specify value – The value is defined by the end customer in terms of a specific products with certain capabilities at a certain time and place. The customer only wants to pay for process this added value.
2. Map the value stream – The value stream are all actions that are necessary in the process of the product and add value to the product. The value stream contains the production process, the design process and information management.
3. Create flow – Flow will created by eliminating waste from the process. Waste is defined as any (human) activity which absorbs resources but creates no value. When removing waste from the process, the lead time will be reduced .
4. Establish pull – To reduce inventories production should be activated by pull systems. The production starts when downstream activities asked for them. This is only possible when flow created and the production is fast.
5. Pursuit perfection – After the following the steps the process will change and the steps should be repeated to optimise the process. Finally, the process will be transparent where all actors can see everything.

To create a lean production all waste should be removed from the process. There are seven types of waste that are described in lean. Safety is added in this research, because of its importance in asset management.

- Transport – Movement of products
- Inventory – Waiting of products
- Motion – Movement of employees
- Waiting – Waiting of employees
- Overproduction – More products then needed
- Over-processing – More capabilities then needed
- Defects and rework – Not right at first time

Lean production makes the system more vulnerable. By removing inventories, reducing lead times and creating pull systems. The production become more dependable of the assets. Therefore, asset reliability will be more important when applying lean thinking in the production.

2.2.4. Continuous improvement

Continuous improvement (CI) or pursuit perfection is one of the steps in lean manufacturing. The aspect of continuous improvement is described and developed by Masaaki Imai in his book Kaizen, The Key to Japan's Competitive Success. Kaizen means ongoing improvement involving everyone, from managers to workers and must be applied on the way of life and work. To do this first Standard Operating Procedures (SOP) should be developed. If these are not followed by employees the discipline should change, but if employees are unable to follow them, trainings are necessary. These SOP should be continuous improved, so the quality, cost and delivery of the business will be improved (Imai, 1986) (Terziovski and Sohal, 2000).

In research of Terziovski and Sohal (2000) is found that the motivation for CI is related to quality conformance, increased productivity, reduced costs, and improvement in delivery reliability. Also is found that the amount of employees involved, the amount of training, the time of use of CI and breadth of its application all have a positive effect on the experiences of companies with CI.

2.2.5. Implementation of Lean in literature

Lean is implemented in all kind of production companies in all kind of industries. Starting in the automotive industry, suspending to the process and service industry. Here lean has been successful implemented to create a more efficient production. To implement lean in a company not only the production should be changed, but also the culture is important. Lean has been implemented in the production of the different industries of Stork. In the oil and gas (Buell et al., 2004), chemicals and process(Melton, 2005), metals and mining (Abdulmalek and Rajgopal, 2007) (Wijaya et al., 2009) and manufacturing (Stehn and Höök, 2008).

Lean has already been implemented on activities of asset management, mostly operations and maintenance. Lean originates from production and this is includes the operation of the system. Lean operation is used since the start of lean. Lean maintenance is also used and defined as producing a desirable maintenance outcome with the fewest inputs possible (Levitt, 2008). To measure how lean a organisation is performing different aspects can be scored. Hujdurovic (2008) has developed a scoring card where on 38 lean aspects are scored on five levels. This model can be seen as a maturity model of different lean tools. With the maturity levels the performance of the company can be defined.

2.2.6. Lean tools

In table 2.1 different lean tools that are analysed in different literature studies are given. These lean tools are explained in appendix E. Sometimes, in literature different names are used for the same tool, they all have a Japanese name and an English name. In this report the English name of the different lean tools are used. These tools all belong to, but not complete the lean tools. In this table the most important tools are given, but within the literature some other tools might be found. Some of the tools originate form other optimisation processes, which are shown in figure 1.2, but are also used in a lean environment.

2.2.7. Conclusion Lean

Lean is a management philosophy focusing on creating maximum customer value with minimum resources. Lean originates from Toyota Production System in Japan, but is currently implemented in supply chains in different industries all over the world. The fundamentals of lean consists of five steps; specify value, map the

Table 2.1: Lean tools used in literature

			1	2	3	4	5	6
Policy Deployment	Strategisch	Management improvement				x	x	
Continuous Improvement	Strategic				x	x	x	x
Plan Do Check Act	Strategic						x	
TQM	Strategic			x	x			
Six big losses	Tactical	Performance Measurement				x	x	
Visual Management	T/O		x				x	x
SMART goals	Operational						x	
PMS	S/T/O		x				x	
Waste management	Tactical	Waste management				x	x	
VSM	Tactical		x				x	
Continuous Flow	Tactical		x	x		x	x	
Root Cause Analysis	T/O	Analyse process	x				x	
Bottle Neck Analysis	T/O				x		x	
TPM	T/O	Productive Maintenance	x	x	x		x	
Autonomation	T/O	Automation	x				x	
Cross functional team	T/O	Integration		x	x	x		
Customer involvement	S/T/O			x		x		
Employee Involvement	T/O			x		x		
Gemba	S/T/O						x	
Group problem solving	T/O			x	x	x		
Supplier involvement	S/T/O			x		x		
Workforce management	Operational			x	x			
Training	Operational	Human mistakes		x				
Standardised work	Operational		x				x	
Error proofing	Operational		x	x			x	x
Equipment layout	Operational			x	x			
Production Preparation	Operational	Reduce waiting in supply chain	x					
Pull system	Tactical		x	x	x		x	x
Level Scheduling	Tatical		x	x	x		x	
Takt Time	Operational		x		x		x	
SMED	Operational		x	x	x		x	x
Just in Time	S/T/O			x	x	x	x	
5S	Operational		x				x	x

1=(Hujdurovic, 2008), 2=(Shah and Ward, 2007), 3=(Shah and Ward, 2003), 4=(Karlsson and Åhlström, 1996), 5=(Vorne, 2016), 6=(Melton, 2005)

value stream, create flow, establish pull and pursuit perfection. To perform these steps different tools have been developed. In total 33 lean tools are mapped, which all work on strategic, tactical or operational level.

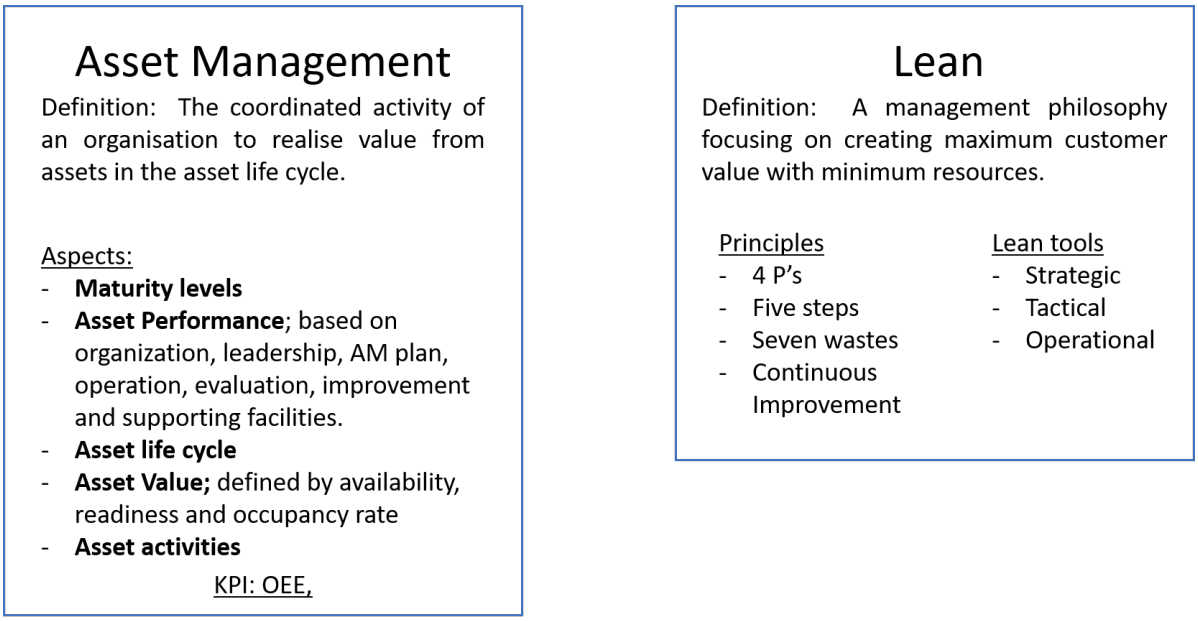


Figure 2.9: Main findings from the definition phase: Literature Framework

2.3. Conclusions define phase

In this section, the first two research question are answered. The answers on the research questions can be found in the boxes below and the the main aspects of this chapter are shown in figure 2.9. This conclusion ends the definition phase. At this stage the problems and main concepts are defined.

Research Question 1: What is asset management and what are its main aspects?
Asset management is defined as the coordinated activity of an organisation to realise value from assets in the asset life cycle. Four important aspects in asset management are found. First, the asset management maturity model is important. Here, the performance is provided with a level. Second, the performance measurement is mentioned. To define the performance research on seven aspects is needed. These aspects are; organisation, leadership, AM plan, operation, evaluation, improvement and supporting facilities. The third aspects is the asset life cycle, all the sub-activities in the life cycle should be taken into account (engineering, maintenance, operations and disposal). The fourth aspects is the value of the asset. This can be defined in the factors availability, readiness or occupancy rate. Which of them, needs to be defined by the asset owner.

Research Question 2: What is the lean philosophy and what are its main aspects?
Lean is defined as a management philosophy focusing on creating maximum customer value with minimum resources. In this philosophy it is important that the fist this customer value is defined. The second step is to map the process of adding value and maximizing this value, third step is about minimizing this inputs. The forth step is to reduce the lead time and create a pull system. The last step is the continuous improvement. Aspects of lean can be implemented by using lean tools

3

Measure
Practical review on asset management

This chapter will describe the measure phase of this research. The current state of asset management at three different case studies are defined. In this chapter is looked how the concepts explained in literature are used in practice. In the definition phase, the aspects of asset management are explained. In this chapter the asset management performance and maturity is measured. Also the implementation of lean and use of lean tools is researched at the different case studies. Each case study is described in one section (Section 3.1, Section 3.2, Section 3.3). With this new information an actor analysis can be performed for the different actors involved in asset management (Section 3.4) and differences between the different companies can be defined (Section 3.5). These different findings are concluded in the last section (Section 3.6). The relation between the different section is shown in figure 3.1.

In the three case studies the level of implementation of asset management, the industry and organizational structure differs. Therefore, these case studies give insight in the differences and similarities between organizations in their processes, markets and management. It will give insight in the current practical problems. It will also show where the lean can be used in asset management from a practical view. The differences between the different cases, was the main aspect on which the case studies has been chosen.

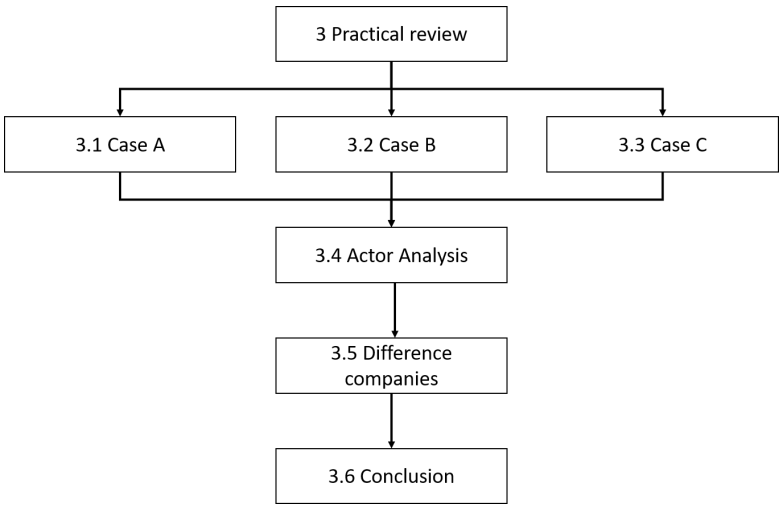


Figure 3.1: Chapter layout

This chapter will answer the following research question:

- How is asset management currently implemented in related industries?

3.1. Case A - Tank terminal

The first case study is performed at a tank terminal. To perform this case study two interviews are performed with the maintenance manager, [redacted] and engineering advisor, [redacted] Appendix A). Besides, internal data about work flows, organisational structure and the process description is provided. Based on this information the case is researched. More figures and data are given in appendix B.

Information about the process is collected with a visit and internal data describing the process. At the terminal the main activity is the storage of fluids, but also transshipment of fluids and adding additives are adding value activities. The assets that are used in the process are; loading arms, pumps and storage facilities. The process at the tank terminal starts when a oil vessel that barges at the jetties, special quays. At these jetties a loading arm can unload the vessels. Via pumps the fluids are transported to the tanks. At the tanks additives can be added to the fluids. When requested the fluids are pumped out of the facility to the loading arm, in this process there is another possibility to add additives. From the storage facilities the fluids are loaded in another (short sea shipping) vessel or truck.

The organisational structure is provided from internal data. The terminal manager has the lead at the tank terminal. The planning department does the overall planning of large projects and the Health Safety Security Environment and Compliance department ensures the safety of the plant and prevent incidents to happen. The maintenance department is mostly outsourced to Stork, but the leader of the maintenance department is from the tank terminal. Projects and engineering projects are designed by different intern or external groups, but the execution of the project is always outsourced. The operations at the terminal are all internal.The relationship between departments is visualised in figure 3.2. The bottom four departments have their own purchasing and planning activities inside the departments. From the interviews can be defined that the departments are independent and are responsible for their own activities and do not cooperate. The different departments are even located in other buildings on the terminal.

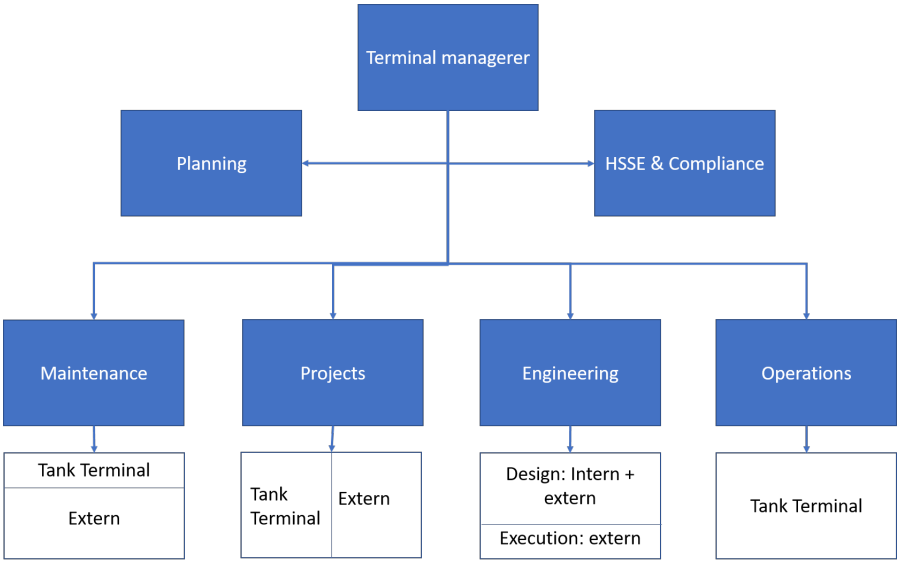


Figure 3.2: Organagraph of the tank terminal (based on internal data)

3.1.1. Maturity in asset management

The performance of asset management is based on the interviews. The management of assets is not coordinated over the different activities. Value of the assets is created inside the own departments. An example is provided by [redacted] pumps are engineered for a certain capacity, but this capacity will not be reached. Therefore, these pumps are not operating well. The physical borders between the departments, in work location and company, are a obstacle in the start of the coordination of the activities, which is mentioned by [redacted] Following the maturity scale as described in section 2.1.4 and in figure 2.6 the maturity of the tank terminal is still level 0, the asset management performance is shown in figure 3.3 (detailed description in appendix B). The aspects that score better are the supporting facilities, operations and evaluation. Here some

aspects of asset management are visible in the organization. In the other aspects they have not recognised the need for asset management requirements as defined in the ISO 55000. Currently their are no plans to develop an asset management strategy as is mentioned in both interviews.

Figure 3.3: Asset management performance at the tank terminal

3.1.2. Current problems

The work is not coordinated between the different activities in the asset life cycle and work is not pulled in this system. From engineering new assets are pushed without the requirements and demand from downstream activities. Based on the asset management performance and goals the main remarkable points that can be concluded from the interviews are:

- Difficult to review the performance of the asset.
- The work is not flowing in the process.
- Large boundaries between the different departments which make it difficult to involve all employees.
- Safety is very important.

3.2. Case B - Brewery

The second case study is performed at a brewery. At this case study, three interviews are held. First, the implementer of TPM, [redacted] The asset is visit and the process is analysed. Some internal data about the organisational structure and work flows are researched. In appendix A the interviews can be found and in appendix B more figures and data of the Case B can be found. At the brewery packaging lines were researched. At the brewery the lean tool TPM is implemented, the implementation of TPM is researched with interviews. At the brewery maintenance tasks are divided between the operations (autonomous work) and maintenance department (predictive work). Both departments are involved in the engineering process. The engineering process is designed for TPM and enables coordination between operations and maintenance from start of production. These benefits are mentioned by Gerben Niehof, but a also mentions that the sharing of information is still difficult over department, since different software systems are used.

Based on internal data the structure of the company is researched. At the brewery most tasks are performed internal. There are departments for the brewing and packaging process, they share a maintenance, quality and safety department. The maintenance department is responsible for all maintenance of assets inside the building. Within this department one group focusses on modifications and is responsible for re-engineering projects. There is no engineering department, external parties are hired. Besides the familiar departments, the brewery has a TPM department which monitors and improves the use of TPM at the plant.

3.2.1. Maturity in asset management

The company has multiple breweries all over the world where similar processes are performed. The same assets are deployed with the same strategies, adapted to the local environment of the specific brewery. To make the operation and maintain efficient TPM is introduced in all breweries. An internal audit committee scores the performance of the TPM at the brewery. This ensures the continue improvement of the asset maintenance and operations. The integration with engineering is only missing currently and good systems to analyse the work are missing, as is mentioned by [redacted] Following the maturity scale as described in section 2.1.4 and in figure 2.6 the maturity of the brewery is in certain aspects beyond maturity level 3, the result of the asset management performance is shown in figure 3.4 and described in appendix B. With TPM as main goal the brewery is very mature and fulfilling the requirements set as explained in appendix D. These requirements are not set for the TPM methodology but for asset management. Therefore the brewery should expand their TPM facilities and focus on the parts which are no less developed following [redacted] These areas are the integration with engineering, coordination on a tactical and structural level, and performance analysis and evaluation.

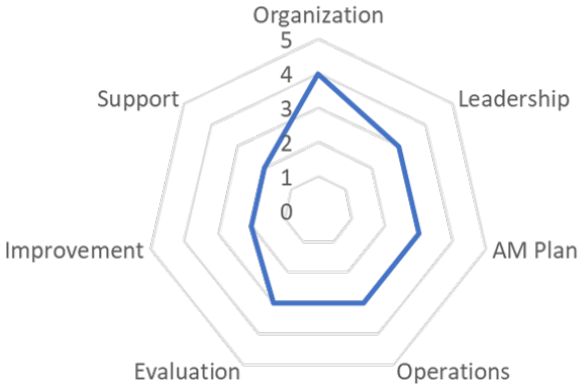


Figure 3.4: Asset management performance at the brewery

3.2.2. Current problems

In the interviews the current situation at the brewery is described. Based on this information some remarkable aspects in the process in relation to asset management can be found. From these interviews the following aspects are selected:

- Cooperation between maintenance and operation is good due to the TPM program.
- Information sharing is difficult over departments.
- No freedom in the design of assets.
- Focus on efficiency instead of effectiveness.

3.3. Case C - Gas storage

The third case is a gas storage facility onshore in the Netherlands. To research this case three interviews are held with a [redacted] For this case performance data is researched. Also, some internal data about the facility and organisation is used. The interviews can be found in appendix A and figures can be found in appendix B. This facility enables to store gas when when the demand is low and extract it when the demand is high. The storage facility is flexible and is used to make profit with the fluctuating gas prices.

The activities at the gas storage facilitation are organised with standard work flows. Currently, these standard work flows do not fit the process. One example of a problem mentioned by Paul Stam; some supervisors need to approve certain steps, but they are not working full-time and are not aware of their influence. This stops the flow in the process and causes delays.

At the gas storage facility different external actors are hired to perform task in the process. The function of asset manager is divided over three employees; a maintenance manager, an operation manager and a technical manager. These managers are all responsible for one of the main activities in the asset life cycle. The operations are in-sourced. The other activities are mainly outsourced. The HSSE and planning department are internal organized. Here the regulations according to health, safety, security and environment and the planning of the plant are made. The relationships between the actors is quite similar to case A.

3.3.1. Maturity in asset management

The activities in the asset life cycle are separated by different departments. These departments do not have asset management related performance indicators and the are all trying to optimize their own process as mentioned by [redacted] At the same time, the data used for the performance indicators are not reliable. Following the maturity scale as described in section 2.1.4 and in figure 2.6 the maturity of the gas storage facility is level 1, the asset management performance is shown in figure 3.5 (detailed description in appendix B). [redacted] mentioned that they have indicated that asset management is important and want to improve. Currently, they are hiring an asset manager and making asset management plans. But asset management plans have not been implemented yet. The facilities at the plant are also quite good. The improvement cycle is completely missing at the gas storage facility. At the gas storage facility safety is very important. Safety environmental critical equipment (SECE) is equipment at the plant which needs to prevent major accidents. These parts have strict regulations concerning inspections and maintenance. At the facility there are problems to manage these SECE's, as mentioned by Paul Stam.

Figure 3.5: Asset management performance at the gas storage facility

3.3.2. Current problems

In the interviews the current situation at the gas storage facility is described. Based on this information some remarkable aspects in the process in relation to asset management can be found. From these interviews the following aspects are selected:

- The isolation of the engineering department.
- The importance of good work flows.
- The lack of coordination in asset management.
- The incapacity of continue improvement.

3.4. Actor analysis in asset management

Three case studies have been analysed in this chapter, from these studies some analysis can be made. In this section an actor analysis is made to gain more insight in the relationships between different actors.
In asset management multiple actors are involved, as shown in the description of the cases in this chapter. All these people are performing activities with the asset or have interest in the activities that are performed. For each stakeholder the interest and goal in asset management, their importance and their attitude is described

Bryson (2004). Their interest and goal defines the objective of the actor related to the asset. The importance of the stakeholder depends on their power, attention-getting capacity and replace-ability. The importance is described in a 5 level scale from very low to very high. The attitude is meant; the stakeholders point of view against the (further) implementation of asset management. This attitude can be positive, neutral, negative and depends, this means that the attitude depends on the implementation. The results can be find in table 3.1 and are explained in appendix C. The information is based on the different interviews performed at the case study as well with experts within Stork. These interviews can be found in appendix A. The most important stakeholders are the asset owner and the operations, maintenance and engineering managers.

Table 3.1: Stakeholder analysis in asset management

	Interest/goal	Importance	Attitude
Asset owner	Minimum total cost of ownership	Very High	Good
Operations manager	Highest availability and production of the asset	High	Good
Maintenance manager	Ensure reliability in a set budget	High	Depends
Engineer manager	Make the design according to set criteria	High	Negative
Customer	A product at the right time and place for the right price	Low	Neutral
Operator	Ensuring availability and quality	Medium	Negative
Mechanic	Ensure reliability and minimize down time	Medium	Negative
Engineer	Construction following the design	Low	Neutral

3.5. Comparison between case studies

In this section analysis is made on the difference between the companies. They have a lot of similarities, but they have certain differences that might have influence on the opportunities of lean in asset management. In this section these differences are mapped and explained. First the difference between the industries are explained. Followed by the influence of in-sourcing and outsourcing of activities. Both analysis are concluded based on the case studies that has been presented in this chapter and if possible supported by literature.

3.5.1. Different industries

Asset management is performed in different industries, the markets of Stork AMS are; oil and gas, chemicals and process, metals and mining, power and manufacturing. The case studies are performed along different industries to get insight of the possibilities of lean in asset management. In research of Shah and Ward (2003) is found that larger plants are more likely to implement lean practices. The age of the plant has also some influence but the direction of this effect cannot always be predicted.

Another big difference between industries is regarding safety regulations inside the plant. Companies in the oil & gas and chemicals industry have larger safety and environmental risks then for example in the manufacturing industry. For these companies the costs of an accidents are really high, not only financial but also regarding the reputation of the company. They invest a lot to ensure a safe production, this is even more important then efficiency and effectiveness. These companies do not want to take risks according safety and are not willing to economize on this aspect.

3.5.2. In-source versus outsource

In the various cases discussed in this chapter are differences shown in the amount of activities that are outsourced by the company. When the assets became more complex, the engineering of the asset is almost always outsourced. The operation is mostly done by the asset owner but the maintenance can be outsourced to a service provider or handled by an internal maintenance department. When different companies are involved in the process, it will become more complex and double functions will exists. The outsourcing of activities will increase when the complexity of the asset will increase. The asset owner is specialised in the production and not in the asset needed.

3.5.3. Production process

The production process influences the implementation of asset management. In continuous processes, as for example the gas storage facilitation, maintenance will always lead to a reduction of the asset value. In line-flow processes the maintenance can be done in the time that the plant is not operating. The type of production that is chosen influences the importance of coordination between maintenance and operations.

3.6. Conclusions measure phase

In three different cases is looked at asset management and how this is organized. The information is collected by visit the assets, interviews and meetings with actors of the different assets. Based on this case studies an actor analysis and comparison analysis are made.

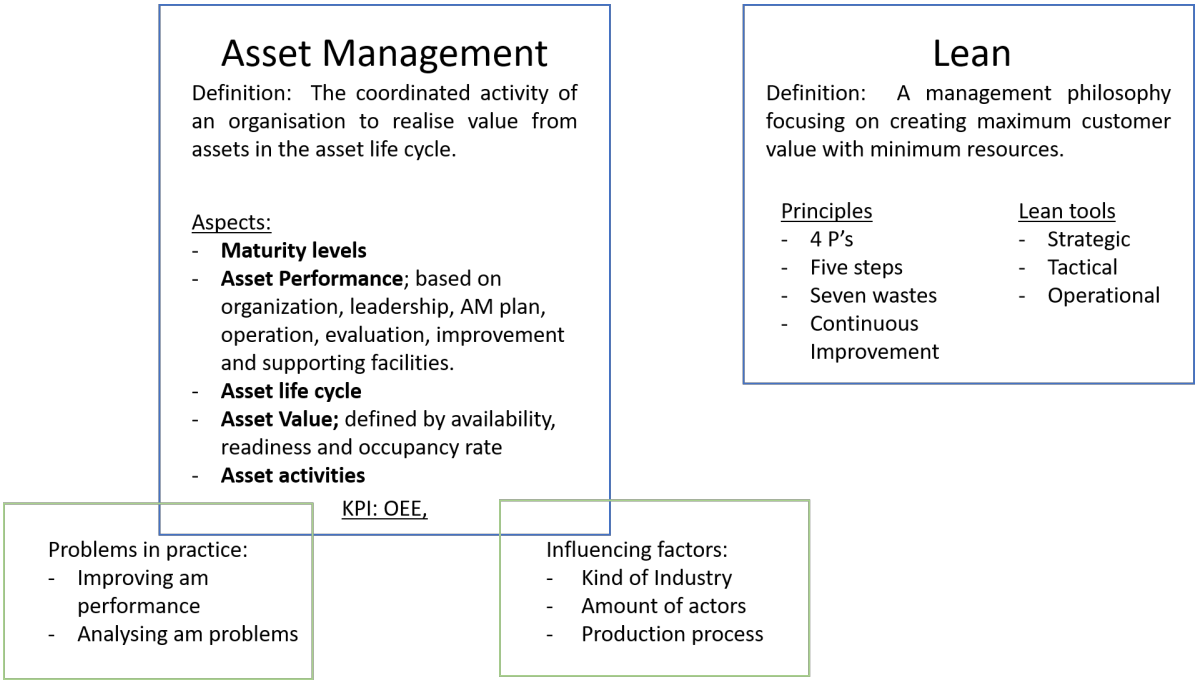


Figure 3.6: Main findings measure phase: Current state framework

The maturity in asset management differs between the different cases, but they still have the same problems. The main problems related to asset management are:

- There are boundaries between departments this leads to the following problems:
  - Involving all employees in changes.
  - Ensuring the sharing of information.
- Measurement of the performance of the asset.
- Creation of flow in the process is difficult.
- Applying a continuous improvement cycle in asset management is still infancy.

As shown in the case studies there are boundaries between the different departments which are difficult to remove. These boundaries make it difficult to work together and ensure that information is shared. Even if the boundaries between the departments are getting smaller, the sharing of information appears to be difficult by the various software systems. Working together to coordinate activities is more difficult when the different activities are outsourced instead of in-sourced. Besides, performance measurement of the asset is still difficult. The flow in the process is difficult, in all cases this is difficult to achieve. Continuous improvement system to

realize this flow are not implemented yet. As also concluded in van Rijn (2017) continuous improvement and the right incentive to achieve this is difficult for companies. The different actors have different goals and the interests are not equal. These differences should be taken into account. The main findings can be added to the literature framework shown in figure 3.6. This figure is similar to the figure in the conclusion of chapter 2, but the two boxes are added in this chapter.

Research Question 3: How is asset management implemented in case studies?
Asset management is implemented in different maturity levels. There are still problems in the implementation of asset management. Information sharing and overall goals are difficult to achieve. Creating flow and measuring the performance are still difficult for most companies. Most problems have as source that a continuous improvement cycle is missing.

4

Analysis
Synthesis of using lean in asset management

In the define and measure phase the aspects lean and asset management are reviewed from literature and practice. This information will be combined and analysed in this chapter. The important factors are selected and the opportunities of using a lean perspective to asset management are defined. First, the information from the define and measure phase are synthesised (Section 4.1). From this synthesis, the opportunities of using lean in asset management are given (Section 4.2). Next, the lean tools are selected based on their capabilities in an asset management context (Section 4.3). Finally, the requirements for the design will be given, these are set based on the different analysis that are made. The relationship between the different sections is shown in figure 4.1.

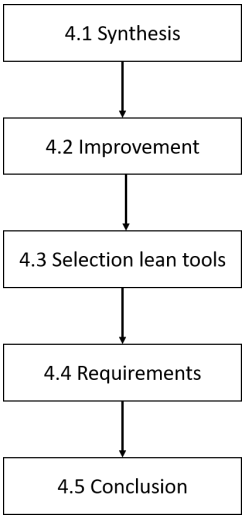


Figure 4.1: Chapter layout Opportunities of Lean in Asset Management.

In this chapter the following research questions are answered:

- How can lean contribute in asset management?
- What are the requirements for the contribution of lean in asset management?

4.1. Synthesis of the concepts lean and asset management

In the previous chapters asset management and lean have been introduced, defined and measured. Asset management is defined as the coordinated activity of an organisation to realise value from assets in the asset life cycle, section 2.1. While lean is defined as a management philosophy which focuses on creating maximum customer value against minimum waste, section 2.2. Here, the contribution of lean in the asset management perspective will be synthesised.
Two main problems are found in the practical analysis of asset management. First, the difficulty of implementing and measuring asset management for all kind of companies. Second, the lack of continuous improvement in the asset management performance models. Besides, different actors are acting for their own purpose and do not focus on effectiveness. However, improvement is part of asset management, the direction for improvement is not defined yet. The two main problems can be stated as follows:

- Analysing the problems in asset management.
- The lack of structural method to continuously improve asset management.

The lack of structural method for improvement is also concluded in the literature review. The current asset management maturity model is limited. The model is a comparison model and benchmarks the performance, it does not provide guidelines for improvement. Companies do want to improve their asset management performance due to the gains in efficiency and effectiveness. Lean will be used to improve as optimisation method. The lean philosophy provides lean tools to optimise processes, which can be used in asset management.

Just implementing lean tools will not work, as is concluded in section 2.2. The company who wants to improve asset management with lean tools, should also take the five principle steps of lean. These steps ensures that the customer value will be created and the optimisation will be effective. The five main steps of lean can be placed in an asset management context as follows:

- Indicate value – The value of the asset is defined in the availability, readiness and occupancy rate (chapter 2.1). Which of these factors, should be defined by the asset owner.
- Map the value stream – Indicate which steps are necessary in the current process to create this value. In asset management the influence of downtime on the asset value should be determined.
- Create flow – Remove waste and relieve bottlenecks. The value should be maximised with minimum inputs. Different priorities should be defined for the assets based on risks as determined in the previous step.
- Create pull – Ensure for the right incentives for changes in the process.
- Continuous improvement – Try to optimize the process constantly.

The other lean principles that have been defined in the literature framework, 4-P's, seven wastes and continuous improvement, are not further researched. The 4-P's are already visible in the asset management framework. Where the philosophy, process and people and partners are aligned. The problem solving element is visible in the five step model. The seven wastes and continuous improvement are also visible in the five step model. And since lean is used as tool to improve performances, the description as in the five step model is sufficient. The principles are to detailed for the application that is used.

In the literature framework, different asset management aspects are defined, but not all are taken into account in this research. In asset management the sub-activities are equal for all companies. They all have engineering, maintenance and operations activities and however the execution differs, it is not referred as an influencing factor in literature or practise. The aspect sub-activities is therefore not taken into account in the design of the improvement method. The asset life cycle has a certain influence on the asset management performance, but smaller than the for example maturity and asset value. The asset life cycle will be used as an influencing factor in the design of the improvement method, but not as input.

As can be concluded, not all factors that are discussed in the define and measure phase have influence on the asset management performance. The framework that have been created can be reduced based on this

synthesis. In figure 4.2 the current state framework for improving asset management is shown. Here, all factors that will influence the improvement of asset management with a lean perspective are shown, these should be taken into account in the improvement method that will be developed.

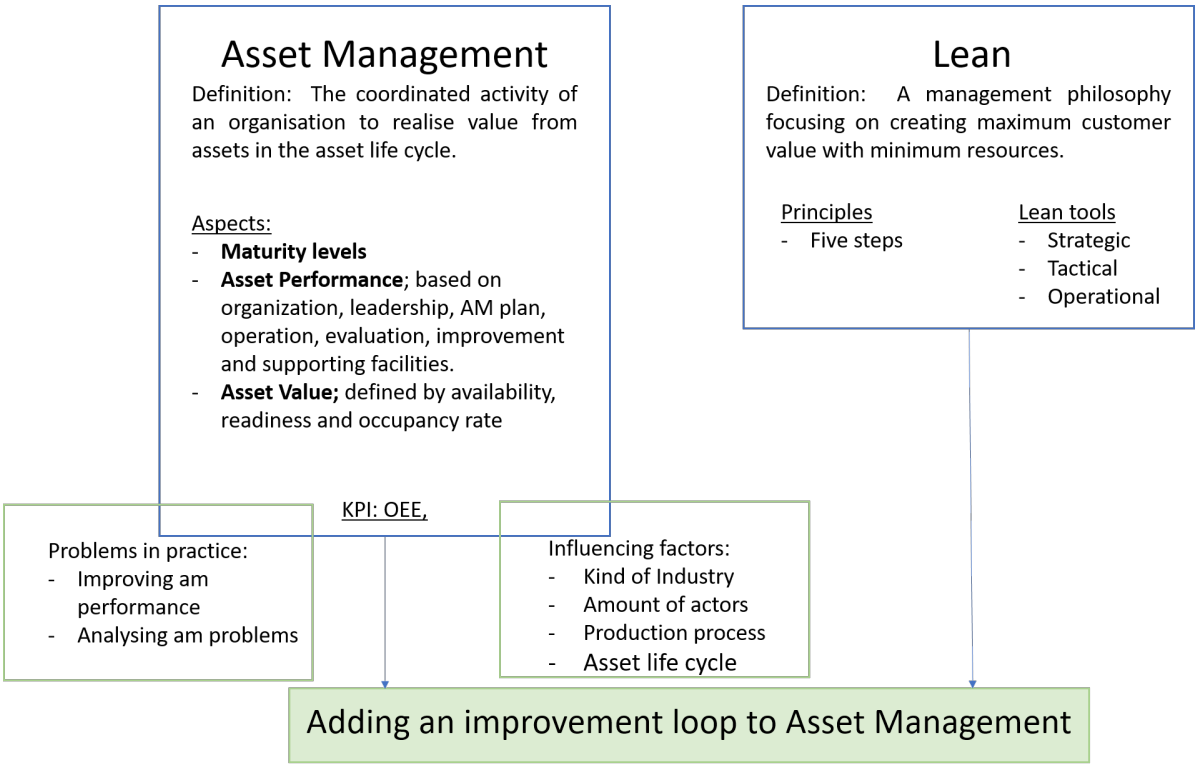


Figure 4.2: Current state framework for improving asset management

4.2. Improving asset management with a lean perspective

The asset management performance should be improved. In the current asset activities no improvement loop is available (see in figure 2.4 in chapter 2). This improvement loop is added to the current asset activities (figure 4.3).

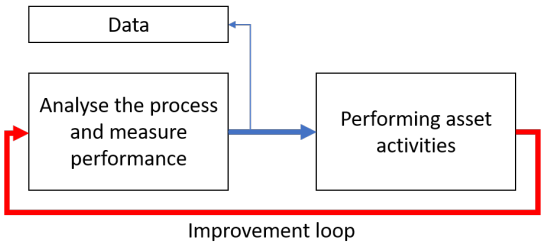


Figure 4.3: Asset activities with continuous improvement loop

This improvement loop should be performed in different steps. These steps are following a plan-do-check-act method and therefore a continuous improvement environment is created. The plan-do-check-act circle is a continuous improvement cycle which can be used in all kinds and levels of organisations (Moen and Norman, 2006). The different steps are explained in more detail. The asset activities will be performed at the plant as normal and the performance should still be analysed which gathers data as input for the improvement loop. The improvement loop consists of three different steps which are as follows:

1. When the performance is known, areas for improvements can be found. To perform this step current

asset management maturity levels can be used.

2. To find methods to improve the coordination between the asset activities a lean tool can be used. A method which assigns the best suitable lean tool should be developed.

3. The improvement method should be implemented in the process.

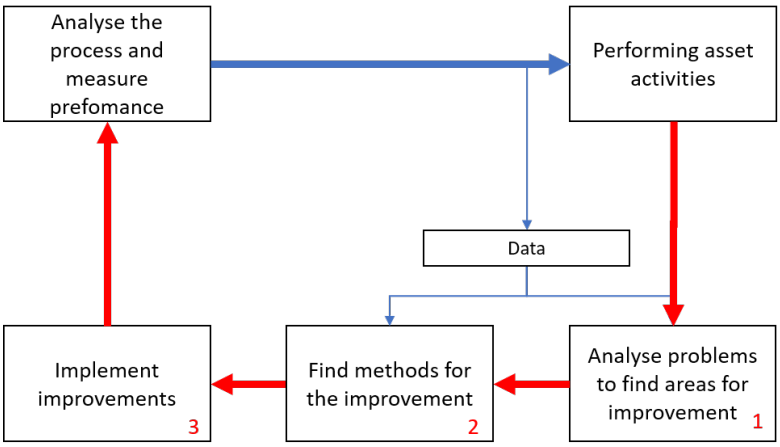


Figure 4.4: Asset activities with continuous improvement loop

4.3. Selection of lean tools to use in asset management

In the define phase 33 lean tools have been presented. Not all of these lean tools can be used in an asset management context. The different tools originates from a supply chain environment and cannot all be used in an asset management environment. In asset management the different lean tools should be able to coordinate activities in the asset life cycle.

Nine lean tools are omitted because they cannot be used in the integration of the asset activities. These tools are; customer involvement, supplier involvement, production preparation, pull system, level scheduling, takt-time, SMED, JIT, and 5S. These tools focus special on supply chain coordination or focus on optimising one sub-activity. These tools are not used in this research.

Another nine tools are omitted, because of their large similarity with other tools. The tool that is most suitable in the asset management is selected. The tools that are left out are; PDCA, TQM, Six big losses, SMART-goals, waste management, continuous flow, workforce management, error proofing and equipment layout.

In table 4.1 the selection of fifteen lean tools that are used in asset management are shown. In this table the tools are grouped by similarity. The detailed explanation of the selection can be found in appendix F.

4.4. Requirements

In the previous sections the possibilities and opportunities of lean in asset management are defined. In the define and measure different requirements for the improvement method are shown. In this section these requirements are presented. First, some influencing factors in the result of the model will be discussed. These are the influencing factors as defined in the current state framework in figure 4.2. Followed by the requirements and constraints for the improvement method.

4.4.1. Influencing factors on the Improvement Method

The improvement method cannot be used in all situations. To use the method certain information needs to be available, otherwise it is impossible to make well-advised decisions. At the same time, the model is not

Table 4.1: Tools used in the model, divided over categories and solution area

Lean Tool	Group	Function in AM
Policy Deployment Continuous Improvement	Management improvement	Improve
Visual Management PMS	Measure performance	Analyse & Improve
VSM	Waste Management	Analyse
Root Cause Analysis Bottle Neck Analysis	Analyse process	Analyse
TPM		Improve
Autonomation		Improve
Cross functional team Employee Involvement Group problem solving Gemba	Integration	Improve
Training Standardized work	Human mistakes	Improve

suitable for all companies. Therefore, the influencing factors of the model needs to be discussed. These user requirements are based on the influencing factors that are result in figure 4.2.

1. Industry of the company.
   The kind of industry influences the possibilities in efficiency improvement. In safety-related industries less risks will be taken and the efficiency of the company is less important. Therefore, asset management has less potential in safety-related industries.

2. Amount of actors that are involved.
   The asset should have a sufficient size. The different activities need to be coordinated by different people, otherwise the coordination of the activities is irrelevant. At the same time, asset management is more relevant if different sub-activities has been outsourced. This makes the implementation more difficult but also brings more improvement potential.

3. Type of production process
   The type of production process influences the asset management execution. Line-flow processes are easier to maintain than continuous flow processes. In line-flow cases, the coordination between the sub-activities becomes easier.

4. Life-span and design of the asset
   The life-span and design of the asset influences the potential in asset management. When the life-span of the asset is short, the potential of improving asset management low. The investments in the beginning will not be paid of in the life-span of the asset. At the same time, the design of the asset is important. Asset management should be taken into account during the design of the asset. If not, this will influences the possibilities of improvement.

4.4.2. Requirements of the Improvement Method

The different functional requirements and constraints of the improvement method are given. The functional requirement of the method is something that the it needs to be do. The constraints are restrictions of the functional requirements that can be used.

Constraints

1. The improvement method should be usable without in depth knowledge of lean (Stork AMS).
2. The improvement method should be usable by the consultants of Stork AMS (Stork AMS).
3. The considerations in the method should be clear.
4. The lean tool should be usable in asset management (Chapter 2.3).
5. The lean tools used in the model should be different from each other (Chapter 2.3).

Functional Requirements

1. The improvement method should be usable on and should make a distinction between strategic level, tactical level and operational level (Stork AMS).
2. The method should focus on the improvement of asset management, not on the improvement of one of the activities within asset management (Chapter 4.4).
3. All aspects of asset management as defined by the ISO standard ISO (2014a) should be taken into account in the method (Chapter 2.1).
4. When multiple tools can be used for one aspects distinction between them should be made (Stork AMS).
5. The lean tool should improve at least one aspect of asset management as defined in ISO (2014a). (Chapter 4.5).

4.5. Conclusion analysis phase

In this chapter the opportunities of lean in asset management are defined and research question 4 and 5 are answered.

Research Question 4: How can lean contribute in asset management?
The current asset management maturity model is a comparison model. Based on the asset management performance a maturity level is provided. An improvement loop in the maturity model is missing and should be added. Lean tools can be used to give direction for the improvement in the maturity levels. Before these tools can be used, the asset value must be defined. Influencing factors for the improvement method are; the industry, actors, production process and asset life cycle.

Research Question 5: What are the requirements for the contribution of lean in asset management?
For the improvement method that can be used in asset management five constraints and five functional requirements are defined. These are shown in section 4.4.2.

5

Design Improvement method

In chapter 4 is concluded that an improvement loop should be available in asset management and different requirements of the improvement method are discussed. In this chapter the improvement method with a lean approach is developed. This is the design phase of the research.

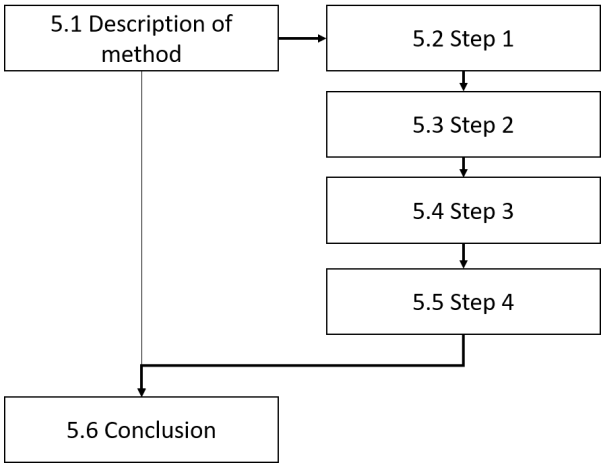


Figure 5.1: Chapter layout

First the improvement method is explained (section 5.1). Then the different steps in the model are explained in different sections; step 1 in section 5.2, step 2 in section 5.3, step 3 in section 5.4 and step 4 in section 5.5. This chapter is ended with a sub-conclusion in section 5.6. The relationship between the different sections is also shown in figure 5.1.

This chapter will answer the design objective of this research.

- Develop a tool which will guide the improvement in asset management using a lean approach.

5.1. Development of the Improvement Method

In chapter 4 the improvement loop that will be added to the asset activities is explained. In this improvement method three steps should be taken these steps are:

- Analyse problems to find areas for improvement

- Find methods for the improvement
- Implement improvements

These three different steps will be taken in an improvement method. To use this improvement method different inputs are needed. The input came from the main aspects of the current state framework and consists of three aspects:

- Asset management maturity - The current maturity level measured based on ISO (2014a).
- Asset management performance - Performance on the seven aspects defined in appendix F.
- Lean tools - The lean tools that can be used as defined in Chapter 4.3.

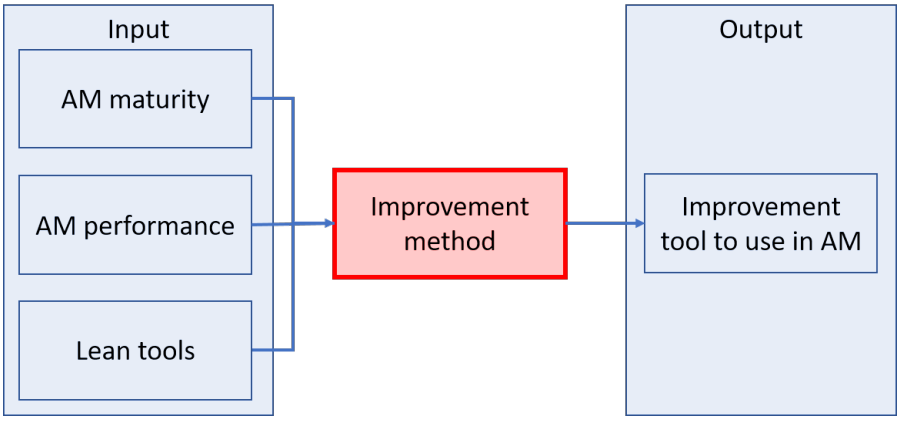


Figure 5.2: In- and output in the model

Based on this information an improvement method can be chosen. In the improvement method four different steps need to be taken. Each of the inputs will have influence on the model, this consists of the first three steps. Besides an implementation plan should be written. These different steps will be explained in different sections in this chapter and are as follows:

Step 1 Decide which schedule should be used based on the maturity level in asset management.

Step 2 Decide which aspect in asset management needs to be improved based on the asset management performance.

Step 3 Find the right tools to improve asset management.

Step 4 Developing an implementation plan based on company characteristics.

5.2. Influence of the asset management maturity level

The maturity level in asset management influences the selection of lean tools that can be used to improve the asset management performance. In cases with a low maturity different tools are better to improve asset management then in cases with a high maturity. In this research a difference between three situations are made. In table 5.1 the relations between the maturity levels and schedules which are used in step 3 are given. For each two maturity levels, one schedule is available.

5.3. Influence of asset management performance

The second step is to decide which aspect in asset management needs to be improved. Based on the asset management performance these aspects can be selected. The performance is measured as shown in figure 5.3, the aspects which scores lowest should be improved. In this case is the lowest performing asset management aspect the improvement aspect.

Table 5.1: Relations of schedules to maturity levels

Maturity level	Used schedule
Level 0	Schedule A
Level 1	
Level 2	Schedule B
Level 3	
Level 4	Schedule C
Level 5	

Figure 5.3: Asset Management Performance Gas Storage

5.4. Selection of the best lean tool

The next step is to select the best lean tool for the improvement. Different schedules are developed to make this selection; for the three different maturity levels and for the two main problems; analyse and improve. The schedules are based on the aspects of asset management as given in chapter 2.1. Here, seven aspects of asset management are given (further divided in eleven aspects). These aspects are shown in the top two rows of the model. The schedules can be used to find lean tools to analyse or improve each of the asset management aspects. A distinction is made between, certain usable, certain unusable and unknown.

5.4.1. Schedules to analyse asset management

In table 5.2 the schedules to analyse asset management for the different maturity levels is given. In this model a total of four lean tools can be used. In the model is given which aspect of asset management each lean tool can analyse. For each aspects of asset management as shown in the top row of the model (as defined in 2.1), the usable lean tools are given. These are discussed in appendix G. In this schedule the lean tools are given from strategic level on the top to operational level on the bottom.

5.4.2. Schedules to improve asset management

In table 5.3 the schedules to improve asset management for the different maturity levels is given. In this schedule a total of eleven lean tools can be used. In the schedules is given which aspect of asset management each lean tool can improve. For each aspects of asset management as shown in the top row of the model (as defined in 2.1), the usable lean tools are given. These are discussed in appendix G. In this schedule the lean tools are given from strategic level on the top to operational level on the bottom. As can been seen in the schedule some lean tools are more usable with higher maturity levels, as for example autonomation, and other tools can be used with low maturity levels, as for example visual management. For other lean tools no different can be found (Policy Deployment).

Table 5.2: Schedules to analyse asset management

Red = Do not use, Yellow = Depends, Green = Use
Lean tools are ordered from strategic at the top to operational in the bottom.

Schedule A.1	Strategic			Tactical		Operation	S/T/O	T/O			
	Organization		Leadership	AM Plan		Operation	Evaluation	Improvement	Supporting facilities		
	Govern.	Risks	p & s	concept	plan	SP	perf. Meas.	a & i	Organ.	People	Means
PMS											
Root Cause Analysis											
Bottle Neck Analysis											
VSM											

Scedule B.1	Organization		Leadership	AM Plan	Operation	Evaluation	Improvement	Supporting facilities	
PMS									
Root Cause Analysis									
Bottle Neck Analysis									
VSM									

Schedule C.1	Organization	Leadership	AM Plan	Operation	Evaluation	Improvement	Supporting facilities	
PMS								
Root Cause Analysis								
Bottle Neck Analysis								
VSM								

Table 5.3: Schedule to improve asset management

Red = Do not use, Yellow = Depends, Green = Use
Lean tools are ordered from strategic at the top to operational in the bottom.

Schedule A.2	Strategic			Tactical		Operation	S/T/O	T/O			
	Organization		Leadership	AM Plan		Operation	Evaluation	Improvement	Supporting facilities		
	Govern.	Risks	p & s	concept	plan	SP	perf. Meas.	a & i	Organ.	People	Means
Policy Deployment											
CI											
Autonomation											
TPM											
Group problem solving											
Employee Involvement											
Gemba											
Cross functional team											
Visual Management											
Training											
Standardized work											

Schedule B.2	Organization		Leadership	AM Plan		Operation	Evaluation	Improvement	Supporting facilities		
Policy Deployment											
CI											
Autonomation											
TPM											
Group problem solving											
Gemba											
Employee Involvement											
Cross functional team											
Visual Management											
Training											
Standardized work											

Schedule C.2	Organization		Leadership	AM Plan		Operation	Evaluation	Improvement	Supporting facilities		
Policy Deployment											
CI											
Autonomation											
TPM											
Group problem solving											
Employee Involvement											
Gemba											
Cross functional team											
Visual Management											
Training											
Standardized work											

5.5. Implementation of the improvement

After the selection of the different lean tools an implementation plan for the improvement of the lean tools should be developed. To give a direction to the implementation of the lean tools a maturity matrix is made. This plan should be developed for every company on its own.

The experience with lean tools will have influence on the implementation. Some companies will be more mature than other. A model to measure the lean maturity is developed by Hujdurovic (2008). In this research the maturity of the lean tools is focussed on maintenance. These maturity levels needed to be adopted to fit in an asset management context. Besides, a continuous improvement element is added for all lean tools. The results of these adoption is shown in appendix H. The maturity model has five levels which all indicate different maturity, from one to five. The lowest level is not making use of the tool and the highest is using the tool efficiently. This maturity level will help where to improve in the organisation. In the last level of maturity exists always a continuous improvement element, since this is the main advantage of lean compared to the current asset management models. The choose of to use a certain tool can also be based on the maturity level of the tools. In this case, other tools can be used than described in the previous section. The further implementation of the lean tool can be done as described in different cases and literature.

5.6. Conclusion design phase

In this chapter an improvement method is developed to improve asset management with a lean perspective. This method is based on the opportunities of lean in asset management and the requirements stated in chapter 4. This method answers the design objective of this report.

Design Objective: Develop a tool which will guide the improvement in asset management using a lean approach.
The improvement of asset management from a lean perspective should be perfomed by four different steps. For every step a prescriptive decision schedule is available. These steps are:

Step 1 Decide which model should be used based on the maturity level in asset management.

Step 2 Decide which aspect in asset management needs to be improved based on the asset management performance.

Step 3 Find the right tools to improve the asset management aspects.

Step 4 Developing an implementation plan.

6

Evaluate
Verification and validation

This chapter evaluates the improvement model designed in the previous chapter. First the verification will be presented. The method will be verified on the requirements and constraints is checked (section 6.1) and by an interview held with the consultants (section 6.2). After that a validation is presented. First a validation based on case studies and papers (section 6.3) followed by a validation on a case study(section 6.4). The layout of this chapter is shown in figure 6.1. .

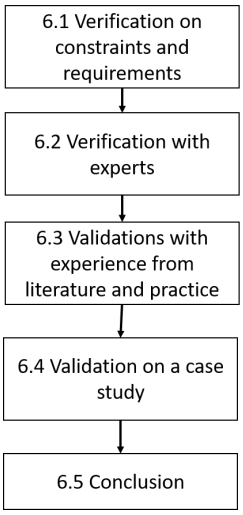


Figure 6.1: Chapter layout Validation and Verification.

In this chapter the following research question is answered:

- What will be the influence of the lean perspective in asset management?

6.1. Verification on requirements and constraints

In Chapter 4 the different requirements are defined for the method and the tools that are used in the model. In this section will be checked if these requirements and constraints are met. The detailed description of the verification can be found in appendix I.

For the improvement method five constraints and five functional requirements where given. The constraints and requirements of the method are all met. Because the selection of a tool is based on the desired asset management aspects, the method can be used without in deep knowledge about the chosen tools. Besides,

the considerations in the method are all described and guided this makes the method usable for the consultants of Stork AMS and shows clear considerations. The method provides solution for the improvement of strategic level (Management improvement), on tactical level (Working together) but also on operation level (TPM). The tools are linked to the asset management aspects and therefore related to coordination instead of the performing activities. As shown in table 5.3 and 5.2 all aspects of asset management are included in the method and in chapter 5 the method is clearly described. So, all requirements of the model are met in the design of the current model.

Constraints

- ✓ The improvement method should be usable without in depth knowledge of lean (Stork AMS).
- ✓ The improvement method should be usable by the consultants of Stork AMS (Stork AMS).
- ✓ The considerations in the method should be clear.
- ✓ The lean tool should be usable in asset management (Chapter 2.3
- ✓ The lean tools used in the method should be different from each other.

Functional Requirements

- ✓ The method should be usable on and should make a distinction between strategic level, tactical level and operational level (Stork AMS).
- ✓ The method should focus on the improvement of asset management, not on the improvement of one of the activities within asset management (Stork AMS).
- ✓ All aspects of asset management as defined by the ISO standard ISO (2014a) should be taken into account in the model (Stork AMS)
- ✓ When multiple tools can be used for one aspects distinction between them should be made (Stork AMS).
- ✓ The lean tool should improve at least one aspect of asset management as defined in ISO (2014a), (Chapter 4.5).

6.2. Verification with experts

The improvement method with four different steps is verified by different experts. These experts are consultant, who can use the new improvement method. The experts have knowledge about lean and asset management, and can be seen as experts on this subject. With interviews the usefulness of the model is shown, the experts that have been interviewed are [redacted] The interviews can be found in appendix A.

The experts recognise the problems that have been found in this research, the lack of improvement and problem analysis method are confirmed. All three experts recognise the influence of maturity level on improvement method. All experts found lean tools suitable for both the analysis and the improvement of asset management. The usefulness is ranked with a factor of 8 out of 10. They recognise the importance of policy deployment on all maturity levels. They confirm the use of visual management, training and standardised work as tools for lower maturity levels to improve the operations. Autonomation and TPM are given as tools to improve almost the whole range of asset management, but only at higher maturity levels. This is due to the costs and difficulty of implementation. The group of integration tools are important for levels of maturity.

6.3. Validation with experience from literature and practice

The different lean tools that can be used in the improvement method have been used in different cases. To show the effect of implementing the tools different examples will be discussed. In table 6.1 these tools and different examples from practice and literature are given. Not every example shows exact numbers, but every case is an example of a successful implementation. The examples from practice are from Stork AMS and all examples in asset management related areas. The examples from literature are more from supply chain related areas.

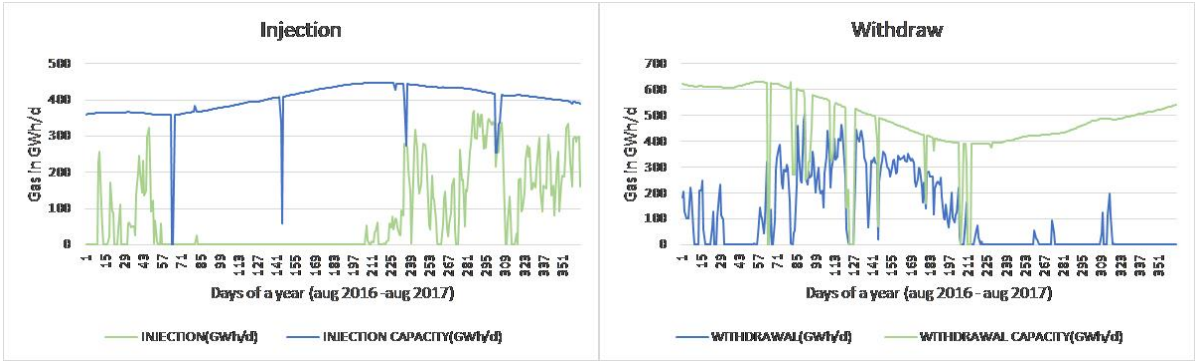


Figure 6.2: Graphs of withdraw and injection over one year (source: internal data)

Table 6.1: Validation of lean tools in practice and in literature

Lean Tool	Examples from practice		Examples from literature	
	Improvement	AM Aspect	Improvement	AM Aspect
PMS	10 % OEE[10]	Eval. & Impr.		
Root Cause Analysis	5% less downtime [13]	Oper.	[3][8]	Impr. & Supp. F
Bottle Neck Analysis			[2]	Oper.
VSM	productivity SC +40% [11]	Org. & Lead.	[6]	Lead. & AM. Plan
Policy Deployment				
Continuous Improvement	[11][14]	Impr.	[2][6][8]	Lead. & Impr.
Autonomation			[6][7][8]	Oper. & Supp. F.
TPM	18 % OEE [10]	AM plan & Oper.	[4], 20% OEE [5]	Oper. & Supp. F.
Group problem solving	[12]	Oper. & Impr.	[2][7][8]	Oper. & Impr.
Gemba			[7]	Impr.
Employee Involvement	[9][12]	AM Plan		
Cross functional team	10% less rework [9]	Oper.	[7]	Oper. & Impr.
Visual Management			[1]	Perf. M. & Oper.
Training			[2][7]	Oper. & Supp. F.
Standardised work				

1 = (Parry and Turner, 2006), 2= (Terziovski and Sohal, 2000), 3= (Carroll et al., 2002), 4= (Chan et al., 2005), 5=(Singh et al., 2013), 6=(Belekoukias et al., 2014), 7=(Slack et al., 2010) p. 579, 8=(Slack et al., 2010) p.589, 9=Interview Onno Jansen, 10=Interview Harm-Jan Smit, 11=(Singh et al., 2010) 12=Case NAM (EI / GPS) 13=Interview Roy van Ginkel. [14]= Case Dr. W. Kolb (CI)

6.4. Validation in a case study

To measure the effects of the improvement method and to show an example of how asset management can be improved from a lean perspective, the case at the gas storage facility, as discussed in chapter 3, is researched in more detail. This facility is new and therefore the design phase can still be taken into account. The process is already explained in chapter 3. Data about the losses at the facility are shown in figure 6.2.

The data about the production losses is split in unplanned downtime and planned downtime. Besides, the data is split in the different sources for each downtime. This data is used as start point for the implementation of the conceptual model. The losses due to the different sources are given over a year (August 2016 until August 2017) and summed up. The capacity from injection and withdraw are calculated as average over the whole year, since this capacity depends on the amount of gas that is stored. With this data the production losses are currently calculated at 30 % for withdraw losses and 16% for injection losses. But at the same time

is the demand for the injection and withdraw of gas from the storage facility not constant over a year. As shown in figure 6.2. The injection losses are all losses related to the injection of gas in the storage location. The withdraw losses are all losses related to the withdraw of gas from the storage location.

At the gas storage facilitation the improvement method is implemented. Here, the results of the different steps are explained.

Step 1 The maturity level of the gas storage facility is level 1 as defined in chapter 3.

Step 2 The aspects that need to be improved are the improvement and operations aspect.

Step 3 The lean tools that will be used are root cause analysis and continuous improvement.

Step 4 Implementation plan is not made, since results are based on interviews.

With three interviews with Joop Zandvliet, Henk van der Heijde and Roy van Ginkel the effect of the tools on the data shown in table 6.2 is estimated.

6.4.1. Current state performance

In literature two performance indicators for asset management are explained. At the gas storage facility performance indicators are not often used and they are not measured. Since the gas storage has to publish all production losses they some data about the current performance can be used. To calculate the overall equipment efficiency three production losses should be known; the downtime, speed losses and quality losses (see equation 6.1. The production losses as published shown the downtime and speed losses. The quality losses have not been calculated due to a lack of data. They have been set as zero in this case study to calculate the OEE.

$$OEE[\%] = Availability * Performance * Quality \tag{6.1}$$

with

$$Availability = \frac{operating\,time}{schedulud\,time}$$

$$Performance = \frac{parts\,produced * ideal\,cycle\,time}{operating\,time}$$

$$Quality = \frac{units\,produced - defect\,units}{units\,produced}$$

6.4.2. Future state performance

The changes in losses is for most aspects set on 5%, since this is the average value according to the interviews. A few aspects, as for example the drying units unavailability will change radical due to the implementation of lean in asset management. In the design of the plant different mistakes are made. These mistakes are fixed during the turn around that is planned, three years after the construction. At this facility a turnaround is required every four years, because the pressure values need to have a visual internal control. Now the turnaround is done one year in advance to fix current losses, the turnaround losses can be reduced with 25%. The six compressors that are located at the plant are not reliable. The design of the compressors is insufficient. These problems lead currently to lower production. During the turn around the compressors are not fixed, because they can also be fixed when the plant is in operation. But expected is that these become 30% more available due to continuous improvement. In the two heating installations are together 72 valves installed. At the other installation of the same company certain valves are installed, which are working very good already for 10 years. In this design cheaper valves are chosen. These valves are broken down and need to be replaced after three years. Normally, valves have a life time as long as the plant and are not replaced. The downtime of the drying units can become zero. The numbers can be seen in table 6.2.

Table 6.2: Changes in data due to conceptual model (based on internal data and interviews)

Type of production losses	Withdraw (GWh/d)		Injection(GWh/d)	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]%

6.4.3. Relation to maturity model and problems

Since the changes are not implemented the future state maturity level cannot be determined based on actual data. But a guess can be made about the changes in maturity level. Due to the implementation of the root cause analysis the improvement and operations aspect will be increased in maturity. The continuous improvement will be also effect the improvement aspect, but also the organisational aspect. An improvement method will be implemented by improving the coordination. The results can be seen in figure 6.3. In the measure phase four major problems are stated at the gas storage facility: The isolation of the engineering department, the importance of good work flows, the lack of coordination and the incapacity of continuous improvement. These last two problems are addressed in this improvement cycle. The implementation of continuous improvement will solve the last problem, but will also help to improve the coordination in asset management. The other problems are not solved yet, but might be solved in the next improvement cycle.

6.5. Conclusion evaluation phase

In this chapter the improvement method is verified and validated. The method fulfil all requirements and constraints. Different experts have also verified the usefulness and correctness of the improvement method. The implementation of the different lean tools is validated by case studies and literature. The lean tools have been implemented in other similar scenarios where they have proven to be successful and have had effects of in OEE increase and rework decrease of 10%.

Figure 6.3: Estimation of Asset Management Performance at the Gas Storage Facility; Current and Future state

The improvement method has been validated by a theoretical implementation in one of the case studies. At the gas storage facilitation the problems have been analysed and the right lean tools for improvement have been selected. Based on interviews the effect of the changes have been determined. In this case the losses at the plant could be reduced with 30 %. These percentage is very high, since large problems still exists. In more mature cases, lower improvement percentages are expected.

Research question 6: How much can lean improve asset management?
Lean can improve asset management. TPM and PMS can increase the OEE with 10%, as have been proven in case studies. At the same time can integration reduce the amount of rework with more than 10%. This leads to the validation of the prescriptive decision models. The conceptual model can reduce the production losses at the gas storage facility with 30%.

7

Conclusion and Recommendation

In this chapter the results of this report will be discussed. First, the conclusion is given and the answer on the main research question is presented (section 7.1). After the conclusion, recommendation for further research are given (section 7.2). This chapter ends with limitations of the research (section 7.3).

7.1. Conclusion

This section answers the main research question: *How can the coordination between sub-activities in asset management be improved using a lean perspective and what is the impact of the lean perspective on the asset management performance?* In this report the main research question is answered based on six sub-questions, these are as follows:

- What is asset management and what are its main aspects?
- What is the lean philosophy and what are its main aspects?
- How is asset management currently implemented in related industries?
- How can lean contribute in asset management?
- What are the requirements for the contribution of lean perspective in asset management?
- What will be the influence of the lean perspective in asset management?

Besides, this report has a design objective which was defined as: *Develop a tool which will guide the improvement in asset management using a lean approach.* Both the main research question, and the design objective have been answered.

Literature review
In the literature review, the first two research questions are answered. Asset management is defined as *the coordinated activity of an organisation to realise value from assets in the asset life cycle.* Four important aspects in asset management are found. The first aspect is the asset management performance. To measure the performance an asset management maturity model is developed. The second aspects is the asset life cycle. All the sub-activities in the life cycle should be taken into account; engineering, maintenance, operations and disposal. The third aspect is the lifespan or the design of the asset. The forth aspect is the value of the asset. The value can be defined in the factors; availability, readiness or occupancy rate.

Lean is defined as *a management philosophy which focusing on maximizing customer value with minimum inputs.* Lean consists of the following five steps: First, the value is defined. Then, the value stream is mapped. Third, flow is created. The fourth step is creating a pull system. Finally, continuous improvement should be strived for. Aspects of lean can be implemented by using lean tools. In the literature 33 lean tools have been found, these can be used on strategic, tactical and operational level.

Practical review
In the practical review, the third research question is answered. With three different case studies the implementation of asset management has been researched. The two main problems in asset management are as follows:

- Analysing the problems in asset management.
- The lack of structural method to continuously improve asset management.

There are three factors which influences the practical implementation of asset management. First, the industry of the company influences the importance of asset management. Second, the number of actors and companies involved in the asset management influences the ease of change. Third, the type of production process of the company. A line flow production is easier to manage than a continuous flow production. At the same time it is seen that the lean tools are mostly used in the more mature companies.

Synthesis; Improvement in Asset Management
In the synthesis the fourth and fifth research question are answered. The current asset management maturity model is a comparison model. Based on the asset management performance a maturity level is provided. An improvement loop in the maturity model is missing and should be added. Lean tools can be used to give direction for the improvement in the maturity levels. Before these tools can be used, the asset value must be defined. In figure 7.1 this improvement loop is shown. To perform this loop, an improvement method has been designed.

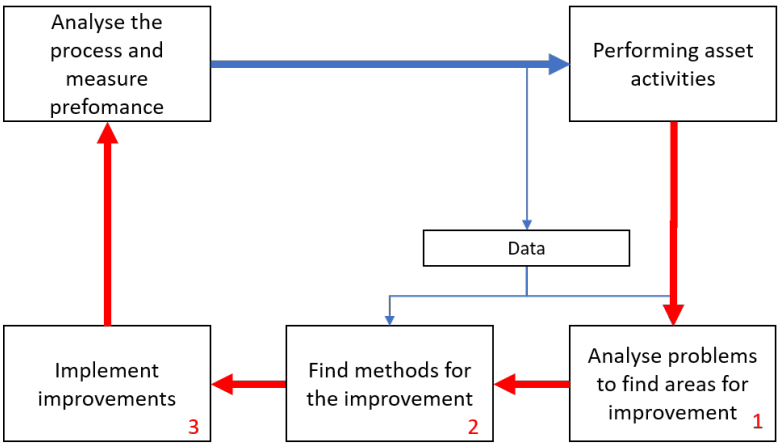


Figure 7.1: Asset activities with continuous improvement loop

To perform this maturity loop an improvement method should be developed. Influencing factors from literature and practice are: Industry, amount of actors involved, production type and life span of the asset. Not all lean tools can be used for the improvement of asset management. From the 33 lean tools, 15 lean tools are selected which are different from each other and all can be applied in the improvement of coordination. Besides, requirements for the improvement method are defined.
Improvement method
The improvement method answers the design objective. This method shows how the performance of asset management can be improved. This method is one circle of the continuous improvement loop shown in figure 7.1. To perform this loop, four different steps should be taken in the following order:

Step 1 Decide which schedule to use based on the maturity level in asset management.

Step 2 Decide which aspect in asset management ro improve based on the asset management performance.

Step 3 Find the right tool to improve the asset management aspects based on the prescribed schedules.

Step 4 Developing an implementation plan based on company characteristics.

Verification and Validation
This improvement method has been verified by different experts which found the method useful with an average of 8 out of 10. The method has also fulfilled all requirements that are set. The method has been validated in two different ways. First, based on different literature and cases. Here lean tools have been successfully implemented and improvements of 10% in OEE are measured. Second, the model has been implemented on one of the case studies. Based on interviews, theoretical improvement of 30% in OEE have been reached.

7.2. Recommendation

In this section the recommendation after this research are presented. The recommendations are split in recommendations for science and recommendation for the case company; Stork AMS.

7.2.1. Recommendations for Science

From a scientific perspective, performing further research and implementing the improvement method in more case studies is recommended. A case study in the oil and gas sector with a significant maturity level should be performed first, to measure the influence of the maturity level. Also the potential in more mature cases should be researched. Then case studies within other industries (manufacturing, process or chemicals) should be performed to measure the influence of the industry. Many different cases need to be studied with differences in the asset management maturity and industry. These case studies could prove whether the model is usable in all these situations.

This improvement method is the first draft. Based on the different case studies, the method might change. The different influencing factors that are defined, should be further research to get more insight in their exact influence.

7.2.2. Recommendations for Stork AMS

For Stork AMS it is recommended to write a proposition that can be offered to clients, based in the improvement method. The proposition should lead to a pilot study at a client. Here the models should be used to analyse and improve their coordination within the activities in the asset life cycle. With the implementation of the improvement method actual data can be generated. This data should be used to validate the method and strengthen the proposition.

After this pilot study all clients or potential clients should be made aware of this new possibility to improve asset management. A workshop for clients could be organised to make them aware of the opportunities of lean in asset management. This workshop could help to find a more cases to implement the different models.

For the first pilot studies consultants with knowledge about lean and asset management can implement the proposition. But after a successful first implementation a training is recommended for all consultants of Stork AMS to update their knowledge about the proposition. This training could be organised by the experienced consultants of Stork AMS and is about sharing information.

7.3. Limitations

Besides the conclusions and recommendation that follow out of the research. Also the limitations are presented. The limitations should be taken into account when implementing the improvement method .

- The validation of the improvement method is difficult since it is developed as management tool. The validation presented is based on interviews with consultants and comparing the models to different case studies and papers. The validation is based on experience and earlier research. It could be possible that an actual pilot will give other results than as expected in this report.
- Data about the different case studies had certain limitations. Although experts of the field has been interviewed and asked for validation, but also the problems are based on interviews. Interviews are not very reliable as research method. This should be taken into account when interpreting the results.

- The scope of asset management is really broad and in this case the performance in the supply chain and asset activities are not taken into account. However, these performances are related to the asset management performance. Further research should get more insight in this effect.

8

Reflection

This research has been performed in a time-span of six months. Due to the iterative character of the master thesis and limited time the research is not always performed ideal. In this chapter a reflection on the research is given. The subject, process and methodology will be discussed. Some limitations in this research will be given and advises how it could have been better will be explained. Also the most important lessons I have learned will be explained.

8.1. Research Subject

The first draft of a research question was; 'How is lean in asset management defined and how can it implemented and measured?' This research question led to a lot of confusion. First, it required me to make a definition and implementation plan. Besides, it made the scope of implementation way to broad. This question was chosen since there is no literature available on this subject and I felt that I could not scope my research due to this reason. But it was better if I had chosen a scope and specified the subject of my research. This would have prevent a lot of misunderstandings. Now, I have specified my research at the end. I have researched a broad scope, but this but made sure I did not have time to go further in depth.

Due to the lack of scope and direction, I found it hard to find a method fitting my research. Therefore, I just choose one methodology which did not fit perfect. This made it hard to follow it and made it difficult to structure my report. Finally, I adapted the chosen methodology to my research. This enabled a structure and a logical line of reasoning in the report.

A benefit of the lack off specification in the beginning of my research, have led to a broad investigation of the possibilities of using lean in an asset management context. I have investigated many options and I feel confident about the direction I have chosen. If I had done this in my proposal I could not have made the same considered decision.

8.2. Research Execution

In the execution of my research, I would also like to have some aspects taken into account afterwards. For example, the selection of my case studies. In this research I have selected the case studies based on their industry and asset management maturity. I did not include the aspect of available data. In the validation of my research I had a problem with the availability of data. For this aspect, I should have selected other case studies.

Another aspects that I should have changed, is to make the process more iterative. I tried to perform a linear process, but this is impossible in scientific research. If I had adapted to this iterative process earlier in my research. This could have let to a better integration of my research.

An aspect that learned during this research, is that I kept my own vision during this process. I have interviewed different people and had five supervisors. This led to different point of views and different advices. I considered them all, but I did not just take over their opinions.

I found it difficult to perform a scientific research, during my study I did not performed research in this way. During my bachelor at Civil Engineering, methods and papers are used often. Therefore, I found it difficult to found out what was expected. But with trying, feedback and improvement I learned the usefulness of method and relevance of papers.

8.2.1. Planning

My planning in the beginning of my research was quite strict, but I was able to follow it for a long time. During the summer holiday and at the end of my research when I had to set multiple appointments with my committee. A few weeks of delay entered my planning, but this was still acceptable. An aspect I have learned during this research is to set intermediate deadlines and goals. I made planning until this intermediate deadline and therefore I was able to motivate myself to work everyday.

Bibliography

Fawaz A Abdulmalek and Jayant Rajgopal. Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of production economics*, 107 (1):223–236, 2007.

Joe E Amadi-Echendu, Kerry Brown, Roger Willett, and Joseph Mathew. *Definitions, concepts and scope of engineering asset management*. Springer, 2010.

Tim Baines, Howard Lightfoot, George M Williams, and Richard Greenough. State-of-the-art in lean design engineering: a literature review on white collar lean. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 220(9):1539–1547, 2006.

Roger Bate, Dorothy Kuhn, Curt Wells, James Armitage, and Gloria Clark. A systems engineering capability maturity model, version 1.1. Technical report, Carnegie-Mellon Univ Pittsburgh PA Software Engineering Inst, 1995.

Ioannis Belekoukias, Jose Arturo Garza-Reyes, and Vikas Kumar. The impact of lean methods and tools on the operational performance of manufacturing organisations. *International Journal of Production Research*, 52 (18):5346–5366, 2014.

WB van Blokland, MA Fiksinski, Sakyi OB Amoa, and Sicco C Santema. Quantifying the lean value network system: The lean metrics of co-investment and co-innovation on organizational level. *Delft University of Technology: Faculty of Aerospace Engineering*, 2008.

John M Bryson. What to do when stakeholders matter: stakeholder identification and analysis techniques. *Public management review*, 6(1):21–53, 2004.

BSI. Publicly available specification for the optimized management of physical assets. PAS 55, Britisch Standards Institution, Geneva, Switzerland, 2004.

RS Buell, SP Turnipseed, et al. Application of lean six sigma in oilfield operations. *SPE Production & Facilities*, 19(04):201–208, 2004.

Business Dictionary. Management, 2017. URL `achievedvia:http://www.businessdictionary.com/definition/management.html`.

JS Carroll, JW Rudolph, and S Hatakenaka. Lessons learned from non-medical industries: root cause analysis as culture change at a chemical plant. *Quality and Safety in Health Care*, 11(3):266–269, 2002.

FTS Chan, HCW Lau, RWL Ip, HK Chan, and S Kong. Implementation of total productive maintenance: A case study. *International Journal of Production Economics*, 95(1):71–94, 2005.

Peter Checkland and John Poulter. Soft systems methodology. In *Systems approaches to managing change: A practical guide*, pages 191–242. Springer, 2010.

Peter Chemweno, Liliane Pintelon, Adriaan Van Horenbeek, and Peter Muchiri. Development of a risk assessment selection methodology for asset maintenance decision making: An analytic network process (anp) approach. *International Journal of Production Economics*, 170:663–676, 2015.

Elisabete Correia, Helena Carvalho, Susana G. Azevedo, and Kannan Govindan. Maturity models in supply chain sustainability: A systematic literature review. *Sustainability*, 9(64), 2017. ISSN 2071-1050. URL `http://www.mdpi.com/2071-1050/9/1/64`.

Robert Damelio. *The basics of process mapping*. CRC Press, 2011.

Clive L Dym, Patrick Little, Elizabeth J Orwin, and Erik Spjut. *Engineering design: A project-based introduction*. John Wiley and sons, 2009.

The Economist. Toyota, the car company in front, January 2005. URL http://www.economist.com/node/3599000#print?Story_ID=3599000. [Online; posted 27-January-2005].

Genesis Solutions. Effective asset management enhances lean manufacturing principles and processes, May 2016. URL http://www.genesissolutions.com/effective-asset-management-enhances-lean-manufacturing-principles-and-processes/. [Online; accessed 10-May-2017].

Ralph Godau. Why asset management should be a corporate function? In *Cairn International Public Works Conference*, Carins, Queensland, Australia, 2007.

Philip Godfrey. Overall equipment effectiveness. *Manufacturing Engineer*, 81(3):109–112, 2002.

Nicholas Anthony John Hastings. *Physical Asset Management: With an Introduction to ISO55000*. Springer, 2015.

Peter Hines and Nick Rich. The seven value stream mapping tools. *International journal of operations & production management*, 17(1):46–64, 1997.

Hasko Hujdurovic. Developing a performance monitoring tool (speelveld) and a quantitative lean assessment for operations of stork fokker aesp. Master's thesis, Technische Universiteit Delft, the Netherlands, 2008.

Masaaki Imai. *Kaizen*, volume 201. Random House Business Division New York, 1986.

IMESA, NAMS and Rowse, Nicholas and Naude, Leon and Byrne, Roger. Infrastructure asset management. *IMIESA*, 2012.

ISO. Asset management - overview, principles and terminology. ISO 55000, International Organization for Standardization, Geneva, Switzerland, 2014a.

ISO. Asset management - management systems - requirements. ISO 55001, International Organization for Standardization, Geneva, Switzerland, 2014b.

ISO. Asset management - management systems - guidelines for the application of iso 55001. ISO 55002, International Organization for Standardization, Geneva, Switzerland, 2014c.

Christer Karlsson and Pär Åhlström. Assessing changes towards lean production. *International Journal of Operations & Production Management*, 16(2):24–41, 1996.

John F Krafcik. Triumph of the lean production system. *MIT Sloan Management Review*, 30(1):41, 1988.

Sherah Kurnia, Mahbubur Md Rahim, Daniel Samson, and Singh Prakash. Sustainable supply chain management capability maturity: Framework development and initial evaluation. *Supply Chain Journal*, 2014.

Lean Six Sigma. Dmaic, 2005. URL https://www.sixsigma.nl/DMAIC-3. [Accessed; posted 22-August-2017].

Joel Levitt. *Lean maintenance*. Industrial press, 2008.

Jeffrey K Liker. *The Toyota Way*. Esensi, 2004.

David Mann. Creating a lean culture. *Volume I*, 2005.

Dennis McCarthy and Nick Rich. *Lean TPM: a blueprint for change*. Butterworth-Heinemann, 2015.

Kathleen E McKone and Elliott N Weiss. Tpm: planned and autonomous maintenance: bridging the gap between practice and research. *Production and operations management*, 7(4):335–351, 1998.

Trish Melton. The benefits of lean manufacturing: what lean thinking has to offer the process industries. *Chemical engineering research and design*, 83(6):662–673, 2005.

Ronald Moen and Clifford Norman. Evolution of the pdca cycle, 2006.

MZ Ouertani, AK Parlikad, and D McFarlane. Asset information management: Research challenges, marrakech, morocco, inst. of elec. and elec. *Eng. Computer Society*, 2008.

Oxford dictionary. asset management, April 2016. URL https://en.oxforddictionaries.com/definition/asset_management. [Online; accessed 25-April-2017].

GC Parry and CE Turner. Application of lean visual process management tools. *Production Planning & Control*, 17(1):77–86, 2006.

H Reefke, D Sundararm, and M Ahmed. Maturity models in business process management. *Business Process Management*, 18:328–346, 2010a.

Hendrik Reefke, David Sundaram, and M Daud Ahmed. Maturity progression model for sustainable supply chains. *Advanced Manufacturing and Sustainable Logistics*, pages 308–319, 2010b.

Reliable plant - Eric Luyer. Asset management leverages lean, May 2016. URL http://reliableplant.com/Read/3269/asset-management-lean. [Online; accessed 10-May-2017].

Rachna Shah and Peter T Ward. Lean manufacturing: context, practice bundles, and performance. *Journal of operations management*, 21(2):129–149, 2003.

Rachna Shah and Peter T Ward. Defining and developing measures of lean production. *Journal of operations management*, 25(4):785–805, 2007.

Aaron J Shenhar and James Renier. How to define management: a modular approach. *Management Development Review*, 9(1):25–31, 1996.

Bhim Singh, S.K. Garg, S.K. Sharma, and Chandandeep Grewal. Lean implementation and its benefits to production industry. *International Journal of Lean Six Sigma*, 1(2):157–168, 2010.

Ranteshwar Singh, Ashish M Gohil, Dhaval B Shah, and Sanjay Desai. Total productive maintenance (tpm) implementation in a machine shop: A case study. *Procedia Engineering*, 51:592–599, 2013.

Nigel Slack, Stuart Chambers, and Robert Johnston. *Operations management*. Pearson education, 2010.

Lars Stehn and Matilda Höök. Lean principles in industrialized housing production: the need for a cultural change. *Lean Construction Journal*, pages 20–33, 2008.

Stork Asset Management Solutions. Asset management scan, 2016.

Stork Consultancy. Stork lean in maintenance. Corporate slides, April 2017.

Milé Terziovski and Amrik S Sohal. The adoption of continuous improvement and innovation strategies in australian manufacturing firms. *Technovation*, 20(10):539–550, 2000.

The Institute of Asset management. The self-assesment methodology plus. Technical report, The Institute of Asset management, 2015.

TMAC. Lean asset management, May 2016. URL http://www.tmac.org/services/lean-enterprise/asset-management. [Online; accessed 10-May-2017].

R van Rijn. Design of a maintenance performance measurement system for performance based contracts. Technical report, Technische Universiteit Delft, Delft, 2017.

Bert Visser and Albert Trip. Maintenance in processing - lean six sigma en asset management, May 2016. URL achievedvia:http://www.maintenancebenelux.nl/artikel/2011/MP2011-3p38.pdf. [Online; accessed 10-May-2017].

Vorne. Lean production – top 25 lean tools, April 2016. URL http://www.leanproduction.com/top-25-lean-tools.html. [Online; accessed 28-April-2017].

Whole Life Consultants LTD. Lean asset management, May 2016. URL https://www.wlcuk.com/services/lean/. [Online; accessed 10-May-2017].

Andi Wijaya, Rupesh Kumar, and Uday Kumar. Implementing lean principle into mining industry issues and challenges. In *International Symposium on Mine Planning and Equipment Selection: 16/11/2009-19/11/2009*, 2009.

Terry Wireman. *Developing performance indicators for managing maintenance*. Industrial Press Inc., 2005.

James P Womack and Daniel T Jones. *Lean thinking: banish waste and create wealth in your corporation*. Simon and Schuster, 2010.

James P Womack, Daniel T Jones, and Daniel Roos. *Machine that changed the world*. Simon and Schuster, 1990.

John Woodhouse. Pas 55: specification for the optimized management of physical infrastructure assets. In *PAS Workshop*, volume 2007, 2004.

Yahaya Y Yusuf, Angappa Gunasekaran, EO Adeleye, and K Sivayoganathan. Agile supply chain capabilities: Determinants of competitive objectives. *European Journal of Operational Research*, 159(2):379–392, 2004.

A

Interviews

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

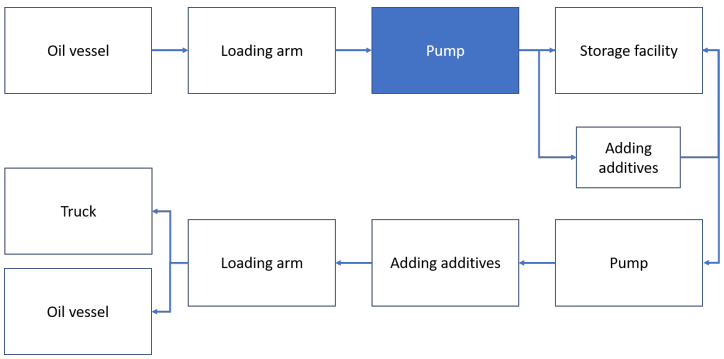
[redacted]

B

Case studies

Case A

Figure B.1: Process at the tank terminal, Case A



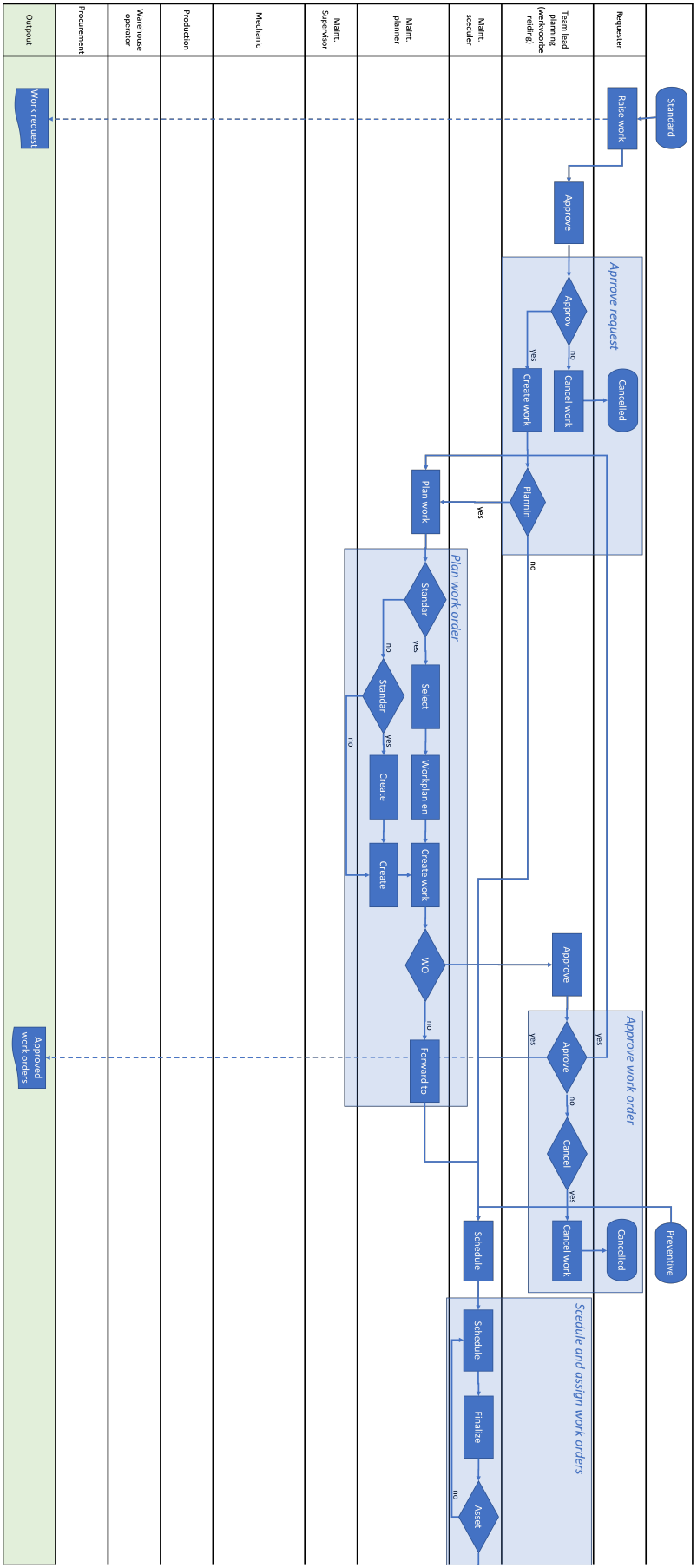


Figure B.2: Maintenance workflow 1 out of 2 at the tank terminal (source: internal data)

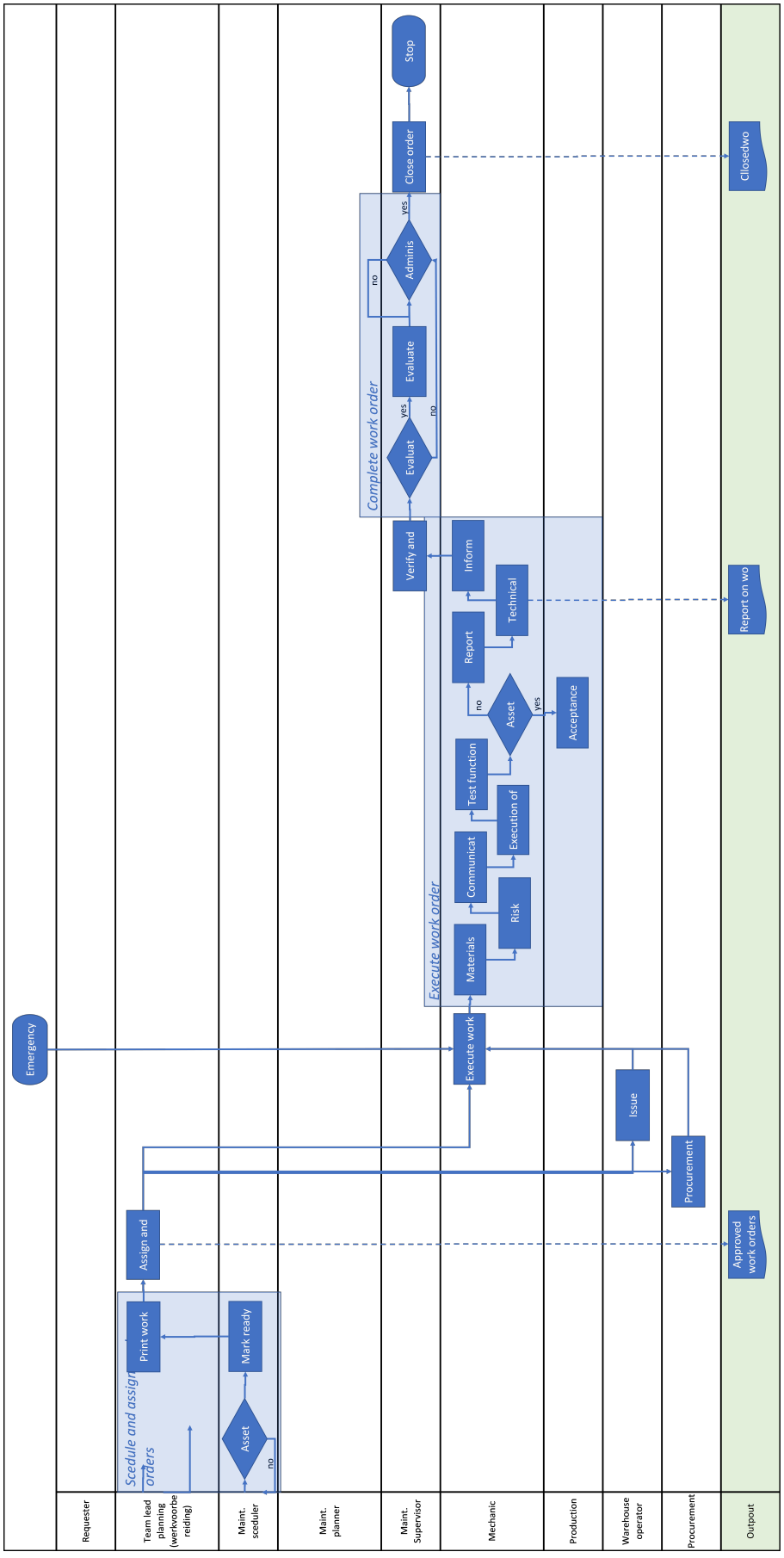


Figure B.3: Maintenance workflow 2 out of 2 at the tank terminal (source: internal data)

Table B.1: Performance of asset management aspects of Case A

Case A		
AM aspect	Score	Explanation
Organisation	0	The need for this requirement is not regocnised and there is no evidence of commitment to put in place
Leadership	0	The need for this requirement is not regocnised and there is no evidence of commitment to put in place
AM Plan	0	The need for this requirement is not regocnised and there is no evidence of commitment to put in place
Operation	1	The need has been identified, for example planned to move the departments so they are located next to each other.
Evaluate	1	The need has been identified, planned to implement sensors to measure performance of the facility and to relate indicators to objectives.
Improve	0	The need for this requirement is not regocnised. No improvemetn loop is available at this facility. Currently, AM is not improved.
Supporting Fac.	1	The need has been identified, planned to hire an asset manager. Wanting to improve the means at the facility

Case B

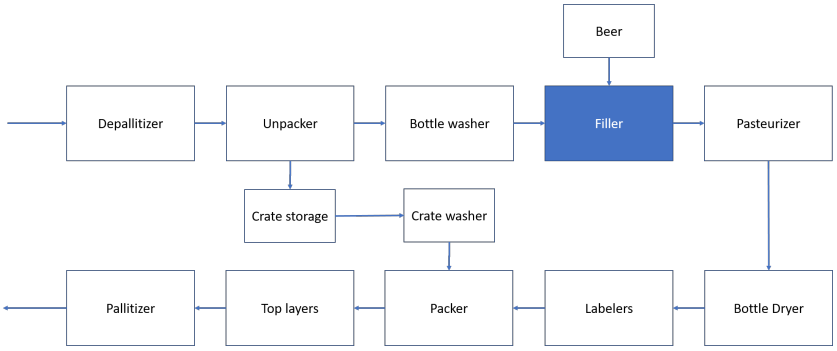


Figure B.4: Brewery packaging line (based on site visit)

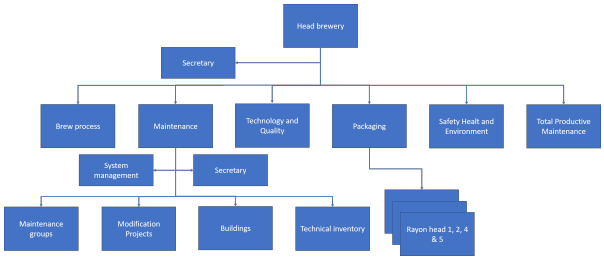


Figure B.5: Organagraph at the brewery (source: internal data)

Table B.2: Performance of asset management aspects of Case B

Case B		
AM aspect	Score	Explanation
Organisation	4	The organisation structure is developed well and stakeholders are involved. Together the objectives are set to get optimal performance
Leadership	3	The objectives of asset management are transformed in strategies and concepts. Best practices are defined according the requirement.
AM Plan	3	The plan of intergrating operations and maintenance is above requirements, but engineering is still lacking behind, average is level 3.
Operation	3	The coordination of operations and maintenance is very gooed, both are included in engineering. Achieving requirements set in the standard.
Evaluate	3	The plants are evaluated based on their performance and best practices. Performance indicators are set based on the objectives.
Improve	2	The improvement at the facilities is less. Progress is created, but the company has diffilculties with finding ways to continuou improve.
Supporting Fac.	2	The facilities are not provided inside the company, external parties are hired and software is not sufficient yet.

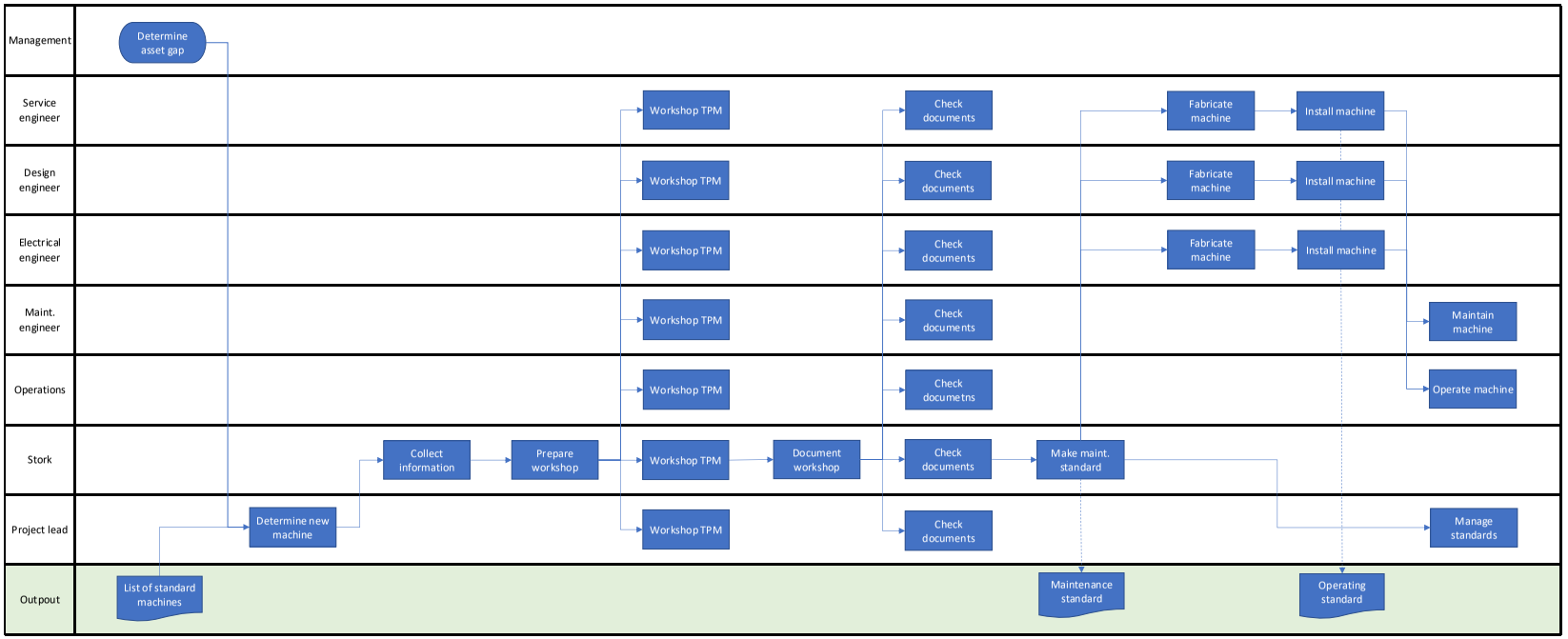


Figure B.6: Engineering coordination with operation and maintenance (source: internal data)

Case C

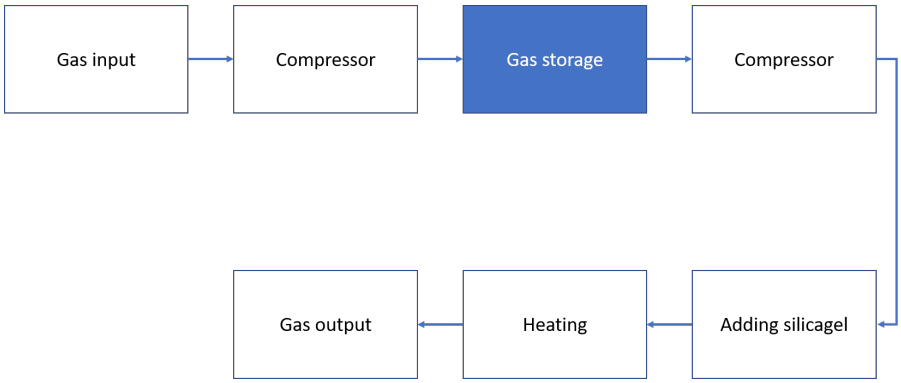


Figure B.7: Gas storage process (based on site visit)

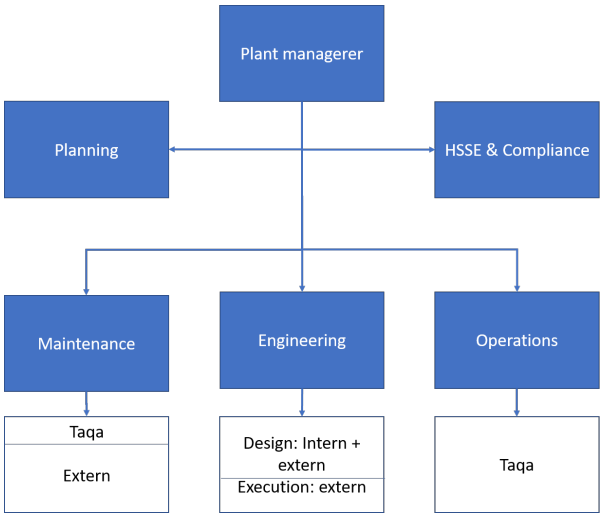


Figure B.8: Organagraph at the Gas Storage (source: internal data)

Table B.3: Performance of asset management aspects of Case C

Case C

AM aspect	Score	Explanation
Organisation	1	The need for this requirement is identified, start of making asset management objectives in line with organisational objectives is made.
Leadership	1	The need for this requirement is identified, the organisational objectives will be translated in asset management policy and strategy.
AM Plan	2	The plan for asset management has been in place for some time now, started from maintenance. The plan is spreading to fit the other AM activities.
Operation	1	In operations the need for this requirement is identified. Currently, they plan to hire an asset manager to integrate activities.
Evaluate	1	At this moment, the performance indicator dashboard is reviewed to get better measurements related to asset management.
Improve	0	The improvement cycle is not visible in this company and no plans to implement an improvement cycle are availabe.
Supporting Fac.	2	The organisation and means are suitable for asset management, the people are currently improved to get the right people at the right place.

C

Actor Analysis

In this chapter the different actors are further explained. The actors are finally summarised in a power interest diagram as shown in figure C.1.

Asset owner The asset owner wants to make profit with the asset. His main goal is to minimize the total cost of ownership. The productions should be high and the operational and maintenance costs should be low. This is difficult to realize, the effect of the different activities in relation to the costs are mostly unknown. The asset owner is part of the production company and pays for the different activities. The asset owner also decides how the performance is measured and if they are in- or out-sourced. The influence of the asset owner on asset management is very high. He can decides on the kind of work an the budget. Certainly the asset owner will be in favour of asset management because it can increase the effectiveness and reduce the total cost of ownership.

Operations manager The operational manager has different names in different companies. For example; operational manager, asset manager and production manager. This person is responsible for the operation of the asset. He strives for the highest availability and highest amount of production out the asset. Those aspects define the performance of the operator. Operating is the asset activities that lays closest to the adding value aspect of the customer. The operations manager has a lot of influence on the implementation of asset management. He needs to coordinate his activity with the other departments. An operations manager looks positive against asset management. Better coordination will increase the availability of the asset and reduce the operating costs.

Maintenance manager The maintenance manager coordinates to maintenance activities of the asset. He wants to ensure the reliability and availability of the asset and within the budget. The maintenance departments budget is in relation to the amount of maintenance tasks he performs. Implementing asset management will increase the efficiency of the process and reduce the amount of maintenance, which means a decrease in budget. Therefore the maintenance manager will not be in favour of asset management, especially when maintenance is outsourced. At the same time the maintenance manager has a good overview of the performance and defects of the asset. Therefore, he is able to see possible improvements. The influence of the maintenance manager is high. When the gains of asset management are shared with the maintenance manager it is possible to change his attitude.

Engineer manager The engineer manager is the manager of the engineering department. This department makes re-designs of the asset. Sometimes large maintenance projects are also performed by the engineering department. The engineering department works on project bases, which means that work is done in projects for which a budget and criteria are set. The projects are initiated by the asset owner or other actors. The engineer manager want to perform the project, make a new design, according the set criteria and within the budget. The engineering manager will not care any more about the asset after the project. Because the engineering phase has a lot of influence on the asset the engineer manager has a lot of influence on the performance of asset management. He will not be in favour of asset management, because this will ensure extra criteria in the design phase or more responsibility of the engineer manager after construction.

Customer The customer wants to use the product of the asset owner. The customer has to pay for the different activities of the asset. The customer wants the right output out of the asset: A product at the right time and place for the right price. To realise this more aspects than just asset management are important, as for example the demand. The customer is at the end of the supply chain and not performing in the asset life cycle, therefore he has no influence in asset management. He is still taken into account because the customer has to pay for the activities that are performed, these should add value for him. The changes toward asset management will not influence him much so his attitude is neutral.

Operator The operator is performing the tasks assigned by the operational manager. His goal is to ensure the availability and quality of the asset. The operator is the actor with the most physical contact to the asset, therefore he has influence on the execution of asset management. But he has no influence in what tasks to perform at what moment, this is decided by the operations manager. The influence of the operator is therefore medium. Asset management will change the tasks of the operator, he will be more involved in the maintenance jobs. This change might be difficult for the operator and therefore his attitude might be negative. It is important to cooperate the operators in the process of implementing asset management to make a smooth transition.

Mechanic The mechanics are performing the maintenance tasks assigned by the maintenance manager. With these tasks he ensures the reliability of the asset and minimizes the down time. The influence of the mechanic is also medium and his attitude negative, similar to the operator explained above. The change to asset management will reduce their work and less mechanics are needed for the tasks.

Engineer The engineer constructs the asset following the design. He has almost no influence on the asset and will not see a lot of changes due to asset management Therefore his influence is low and his attitude neutral.

The asset management stakeholders are concluded in the power interest diagram in figure C.1. In this diagram the power and the interest of the stakeholders are visualized. This picture can be seen as a summary of the actor analysis

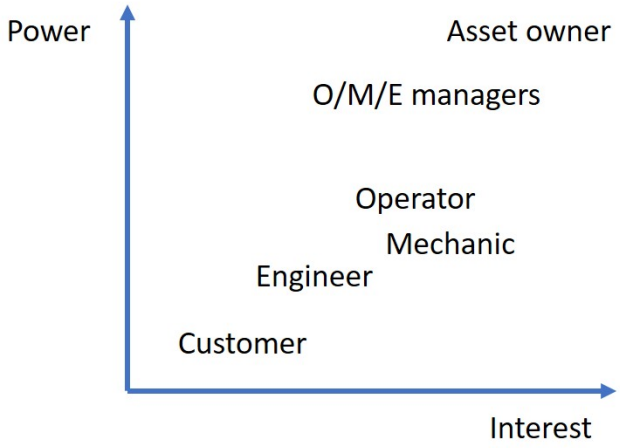


Figure C.1: Power Interest Diagram [source: own author]

D

Asset Management Maturity

A breakdown following the ISO 55000 (ISO, 2014a), (ISO, 2014b), (ISO, 2014c)

1. Context of the organization
   When establishing or reviewing its asset management system, an organization should take into account its internal and external contexts. The external context includes the social, cultural, economic and physical environments, as well as regulatory, financial and other constraints. The internal context includes organizational culture and environment, as well as the mission, vision and values of the organization. Stakeholder inputs, concerns and expectations are also part of the context of the organization. The influences of stakeholders are key to setting rules for consistent decision making and also contribute to the setting of organizational objectives, which in turn, influence the design and scope of its asset management system.

2. Leadership
   Top management is responsible for developing the asset management policy and asset management objectives and for aligning them with the organizational objectives. Leaders at all levels are involved in the planning, implementation and operation of the asset management system. Top management should create the vision and values that guide policy, practice and actively promote these values inside and outside the organization. Top management also defines the responsibilities, accountabilities and asset management objectives and strategies, which create the environment for the asset management system. Leaders should lend their authority to supporting the asset management system, and should ensure its alignment to other management systems within the organization through appropriate organizational design. Top management and leaders at all levels are responsible for ensuring that appropriate resources are in place to support the asset management system. These resources include appropriate funding, adequate and competent human resources, and information technology support. Leaders should recognize and resolve conflicts between the internal culture of the organization and the performance of its asset management system. Top management and leaders at all levels are responsible for communicating the organization's asset management objectives and the importance of its asset management system to all employees, customers, suppliers, contractors and other stakeholders. Communication should be two-way, with leaders being open to receiving information aimed at improving the asset management system from all levels.

3. Planning
   The organizational objectives provide the overarching context and direction to the organization's activities, including its asset management activities. The organizational objectives are generally produced from the organization's strategic level planning activities and are documented in an organizational plan. The principles by which the organization intends applying asset management to achieve its organizational objectives should be set out in an asset management policy (see 3.1.18). The approach to implementing these principles should be documented in a strategic asset management plan (SAMP). An organization's SAMP should be used to guide the setting of its asset management objectives, and to describe the role of the asset management system in meeting these objectives. This includes the structures, roles and responsibilities necessary to establish the asset management system and to operate it

effectively. Stakeholder support, risk management and continuous improvement are important issues to be addressed in the establishment and operation of the asset management system. The SAMP can have a timeframe that extends beyond the organization's own business planning timeframe, requiring the asset management system to address the complete lifetimes of the assets. The organization should also use its SAMP to guide its asset management system in the development of its asset management plans (i.e. in establishing what to do). The asset management plans themselves should define the activities to be undertaken on assets, and should have specific and measurable objectives (e.g. timeframes and the resources to be used). These objectives can provide the opportunity for alignment of operating plans with the organizational plan and any unit level business plans. Aligning the asset management objectives with the organizational objectives, as well as linking asset reports to financial reports, can improve the organization's effectiveness and efficiency, The linking of asset reports to financial reports can also improve and clarify the assessment of the financial status and long-term funding requirements of the organization.

4. Support
   The asset management system will require collaboration among many parts of the organization. This collaboration often involves the sharing of resources. Coordinating these resources and applying, verifying and improving their use should be objectives of the asset management system. It should also promote awareness of the asset management objectives across the whole organization. The asset management system provides information to support the development of asset management plans and the evaluation of their effectiveness. Asset information systems can be extremely large and complex in some organizations, and there are many issues involved in collecting, verifying and consolidating asset data in order to transform it into asset information. Creating, controlling, and documenting this information is a critical function of the asset management system. The asset management system should specify the competency requirements for personnel involved in asset management. The implementation, maintenance, evaluation and improvement of these competencies normally requires close cooperation with the organization's human resource management system. These two systems should be mutually supportive.

5. Operation
   The organization's asset management system can enable the directing, implementation and control of its asset management activities, including those that have been outsourced. Functional policies, technical standards, plans and processes for the implementation of the asset management plans should be fed back into the design and operation of the asset management system. Operation of the asset management system can sometimes require planned changes to asset management processes or procedures, which can introduce new risks. Risk assessment and control in the context of managing change is an important consideration in operating an asset management system. When an organization outsources some of its asset management activities, this should not remove those outsourced activities from the control of the organization's asset management system. In situations where interacting activities are outsourced to different service providers, the responsibilities and complexity of control will be increased.

6. Performance evaluation
   The organization should evaluate the performance of its assets, its asset management and its asset management system. Performance measures can be direct or indirect, financial or non-financial. Asset performance evaluation is often indirect and complex. Effective asset data management and the transformation of data to information (see 2.5.3.5) is a key to measuring asset performance. Monitoring, analysis and evaluation of this information should be a continuous process. Asset performance evaluations should be conducted on assets managed directly by the organization and on assets which are outsourced. Asset management performance should be evaluated against whether the asset management objectives have been achieved, and if not, why not. Where applicable, any opportunities that arose from having exceeded the asset management objectives should also be examined, as well as any failure to realize them. The adequacy of the decision-making processes should be examined carefully. The performance of the asset management system should be evaluated against any objectives set specifically for the system itself (either when it was established, or following previous evaluations). The primary purpose of evaluating the system should be to determine whether it is effective and efficient in supporting the organization's asset management. Periodic audits should be used to evaluate

the performance of the asset management system; these may be complemented by self-assessments. The results of performance evaluations should be used as inputs into management reviews.

7. Improvement
   An organization's asset management system is likely to be complex and continually evolving to match its context, organizational objectives and its changing asset portfolio. Continual improvement is a concept that is applicable to the assets, the asset management activities and the asset management system, including those activities or processes which are outsourced. Opportunities for improvement can be determined directly through monitoring the performance of the asset management system, and through monitoring asset performance. Nonconformities or potential nonconformities of the asset management system can also be identified through management reviews and internal or external audits. The nonconformities require corrective action and the potential nonconformities require preventive action. Of particular importance are asset-related incidents or emergency situations, for which emergency response planning and business continuity planning for identified risks should be addressed by the asset management system. All such incidents, including unanticipated events, should be investigated and reviewed to see if any improvements are needed to the asset management system, to prevent their recurrence and to mitigate their effects. Improvements should be risk assessed prior to being implemented.

The breakdown following A field proven vision on asset management

1. Governance
   The description and documentation of the system, methods and techniques, best practices and processes that must be followed throughout the company.

2. Risk Management
   Risk management is about identifying, analysing and evaluating risks and implementing the appropriate countermeasures. The risk management approach is the core methodology in order to take measurements and decisions in the other asset management domains.

3. Policy & Strategy
   A company should explicitly set out their asset management policy (direction) and strategy (long term objectives and plans). This starts from the stakeholders' values and overall company policy. Strategic analysis lies at the base of the asset management strategy. The company must establish asset management goals and objectives.

4. Concept Management
   Concepts describe "what to do" (the measures to reduce risks or seize opportunities), and why (the reasons and justification for the "what"). The reasons and justification are derived from the asset management policy and strategy, and based on a risk management approach.

5. Plan
   Asset management concepts will be integrated in long-term and medium-term plans, with the identification of all necessary resources. These plans will be used for budget plans. Investments, turnarounds and production schemes will be integrated into asset management plans.

6. Service Providing
   Providing services means effectively, efficiently, qualitatively and safely implementing and executing the various concepts and plans.

7. Performance measurement
   Besides the condition of the assets and their associated performances, expenditures and risks, the implementation and effectiveness of the plans needs to be monitored and controlled.

8. Analyse and Improve
   Based upon the measurements and performance of the installations, check whether the asset management process is effective and efficient. Deviations from the stated objectives or potential opportunities are reason for conducting a critical analysis to prompt the necessary measures to correct and/or improve the process.

9. Organization
   An organisation that is capable of carrying out the asset management processes must be installed and maintained in a uniform, clearly structured and managed way.

10. People People involved in asset management processes need to have the appropriate competencies, skills, leadership styles and attitude. Activities to assure this, such as training, communication and participation, belong to the domain of asset management.

11. Means The infrastructure and means necessary to support the implementation and execution of the asset management process (e.g. Computerized Maintenance Management System).

E

Lean Tools

A lot of different lean tools are developed to implement Lean. Here the 20 of them will be discussed shortly, these are the ones that are most widely used in the current implementation (Vorne, 2016) (Shah and Ward, 2003) (Shah and Ward, 2007). Because asset management is not a supply chain, the tools that only focusses on suppliers are not mentioned.

5S Organize the work area with the 5S; sort, set in order, shine, standardize and sustain. First eliminate at the work area what is not needed and organize the remaining items. The work area should be clean and standards for the appearance should be made. This need be controlled now and then.

Bottleneck analysis When continuous flow is wanted in the process all bottlenecks which prevent this continuous flow must be found and removed from the process. Bottleneck analysis is a method to find the bottlenecks in a process.

Continuous Flow Buffers in the process should be reduced, the product should flow through the production line. This will be implemented by reducing waste in the process.

Kaizen / Continuous Improvement A company should try to improve their performance constantly. Therefore, the policy in the company should focus on continuous improvement. The aims for CI should be clear and performance should be evaluated based on CI.

Cross Functional team Most of the time the different teams are focussed on a department and these department have physical boundaries in a company. With cross functional teams this physical boundary is removed and working together is made more natural. The teams are located in the same buildings and if possible at the same desks or rooms.

Customer Involvement With the customer a good involvement is needed. When the relationship with the customer is open and clear, inventories between both can be removed and a process can become more reliable, productive and effective.

Employee Involvement Lean is more than just applying a tool. At the same time all employees at all different management levels should be involved in the process. They need to know how to apply lean and what benefits it might bring. Also the consequences to the production process, when not correctly performing the tasks should be known.

Equipment layout The layout of the equipment should contribute to an efficient process. The maintenance and operation of the equipment should be clear and logical.

Poka-Yoke / Error Proofing To create an efficient process with zero defects an error detection and prevention system need to be designed.

Gemba All managers should spend time on the work floor. To see which problems occur and how the can support the employees. This will improve the communication and coordination. Depending on the management level the amount of time spend on the work floor need to be determined.

Group problem solving Most problems in the process cannot be assigned to one person or one department. With group problem solving a good solution can be found over the different departments. Temporary meetings are planned to organize this group problem solving.

Jidoka / Autonomation The production process should be automated as much as will be efficient (most of the time partial). This reduce the labour costs of the production process.

Just-in-Time (JIT) JIT will ensure that products are pulled through the line based on the demand of the customer, instead pushing based on forecasts. This will decrease the inventory and space requirements, while it increases the cash flow. To implement JIT different other lean tools are necessary, these are (Hines and Rich, 1997) level scheduling, pull system and continuous flow.

Level Scheduling With Heijunka the production will be done in small batches. This will decrease the lead time of the products and enables the pull system.

Plan Do Check Act The PDCA cycle in an adaptation of the Deming wheel, where this cycle asserts that every managerial action can be continuously improved by performing the plan, do chack act steps Imai (1986).

Performance Measurement System A PMS is necessary to measure the performance of the plant. With PMS as tool the value added activities are measured in the system. Clear indicators are used which show reliable information about the performance. This system will indicate where improvements are needed and of the changes in the process have the desired outcome.

Policy Deployment The strategy of the company needs to be in line with the tactics and work descriptions. All employees at every level of the organization should help to achieve the overall objectives of the company. Policy deployment focussing on the strategic goals and if they fit the objectives at the work floor. Otherwise they should be adapted.

Production Preparation The preparation of production will remove waste and inefficient steps during production. Everything that can be done earlier should be known.

Pull System The productions should be triggered by the demand downstream of the production line. This will decrease the inventory and overproduction.

Root Cause Analysis RCA is a systematic approach which can be used to find the real reasons for effectiveness losses in the system. So not the results are changed but the real cause is found. Removing the root will prevent the undesired outcome to happen.

Six Big Losses Production losses that are experienced in the process.

- breakdowns due to equipment failure
- set-up and unnecessary adjustments
- idling and minor stops
- running at reduced speed
- start-up losses
- rework and scrap

SMART Goals When specifying objectives and goals for the company make sure that these are SMART; Specific, Measurable, Attainable, Relevant and Time-Specific.

Single-Minute Exchange of Dies (SMED) Reduce the start up time of the plant by simplification, standardization and elimination of unnecessary proceedings. If possible the set up or change over should be performed during production.

Standardized Work Most of the work in a lean company need to be standardized. Procedures to achieve best practices should be made. The documentation must be adaptable to strive for continuous improvement.

Supplier Involvement With the supplier good involvement are needed. When the relationship with the supplier is open and clear, inventories between both can be removed and a process can become more productive and effective.

Takt Time This will provides a method to calculated the available time for the production of one piece. It can be calculated by dividing the planned production time by the customer demand.

Total Productive Maintenance (TPM) TPM is measured with the OEE and will constant reduce the six big losses to create a efficient process. TPM will combine all employees to assign the maintenance tasks to the suitable employees. It will create new accountability for useful output and machine health for operators. They should take care of the assets and can do small routine checks, they can tighten, lubricate and clean the machines. This is only possible with standard work practices, which need to be implemented. The maintenance department becomes more specialized in this case. At the same time the skills and motivation of the employees should taken into account to improve the equipment performance. And apply early management techniques for new products, services and capital projects to deliver flawless operation from day 1and ongoing low operational life cycle costs (McCarthy and Rich, 2015). Total Productive Maintenance is executed in different levels.

Total Quality Management (TQM) TQM can be described as a management system which uses the plan-do-check-act (PDCA) cycle to manage processes. Sometimes TQM is used as a tool in lean but sometimes it used as a apart management philosophy. TQM has eight basis principles, these are:

- Customer focus
- Total employee involvement
- Process centred
- Integrated system, horizontal integration in a company
- Continual improvement
- Fact-based decision making
- Communication

Training Training for the employees is needed when they are not able to perform there tasks. Also when changes are happening in the process (for example when lean is introduced on the plant). Training is a useful tool to create awareness and knowledge by the workers.

Visual Management The performance of the employees and the plant should be visible, also the tasks and job instructions should be visible for the worker. This will increase the productivity.

Value Stream Mapping (VSM) Value stream mapping show the current production process. Here all waste can be indicated and a future state map can be made to find opportunities for improvement. There are different tools to map the value stream. These tools are (Hines and Rich, 1997):

- Process activity mapping – Shows all activities in the production process. This will make unnecessary proceedings visible.
- Supply chain response matrix – This will make clear how much inventory in the process is. The total lead time of a product is added to the total waiting time of the product. In total this will show when a product enters the supply chain en leaves the supply chain.
- Production variety funnel – This will show the allowed variety of the end product in the production process. Upstream of the supply chain less variety is allowed than downstream in the supply chain.

- Quality filter mapping – The defects rate are shown in the whole production process, this makes clear where the most defects occur and where the need for improvement is high.
- Demand amplification mapping – This shows the bull whip effect of the demand managing over the production line.
- Decision point analysis – Where in the process are the crucial decision points. This will sh ow the push-pull boundary in the supply chain.

Most of the time process activity mapping is used, but depending on the needed information other VSM tools can be useful.

Waste Management Waste management focussing on removing the seven wastes from the process. Transport, inventory, motion, waiting, overproduction, over processing and defects should be minimized in the process.

Workforce Management With workforce management the focus lays on the efficient planning of employees over the tasks that need be performed.

Lean Business principles

Table E.1: Business Principles of the Toyota way (Liker, 2004)

Philosophy	1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
Process	2. Create continuous process flow to bring problems to the surface.
	3. Use "Pull" systems to avoid overproduction
	4. Level out the load: "Heijunka"
	5. Build a culture of stopping to fix problems, to get quality right the first time.
	6. Standardized tasks are the foundation for continuous improvement and employee empowerment.
	7. Use Visual Control so no problems are hidden
	8. Use only reliable, thoroughly tested technology that serves your people and processes.
People and Partners	9. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others.
	10. Develop exceptional people and teams who follow your company's philosophy.
	11. Respect your extended network of partners and suppliers by challenging them and helping them improve.
Problem Solving	12. Go and see for yourself to thoroughly understand the situation: "Genchi Genbutsu".
	13. Make decisions slowly by consensus, thoroughly considering all options. Implement decisions rapidly.
	14. Become a learning organisation through relentless reflection.

F

The Selection of Lean Tools

The tools that are shown in table 4.1 can be used in the model. Lean tools can help to analyse and improve in asset management. However, a lot more lean tools are available. All the lean tools are described in detail in appendix E. In this section will for each group of lean tools be discussed which tool to use in which scenario and why the chosen lean tools fit best to analyse and improve asset management.

Analyse the Process

With analysing the process the root causes and bottlenecks in the system can be found. Root cause analysis are useful when the process has certain problems that occur regular. Bottleneck analysis will show the weakest spot in the current process. The distinction between the two tools is also shown in figure F.1

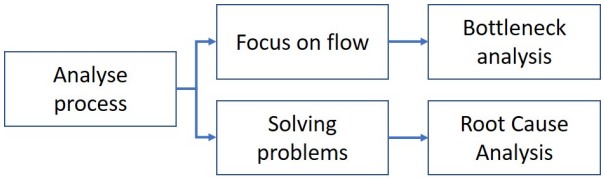


Figure F.1: Tools to Analyse the Process

Waste Management

Waste management will indicate waste in the process, waste is all unnecessary proceedings that occur. The best tool that can be used to perform waste management is Value Stream Mapping (VSM). The other waste management tools are divided from VSM, but provide less guided implementation, also shown in figure F.2

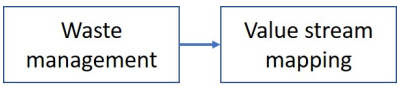


Figure F.2: Tools to Manage Waste

Integration

Different employees need to work together and the cooperation needs to be visible horizontal and vertical. Horizontal integration will lead to a more efficient process and improve the skills of people working on the project. Knowledge sharing will be better. Vertical integration will improve the asset management plans that are made will be more reliable and better fitted for the employees who need to perform the plans.

The different tools that are provided can be divided in tools to improve vertical integration or tools to improve horizontal integration. Vertical integration can be reached with employee involvement and Gemba. Employee involvement has a wider range of implementation and therefore used in this research. To create horizontal integration cross functional teams and group problem solving can be used. Both tools will connect people who do not work together normally. A cross functional team will have influence on continuous work, while group solving is used incidental. Which one is preferred depends on the organisation. The difference between the tools is also shown in figure F.3

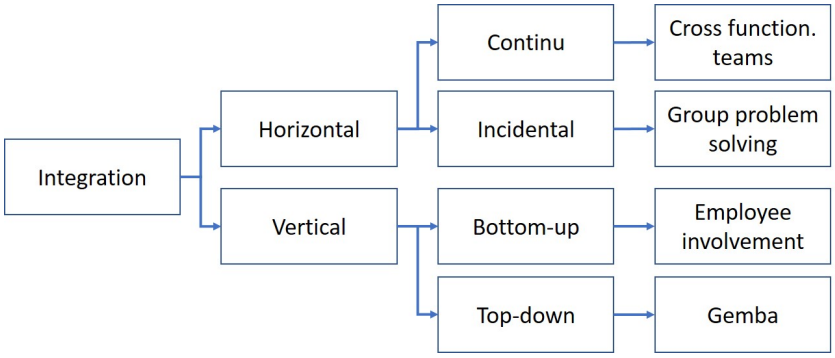


Figure F.3: Tools to Integrate Employees

Human Mistakes

Human mistakes have still a big influence on losses of the company. Tools that will help to reduce the human mistakes will help. This will improve the service providing and the supporting facility of the people. To indicate how human mistakes need to be improved, the reason behind the failure needs to be known (with for example a RCA). Mistakes can be made by lack of knowledge, a difficult process or lack of discipline.

Which tools is used to reduce the human mistakes, depends on the reason behind the human mistakes. For lack of knowledge training is needed. For a to difficult process or discipline, standardized work and error proofing are useful tools, as also shown in figure F.4.

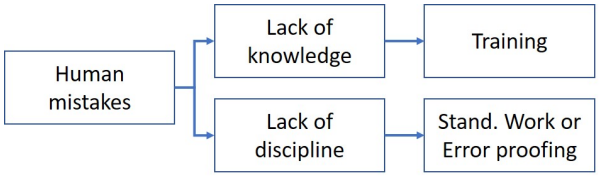


Figure F.4: Tools to Reduce Human Mistakes

Improve Management

The management of the organisation should be provide a plan to implement and improve asset management. The risks that can be taken should be defined well by the organisation. The organisation is a basis for all asset management activities and therefore one of the first steps that need to be improved when needed.

Different tools are available to improve management. Policy deployment is a wider implementation for the making of plans according to the companies objectives. This tool will not guide you and needs more knowledge to be used. Continuous improvement is needed as vision in asset management as found in chapter 4. Continuous improvement is one of the activities under policy deployment. For the implementation of CI guided plans are written, for example by Imai (1986). TQM is a management philosophy with a focus on customers, EI, process centred, horizontal integration, CI and communication. The Plan-Do-Check-Act cycle is an implementation factor in CI and TQM. The difference between the tools is also shown in figure F.5

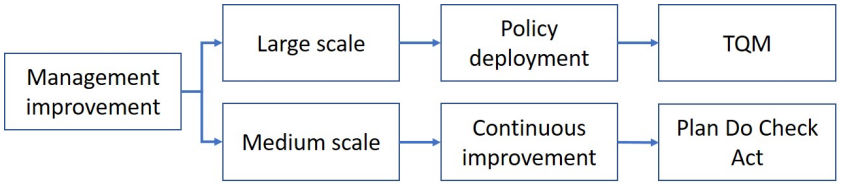


Figure F.5: Tools to Improve Management

Measure Performance

The performance of the process needs to be measured. Performance measurement will be help to know the performance of the system. Accurate performance measurements requires a good PMS. This system must measure the objectives set by the company. When there is no good PMS it should be developed according the companies objectives and goals. When the system is already developed but not used, visual management will help. This makes people aware of the performance of the plant. The PMS system can be used to analyse asset management and the Visual Management can be used to improve asset management. SMART goals and Six Big Losses are tools that are less relevant, but can be seen as requirements for the PMS. In this report they are not taken into account any more. The distinction between the two tools is also shown in figure F.6.

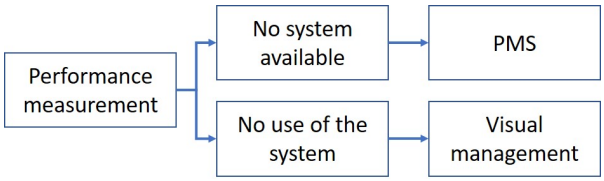


Figure F.6: Tools to Measure the Performance

Total Productive Maintenance (TPM)

TPM is a tool which divides autonomous and preventive maintenance tasks. Operations and maintenance are working together and tasks are divided efficiently. This requires changing employees for whom tasks will become different. TPM will improve the coordination between operations and maintenance in the service providing of the asset. To use TPM successfully good communication between these two activities is required. With TPM the amount of preventive work will increase and the amount of corrective work will decrease. This will increase the performance of the maintenance of the plant and mistakes in the asset will be visible earlier. This will increase the availability and performance of the plant. At the same time the maintenance costs will be reduced, since the motion of employees is reduced.

Automation

Automation will help to make the process more efficient. Automated processes are more reliable and have less fixed costs. Most of the time, processes will become more efficient. Automation can also be used to gather information and use data to get more insight in the asset. Autonomation is a lean tool where the choose of which aspects of the process is automated is defined. This tool can help to implement automation together with the employees.

G

Improvement method

In this appendix the improvement methods will be further explained. First the method to analyse asset management will be further explained, followed by the method to improve asset management.

G.1. Methods to Analyse Asset Management

Organization To analyse the organization within asset management, a performance measurement system should be used. A good performance measurement system will help the company to understand how they are performing related to best practices and what the major risks are they are facing. Other tools might be useful, but this should be further researched.

Leadership To analyse the leadership of the company a value stream map should be used. This lean tool will show the value adding activities in the organization. The focus of the company should lie on these activities, all non value added activities should be minimized. The VSM will help to see if the current goals and objectives of the company are set right. The PMS will not be useful in the leadership aspect. The analysing tools might be useful in some cases.

AM Plan To make an asset management plan the analysis tools can be used. The RCA and BNA can both be used to find the current problems in the process. It will show which factors are the causes of the current performance losses. Which one of the analysis tools should be used is described in section 4.3. The flow diagram that is given in figure F.1 of this section, should be used every time the RCA and BNA can be chosen in the model. The PMS is not useful to analyse the asset management plan and a VSM might be useful, when it is not yet used in the aspect leadership.

Operation To analyse the operation of the process all different tools might be used. The analysis tools are useful to find the main problems in the current situation and should be used when assets are not working frequently. VSM should be used when the distinction between value added activities and non value added activities is unclear and when the flow in the process is not visualised well. A PMS should be used when no data about the plant is available. Installing a PMS will give insight in the performance of the plant.

Evaluation To analyse the evaluation of asset management a performance measurement tool should be used. The PMS system is ideal to use, it will show how good the process is operating and this will show the opportunities for improvement. The analysing tools can be used when a certain problem needs to be evaluated.

Improvement To analyse the improvement of asset management different tools might be used. To choose a tool the similar considerations as explained in the operations part should be made.

Supporting Facilities To analyse the supporting facilities one of the analysis tools should be used. These tools might have as result that the organization, people or means are not sufficient to perform the process. It will also provide what the exact problem is with these tools.

G.2. Methods to Improve Asset Management

Organization To improve the governance of asset management, management tools can be used. Policy deployment is used when the description of asset management and the aligned goals are not well defined. The company's goals should be aligned with asset management goals. The tools autonomation and continuous improvement might be useful to depending on their implementation.

Leadership To create a good policy and strategy for asset management the current state must be known. To make a good policy and strategy according the organizations objectives, the policy deployment and continuous improvement can be used. These tools are related to the making of policies. The involvement of employees and group problem solving can be used if the leadership does not match the asset management plan. Autonomation can be used to create more flow and a more transparent process.

AM Plan To improve the concept that is aligned with the policy & strategy the tools for integration can be used, especially employee involvement. With involving more employees in the concept it will better fit to the policy & strategy as well to the process. The other integration tools are more useful in the asset management plan, since this phase lays closer to the actual operations. Continuous improvement can also be used to align the different plans. Policy deployment becomes less useful, since this tool is better to use on strategic level.

To improve the asset management plan TPM can be used. Integration will be used to involve more employees in the plan and create a plan which better fits the process and the plans. TPM can be used to divide AM and PM jobs. This tool requires more drastic changes then the other tools that have been mentioned.

Operation To improve service providing in asset management multiple tools can be used. Autonomation will automate the process, this tool is expensive but will be used when drastic changes in the process are needed. The tools with human mistakes, training and standardized work, can be used to simplify the process and remove mistakes from the process. To make employees more aware of the performance, visual management can be used.

Cross-functional teams, group problem solving and TPM all make the process more efficient. The first two tools are easy to implement and they will help with communication between the different activities. TPM is a more radical change in the process and only improves the integration of maintenance and operations.

Evaluation To improve the performance measurement two tools can be used. Automation will help to create reliable and available data to measure the performance. Visual management will help to make the performance measurement more visible and ensures that the data is used in the process.

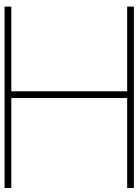
Improvement To improve the analyse & improve aspect of asset management different tools might b used. Integration tools can help to find different views on the process, different department can be involved as well as different management levels. This will ensure a more sustainable solution. Continuous improvement will be useful to ensure a continuous improvement loop in the policy of asset management. Autonomation will help to improve the system and the data that is gathered in this process can help to analyse and improve.

Supporting facilities The organisation can be improved by management tools, policy deployment / continuous improvement and by TPM. The management tools improve the goals and alignment and can be used in a wider scope. TPM is very specified and can only be used to make a good distinction in the operating tasks of operators and maintainers. The cross-functional teams and group problem solving is also a change in the organisation and way of working.

To improve the people aspect in asset management tools in the employee involvement, human mistakes, visual management and TPM group can be used. Employee involvement must be chosen when the communication between people is not good. While human mistakes should be chosen when the skills of the people

does not fit their tasks. TPM will improve the skills and integration, but with TPM and not towards the set asset management goals. Visual management should be used to motivate employees.

The means in asset management can be improved with autonomation and visual management. Visual management provide new means to better work with the PMS. Autonomation will automate the process.



Maturity model

Table H.1: Maturity levels in the different groups of lean tools (source: based on Hujdurovic (2008))

	1	2	3	4	5
Analyse Process	Problemen herhalen zich zelf en geen bottleneck studies	Gelimiteerd gebruik van tools als 5 why meeste zijn nog steeds quick fixes, bottleneck kennis aanwezig	Teams voor root causes grote problemen door middel van PDCA cycli en BN plan	(3) met operators altijd zijn betrokken veel minder herhaling problemen	Root causes en PDCA for alle problemen en erg betrokken personeel
Waste	Product proces flows bestaan niet voor kritische producten	Current and future VS gedocumenteerd voor een paar producten	Current and future VS voor alle key producten, future steeds eens bereikt	Significante opbrengsten behaald uit vs verbeteringen	Als de future state de current state is, wordt er een nieuwe future gedefinieerd
Integration	No communication between departements and management layers				Communication plan for horizontal and vertical integration, continu reviewed and improved
Human Mistake	Geen formele klassen of on-the-job training, zeer weinig medewerkers betrokken bij C.I.	Trainingen gelimiteerd tot ondersteunend, technische en management.	Operators en productie medewerkers zijn bij de training ingesloten	Een degelijk plan is aanwezig, welke iedereen traint en leert C.I. tools te gebruiken	Het plan (4) is volledig ingezet en wordt continu verbeterd
Management	Geen link tussen werkvloer en doelen, geen verbetercultuur en top management focus on high-level oper.	CI op basis van werknemer suggestie. Middelen moeilijk toe te wijzen	CI vindt plaats, maar omvat slecht een gedeelte van het personeel en zijn middelen.	Een gestructureerd CI plan is ontwikkeld en zichtbaar op werkvloer.	PDCA-cyclus wordt gebruikt voor CI en iedereen is zich bewust van de noodzaak. CI is pro-actief vanuit productie i.p.v. staf
Performance	Geen PMS of vage KPI	Enkele KPI maar onafhakelijk en PMS voor werknemers	Alle teams hebben KPI en metriek gekoppeld aan business plan	KPI's per flow en verticale en horizontale afstemming met moeite	(4) maar dan met weinig energie en real time beschikbaar
TPM	Onderhoud is reactief	Een mix van reactief en preventief door ME	Autonoom onderhoudsplan incl schema en training	Gereduceerde ongeplande downtime enig voorspelbaar	(4) en volledig voorspelaar, kritieke onderdelen aanwezig
Autonomation	Er vindt nauwelijks tracking plaats van de activiteiten	Data is grotendeels beschikbaar per afdeling	Systeem dekt alle machines en is beschikbaar voor iedereen	CMMS door productie gebruikt gekoppeld uit ERP	Systemen CMMS, ERP zijn gekoppeld aan operatie en ontwerp

Verification

Requirements and constraints

Explanation of requirements and constraints of the model and lean tools.

The improvement method should be usable without in depth knowledge of lean. To use the model no in knowledge of lean in needed. The choices that are must be made are all prescribed. As the tool is unknown, a short description of the tool that is provided with the model is sufficient to make decisions.

The improvement method should be usable by the consultants of Stork AMS. The consultants of Stork AMS all have certain knowledge about asset management and the aspects of asset management they are active in. This knowledge is needed to make decisions and advice certain lean tools. Other information is not needed and therefore the model can be used by all consultants of Stork AMS.

The considerations in the model should be clear. In the model certain decisions should be made. With different flow diagrams these decisions are visualized. These flow diagram helps to understand why certain decisions are made. At the same time the distinction between usable, unusable and unknown in the model provides a certain nuance which makes the model more logical.

The lean tool should be usable in asset management. The different tools in the model are designed and developed to be used in a supply chain. The different lean tools should also be usable in an asset management environment. With the selection criteria for the lean tools this aspect is taken into account.

The lean tool used in the model should be different from each other. The different tools in the model are distinctive from each other, otherwise the model will become unclear. In the selection of the lean tools a distinction is made and tools are combined or excluded from the research. With the different distinction flow diagrams is shown that the different lean tools are not similar.

The method should be usable on and should make distinction between strategic level, tactical level and operational level. The different aspects in asset management are so developed that the different levels (strategic, tactical and operational level) are visible. The organization and leadership are aspects on strategic level. The AM plan has a focus on tactical level. The operations has on focus on operational level. The other aspects can not specified to one of these levels. The model is usable on each of these aspects and therefore the model can also be used on strategic level, tactical level and operational level.

The method should focus on the improvement of asset management, not on the improvement of one of the activities within asset management. The different lean tools that are used are selected. On of the selection criteria was the fact of the lean tool can be used to improve coordination. This coordination was the coordination of activities in the asset life cycle. So, this selection criteria has ensured that the model focusses on the improvement of the coordination of the activities in the asset life cycle, which is defined as asset management.

All aspects of asset management as defined by the ISO standard should be taken into account in the model. In the model the aspects of asset management as defined by the ISO standard are visible in the first row the column. These performance on these different aspects are needed as input in the model. All aspects are involved in this model, since on every aspects are lean tools that can be used to improve or analyse the model.

When multiple tools can be used for one aspects, distinctions between them should be made. In the model, multiple time are different tools available for the analysis or improvement of an aspect in asset management. To choose between the different tools in one group, different flow diagrams are made to make a distinction between the different tools. The different groups of lean tools are significant different form each other.
The lean tool should improve at least one aspect of asset management as defined in the ISO 55000. The different tools that are used in the model should be used to improve or analyse at least one aspect. If a lean tool is not usable in one of the aspects it should be removed from the model. In the model it is visible that all lean tools are usable in at least one aspect. Therefore, this requirement is met in the developing of the prescriptive decision model.