UNIVERSITY OF TWENTE.

Faculty of Behavioural, Management and Social sciences (BMS), Industrial Engineering and Management

Bachelor thesis: Minimizing the internal costs for the new battery container at Company X

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Preface

You're about to read the bachelor thesis I have executed during the third year of my bachelor Industrial Engineering and Management at the University of Twente. The thesis is conducted at (…), part of the well-known (…), which is a big player at the construction industry in the Netherlands.

A special thanks to my supervisors at The company*, who guided me through this research. Besides their well filled agenda, they were always available for questions and gave very useful feedback to improve my research. Besides this, I want to thank all employees at the company who helped me during this research.

Second, I want to thank my first UT supervisor Engin Topan. Despite we could not meet physically, he did all he could to help me during this research. He was always available for questions and extensive feedback. Especially the feedback he helped me to reflect my own work and improve the quality of my thesis. Moreover, I want to thank my second supervisor, Adina Aldea, who also gave me feedback and is willing to help to grade my thesis.

Finally, I want to thank my girlfriend, friends and family who always supported me during the research. A special thanks for my buddies Maarten van Oosterom and Roy Koers. With the three of us, we formed a team and guided each other through the research by providing feedback and during work sessions.

Thank you for reading my bachelor thesis. Have fun!

Ruben Klaas

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*note: due to confidentiality issues, this thesis is anonymized. When we talk about the company this research is conducted, this will be indicated as "the company".

Management summary

This research has been performed at The company. The company is making producing compressors and gas turbines. Next to this, they are also developing products for the sustainable energy market. They have developed a Battery energy storage system (BESS) of 45 KWh and are developing a BESS of 500 KWh and a hydrogen generator. This study focuses on the development and production of the 45 KWh BESS, the product and is executed at the engineering department of the company.

The company has executed the first project on the product, during which they developed and produced three of the product's by themselves. During this project, they encountered a lot of problems and were able to learn a lot for future projects. However, the budget that was made for this project has been far exceeded. The company wants to close this gap between budgeted cost and actualized cost. This will be the main focus of this research. From this goal, the following research question can be stated:

How can the gap between budgeted and actualized costs for the product projects be minimized?

To get an indication on what the company is doing and how they work, we gave a company introduction first. The company focuses on three types of products/services: (i) assembly, testing and service of compressor and gas turbine packages, (ii)high speed balancing and compete unit testing of gas turbine driven compressor or generator packages and (iii) new business development. This study is focusing on the new business development part of the company.

It became clear that the most important method to minimize the gap between budgeted and actual cost is to standardize the processes within the company. To get an indication on what methods are available to standardize new business projects, we execute a literature review. From this literature review it became clear that the implementation of lean principles is an important factor to standardize the new business processes. We explain what the principles of lean are, how to use Business Process Management. Besides that, the new business development team is already using scrum, but they can use this principle more extensively to increase their efficiency. The principles of scrum are explained.

We want to understand and investigate the current situation. A current system analysis is made to get clear how the previous project on the product went, what the points of improvement are and what should change to transfer from the development of a prototype to a product that can be produced in series. We conduct multiple interviews with all stakeholders and involved colleagues at the company to get a better understanding of the way of working at the company. Besides that, we execute a document review to get an idea of what the idea is behind the current way of working. This theoretical models are compared with the models that have been created out of the interview and from this, the points of improvement can be indicated.

Once the problems are clear, it is time to take a look at the solutions that can be generated. As said, standardization is an important factor in reducing the gap between the budget and actual. We have conducted another round of interviews, in which we have set up a process description as it should be in a standardized situation. Out of this standardization we can see how many hours will be saved when working according to a standardized process, compared to the situation as it was for the first project.

A standardized process is typically not something that can be created and implemented very easily. Therefore, we have investigated what activities should take place to come to this standardized process. Per department, we have asked what actions are needed to set up a standardized process and how many hours it would cost to execute these activities. When we had all these data, we could calculate what the investment to come to the standardized process is going to be and what the return on investment (ROI) would be.

From this research, we can draw the following conclusions, as answer to the main research question:

1. The difference between the budgeted and actual costs of the production and development of the product can be minimized through standardization. By standardizing the process, it will become easier to predict the needed number of hours and therefore the difference between actual and budgeted costs can be minimized.
2. To standardize processes, The company should transfer from Engineer-To-Order (ETO) to Configure-To-Order (CTO) projects. Through CTO, it is possible to work through standards that can be set up. This will make it possible to decrease the throughput time significantly and increase the efficiency of the process from 40% to 80%.
3. An investment is needed to set up the standards to work through CTO. Engineering, MRP and the procurement departments have some work to design and setup the standards they need. This investment will be about €23.774,-.
4. The efficiency of the "white-collar" part of the company will increase from 40% to 80%. If we take the increase in efficiency into account, we can calculate the earn-back time of the investment for the standardization project. Per project, €3800,- will be saved for the Sales, MRP and procurement departments. The investment of €23.774,- will therefore have a return on investment within 6 á 7 projects for the product.

Based on the research performed and the time at the company, we can do the following recommendations:

1. This thesis focuses on the "white-collar" departments that are involved in the development and production of the product. The company is also developing a larger BESS. And an hydrogen generator, the *h*-PU250. Parts of this research can also be implemented in the processes that play within the production and developments in these products too. It is recommended to take a look at this.
2. When the sales of the product increase, it will be beneficial to have more parts of the product on stock, instead of ordering them per order, as happens now for most parts. Especially the MRP department should consider from which point on it will be more beneficial to have a part on stock instead of ordering per order. This should be done for every part.
3. To offer the product through CTO at the customer, the sales department should create a nice tool to show the options to customize to the customer. During this research, it became clear that Tacton, software that can make a quotation out of a CTO tool, could be a suitable program to use for this. It is recommended that sales will investigate this program as option to use.
4. The company is trying to set up a new business part of the company. This research is conducted at the engineering department of the company. Within this department, a team is working on different new business projects. It is recommended to treat these departments more as research and development departments.

Finally, it is advised to focus more on cooperation and communication between departments. Especially for the departments engineering, MRP and procurement, as this was a big issue during this research.

Table of Contents

List of tables

List of figures

List of Acronyms

MOQ – Minimal order quantity

KPI – Key Performance Indicator

ERP – Enterprise resource planning

BOM – Bill of materials

VBS – Vanderleegte besturingssystem

TS – Technical specification

BPMN – Business process modelling notation

PD – Product development

BESS – Battery energy storage system

BPM – Business process modelling

FMEA - Failure Mode and Effects Analysis

DDD – Detailed Design Documents

ETO – Engineering to order

CTO – Configure to order

GA – General arrangement

1. Introduction

This bachelor thesis will be executed at The company. In this chapter, the company will be introduced in section 1.1, after that in section 1.2 the problem is introduced and in section 1.3 the research design will be explained.

1.2 The problem

1.2.1 The action problem

The first project for this new business is executed last year, where they delivered three product's for a customer. This project was set up very fast, and there were no clear procedures for product development and production. The company works together with another company to produce the product. This partner delivers several parts for the battery container. During the first project, the company just started to produce a battery container and they said they will see what they will encounter. As could have been expected, they encountered a lot of problems, and therefore the project run out of time and the budget was a lot exceeded.

As stated above, The company encountered many problems during the first project of The product. This caused that the project ran out of time and that the budgeted costs for the white-collar part of the company was far exceeded. This is one of the reasons why the company wants to work on this problem. Together we formulated the following action problem:

"The budget for the white-collar part of The product project is far exceeded."

In this problem, the problem owner is the management of The company. They want that the budget for each product is met and that there are no unexpected costs.

1.2.2 Problem cluster

To investigate the action problem, further research within the organization is required. In order to get more information and causes, a research is executed on the provided documents about the production of the product, and the common way of working within the organization. From these documents, it became clear that the organization is developing from a project-based company, with very large orders, to a company with more smaller projects.

Also, various orientating interviews are conducted with the involved parties. The goal of these interviews was that the view of the way of working of the company, and the various departments working on the product became clear. From the interviews and the documents, a problem cluster is made (Figure 1).

The cluster starts at the bottom with the action problem. From there, the cluster is split up in problems that are present in the departments. The focus of this research is on the engineering, work preparation and procurement departments, because these departments are strongly dependent on each other and with this selection the scope of the research will not be too large.

The first problem that applies to many departments, is that there are too many hours put in this project. From the interviews, it became clear that they encountered a lot of unforeseen tasks, for example the procurement department who had to buy every part separate, because there are no contracts with suppliers.

Lots of extra hours were spent by the engineering department. This was mainly because the lead engineer was also the project manager and was therefore involved in many other processes and departments. One of the reasons for this is that certain steps in the process were not defined and therefore had to be done by the project manager, because there is no clear procedure about the development and production of the product.

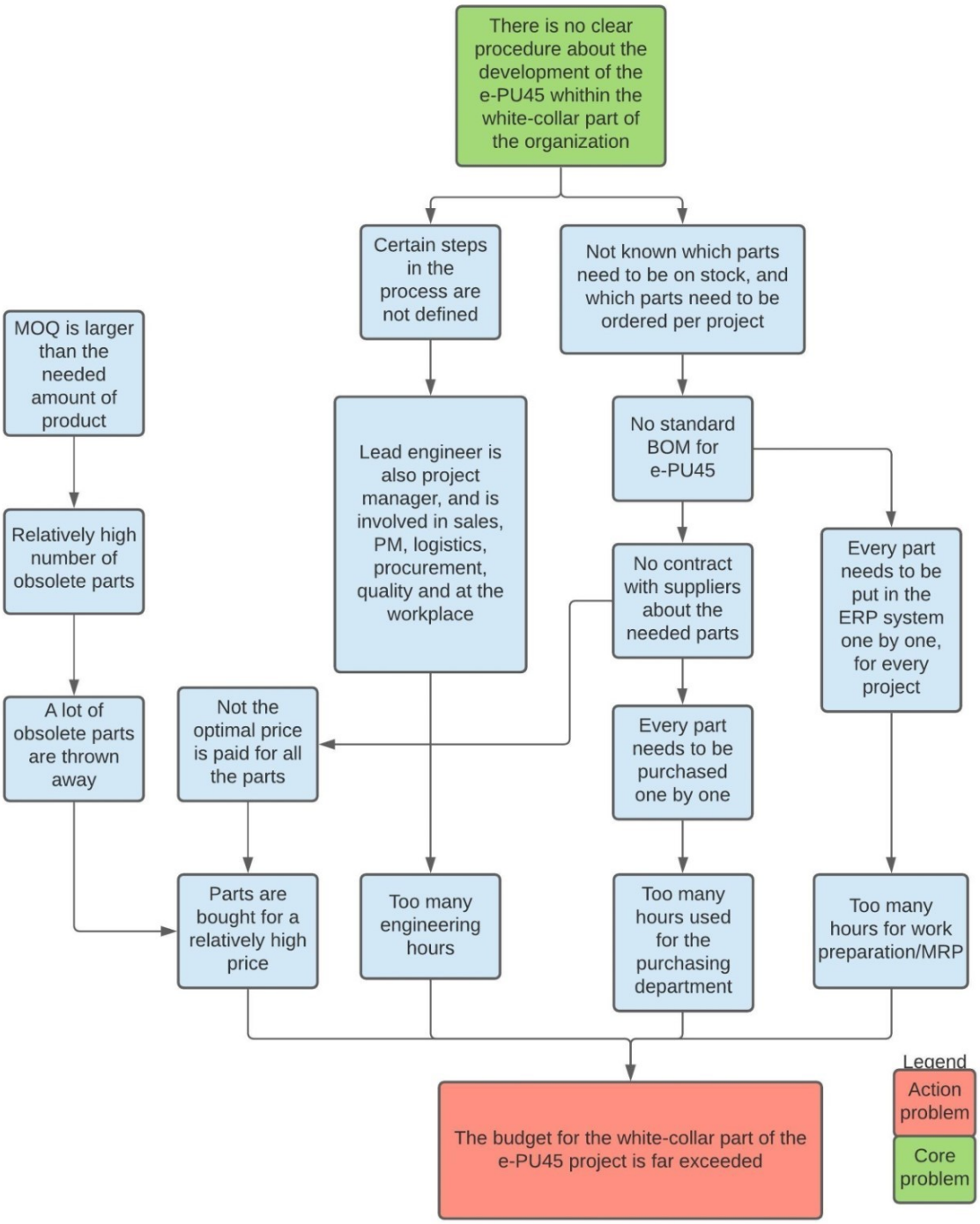

Figure 1: the problem cluster

1.2.3 Core problem

From the interviews that have been executed, the problems in the problem cluster can be indicated. To select a core problem, a closer look will be taken to problems that have no cause by another problem. These can be seen as possible core problems. Once a problem can be influenced by the researcher, the core problem will be selected. “If more problems are suitable, the most important one will be selected as the core problem” (Heerkens and Winden, 2017).

In the problem cluster in Figure 1, there are two possible problems that have no cause by themselves. One is that the Minimal Order Quantity (MOQ) is larger than the needed amount of the product and

the other one is that there is no clear procedure about the development of the product within the white-collar prat of the organization.

The first problem, the MOQ is larger than the needed amount of the product is hard to influence, because the desired number of parts cannot be changed, and also not the MOQ. Therefore, this problem is not the core problem of this research.

From the interviews and the research, it became clear that there is one problem that caused a lot of extra hours and therefore costs. That is that there are no clear procedures for the production and development of the product within the white-collar part of the organization. Therefore, the core problem of this research will be:

> *"There is no clear procedure about the development of the product within the white-collar part of the organization. "*

This core problem is indicated in green in the problem cluster (Figure 1).

1.3 Stakeholders

In this section, we will describe the stakeholders of this research. Different stakeholders are involved, both from the university and the company. The stakeholders are, from top to bottom; the management of The company, the lead engineer, the representatives of the procurement department, the representatives of the work preparation/MRP department and the university of Twente. I will describe them one by one.

The first stakeholder is the management of The company. The people in the management are in the end responsible for what happens at the company. The management will focus on the KPI's set for this research. Especially, the difference between the budgeted and the actual costs for white-collar will be important for managers. This because they do not have unexpected costs if the budget is not exceeded and can therefore be able to plan the work and costs better. Furthermore, when there is less dissatisfaction among employees, they will have less problems to solve with their personnel and have more time to spend on other things.

The lead engineer, or actually the whole engineering department is the next stakeholder of this research. Right now, the engineering process is very inefficient and the lead engineer is involved in almost every step of the process. This causes that he has almost zero time to spend on other projects. It is expected from him to be involved in multiple projects, so it is very important that the processes at the engineering department will become more efficient. The eventual goal is to have as less as possible engineering needed to produce and develop the product. Therefore, the budget for the engineering department was one that was exceeded way too much. If we can improve this KPI, this will have a big impact on the pressure on the engineering department, especially on the lead engineer.

The third stakeholder is the representative of the procurement department of the company. He or she also looks at the KPI of the exceeded budget. In the first project, it was the case that the materials were bought way too expensive and also the hours for the procurement department were exceeded. When there is a smooth process flow for the white-collar of the production of the product, the people at the procurement department will know from which supplier they need which materials for the best price. This will solve the problem of exceeding the materials budget. Besides that, they will spend way less hours on searching the right supplier, which will solve the problem of exceeding the procurement hours. Furthermore, during an interview with the procurement department representative, it became clear that there are a lot of miscommunications between the engineering and procurement department. When there are clear arrangements between the departments over the processes and the information flow between the departments, there will be less frustrations between these two departments.

The representative of the work preparation/MRP department is the fourth stakeholder involved in this research. This department is now doing a lot of not useful work, because they have to put every part of the product in the ERP system of the company by hand. This again causes that the budgeted hours for this department are not met, even far exceeded. One of the deliverables is a tool which will solve that problem. That is why they are an important stakeholder for this research. Besides this, during an interview, someone from this department stated to offer all employees a communication course, which indicates that he or she experiences some frustrations about the way of communicating at the company. By making good and clear arrangements, the communication between departments should become better.

1.4 Problem solving approach

In this section, we will explain how the theory is applied to practice. This will be done via the Managerial Problem-Solving Method (MPSM), developed by Heerkens and van Winden (2017). We will explain each phase of the MPSM, based on the action problem of the company.

1.4.1. Defining the problem

The company indicated that they do not have a process description on their New Business side, where they develop, among other things, the e-PU45. Per department should be discovered what the problems are, and then should be decided which department(s) cause(s) the biggest problems.

1.4.2 Formulating the approach

To design a process, we must first get to know the organization and the current way of working better. To achieve this, we will perform interviews within the different departments, such as engineering, work preparation, material requirements planning, procurement and logistics. After that, we hope to have clear what the actual problem is and that we can make a solution approach.

1.4.3 Analyzing the problem

During this phase we will conduct more in-depth interviews with the different stakeholders of the problem. Besides that, a systematic literature review will be executed to find out what the literature says about a new process description. We will search for methods to make the most realistic process map. Terms to use are Value stream mapping, Business process mapping, configure to order, etc.

1.4.4 Formulating (alternative) solutions

In this phase, we will design a process layout, and check with different stakeholders within the departments whether this process layout is correct. If not, which adaptations should be implemented to make this layout most suitable to apply to practice. For this, the output of the SLR can also be used. It should in some way be measurable whether the process layout is suitable to implement in the organization. Therefore, we need to make a list of criteria on which the process layout can be tested.

1.4.5 Choosing a solution

When choosing a solution, it is very important to get every department involved. Therefore, the solution should be approved by every stakeholder of the different departments. The solution which fits the aforementioned criteria the best will be chosen. Besides that, the intended solution will be checked with the management of the company. They will undoubtedly have an opinion about the chosen solution and whether it will work or not.

1.4.6 Implementing the solution

It is unsure whether this phase can be executed in this research, because it is not known whether there will be a project on the e-PU45. Together with the supervisors, we will investigate what will be the best way to implement the solution. This could be difficult, because many different departments are involved, and the current way of working is settled deeply within the organization. With this we mean that the people working at THE COMPANYare used to a certain way of working they have for many years. They are used to work on very large projects, which were at an engineer-to-order basis, but

they have to change the structure of the company to a configure-to-order basis. Therefore, it is essential to write a clear implementation plan to make sure the new process is understood by all stakeholders.

1.4.7 Evaluating the solution

To measure whether the solution was correct, it is important to evaluate. After the solution was used, we should look at whether the solution was applied correctly, and whether it was correct or not. It could happen that the process is not executed the way it was designed. In that case we should take a look at where it went wrong and what could be adapted or improved to make it work.

1.5 Research design

In this section we will describe the research design of the thesis. The research questions will be stated and explained in the sub sections below, after which the deliverables and limitations of the research are stated. The main research question of this research is:

How can the gap between budgeted and actualized costs for the product projects be minimized?

In the following section, we will describe the sub-research questions of this research.

1.5.1 Research questions

1. Which methods for optimizing the white-collar processes within a company are available in literature?

This exploratory question aims to investigate what literature says about optimization methods for 'white-collar' processes. The research subjects of this study are for example, new products, value stream mapping, business process mapping, etc. This will further be elaborated in chapter 2.

2. How does the current development process of the product look like?

The aim of this question is to notice and describe the current development process for the product within the previously mentioned ‘white collar’ departments. This research is done by interviews with involved stakeholders and by analyzing the available data from the company. This context analysis will be explained in detail in chapter 2 of this thesis.

3. Which data is needed for every involved department and which data does this department generate?

This question aims to investigate the needs and deliverables of every involved department of this research. We will use interviews to gather the data for this.

4. How should the standardization of the development of the product look like?

This is an explanatory study, and is divided into two sub questions: to what extend can the product be standardized? And which options to customize does a customer have? To find an answer to these questions, we will, together with the different stakeholders of the company determine the standardization and the customizability of the product. The outcomes of these sessions will help to answer this question and to develop a standardization tool.

a. To what extend can the product be standardized?

It still needs to be determined to what extend the product can be standardized. This is an important factor in our research, because it determines to what extend the product is customizable and how far engineering is involved in the process.

b. Which options to customize does a customer have?

This partial question is strongly related to the previous one. To determine the BOMs for these options, it needs to be determined which options a customer has for customization.

5. How can the current process be optimized?

In sub-research question one, the current development process is made clear. Next, an explanatory study will be executed with different stakeholders of the company on how the development process of the white-collar part of the business should look like. This will be done via various sessions, where the stakeholders get the opportunity to share thoughts about how their way of working can be optimized, which steps in the current process are waste (Fercoq et al., 2016). These findings will help to answer the knowledge question and to design the optimal process.

a. Which steps in the current process are waste?

When is determined what the current process looks like, it should be investigated where the waste is located in the process. When answering this question, it becomes clear where to improve the process.

b. Which steps are most important?

After indicated which steps are waste, it is also important to which steps are most important to complete the process.

6. How can a new process be implemented and evaluated within the organization?

When the optimal process layout has been found, it is time to implement the solution. It is very important to again involve every white-collar department of the business in this step, because it only works if everybody is in. Therefore, in cooperation with all stakeholders, an implementation plan has to be made. In the end, we will give a qualitative solution: a clear advice on how to implement the solution.

1.5.2 Deliverables

In cooperation The company, the main deliverable of this research has been defined as:

> *"A process description, where the development of the product for the white-collar part of the company is described."*

First, further research is needed to find the optimal framework for this process description. A possible solution could be a process flowchart. Next to that, the company should determine what they find important to include in the description, and KPIs need to be set. Furthermore, a literature study on what a process description or process flowchart should consist of will be executed. We will therefore do a literature review and report this in chapter 2.

Everyone that works on the product should be aware of the changes in the way of working that will arise with this process description. Therefore, an implementation plan is another deliverable of this research.

It should be kept in mind that The company is developing multiple new products related to the product. For example, they are also developing a *e*-PU500, which is also a containerized battery

storage system, but much bigger. It would be optimal if the process description is also suitable for these kinds of products.

Besides the main deliverable,The companyalso indicated that they want to be capable of offering the product via the configure-to-order principle. For example, that a customer can choose the color or the way they want to be able to charge the battery container. We want to develop a tool for the transfer between the engineering department and the MRP. It will be optimal if the (sales) engineer can select the desired configuration in the tool, and that the MRP will automatically get the desired BOM out of the tool.

1.5.3 Limitations

There are various limitations for this research. First, the coronavirus is still influencing our lives a lot. AlthoughThe companyis quite flexible in working at the office, it can still have an influence on the research, because colleagues may be harder to reach. Some interviews will be held online, this can influence the practicality of the research, but should not limit the results.

Second, due to the time span of ten weeks, the research design will have some limitations. Especially for the implementation and evaluation phase it is hard to say whether this can be executed or not, because it is unsure whether there will be a project on the researched product or not.

Third, this research is very specific for the product. It will therefore be hard to validate this research externally. Besides that, the future models made in this research are all based on the experiences and expertise of the people working at the company. Practice should turn out whether these models can be applied correctly or not.

Lastly, this research only focusses on the development of the product at The company. It is therefore very specific on one product, but might not be so useful for other products (within the company).

1.6. Company description

The company is a company that is in a state of transformation. Their main business is on the packaging and testing of gas turbines and compressors. Besides that, they are setting up a new business, which focuses on the energy transition. This new business requires a new way of working because the focus always was on the beneficially procurement of the company, but now shifts to offering a product for a sharp price but sell it in larger quantities.

This research will focus on the processes that are present in the so called "white-collar" part of the company. With this term, we especially mean the departments procurement, work preparation/MRP and engineering. To give an indication of the different departments of The company and their functions, an overview is made which can be found in Table 1.

Table 1: the involved departments

Departments	Description
Sales	Sales is responsible for winning contracts. They make cost estimations and sales prices. Besides that, they create the hour booking orders and the project in the ERP system.
Project Management	As the name says, project management is responsible for managing the projects.
Engineering	The job of engineering is to develop and design the products. They do this through programs like SolidWorks
MRP	MRP is responsible for the transfer of the order into the ERP system ofThe company(called VBS). For each order, they make a Bill of Materials (BOM) and attach specifications to the order. Besides that, they determine whether a part should be purchased.
Procurement	Procurement is responsible for finding the right suppliers for the products. They send the specifications made by MRP to different suppliers and select the right one.
Work Preparation	The work preparation, as the word says, is responsible for the preparation of the work packages for the people in the factory. They make sure every employee gets the right drawings, etc.
Business office	The business office is the umbrella organization for the MRP, Procurement and work preparation.

Table 1 provides an overview of the departments that are involved in this research. It describes the roles of the departments, and how each department contributes to the development process. We will describe the current processes for each department in detail in the next paragraphs.

1.6.1 Sales

Sales is responsible for winning the projects and maintain contact with the customer. Next to that, they make cost estimations and sales prices. The process within the sales starts with the request from the client. If this request is approved, their main next job is to select a project team and organize a kickoff meeting. In this meeting, the scope, goal, etc. of the project are discussed. After this meeting, the selling price can be determined and the quotation can be offered.

1.6.2 Project management

The project management, as the name says, is responsible for managing the project. They should have a helicopter view over the project. They are responsible for making budget hours and a planning. Next to that, they should also make sure that the planning is met.

1.6.3 Engineering

The process at the engineering department starts at the project documentation. For the first project of the product, this was only a 4 pages document with some specifications the product should meet and when it should be finished. After that, an engineering team was selected which consisted out of 3 employees. With these people a project plan was set up. There were basic designs available and so this phase was not to complicated. The product safety assessment was combined with the detailed design review. After which the design detail documents were handed over to the material requirements planning (MRP) and procurement.

1.6.4 Material requirements planning (MRP)

The job of MRP is to put the required materials into the ERP system of the company. They receive the Bill of Materials (BOM) or a technical specification (TS) from the engineering department. With these documents they are and should be able to put the materials in the ERP system and attach specifications of the material to it. This is useful for the procurement department.

1.6.5 Procurement

The procurement department is responsible for finding the right suppliers for the different parts. They receive the detailed design documents from engineering and MRP, and then start searching for a suitable supplier at the market. When they found one or multiple, they check whether the supplier is in the approved supplier's database. This is a database in which well-known suppliers are stored. If this is not the case, the risk of supplier needs to be determined through the material group matrix. When the negotiations with the supplier are approved, the prices will be fixed into a contract. Out of this contract, a purchase order will be created and processed.

1.6.6 Work Preparation

The work preparation is part of the business office, which is responsible for creating work packages for the people in the factory. The work preparation makes sure every employee gets the right instructions, drawings, etc..

2. Literature study: optimizing white collar business processes through lean management

This chapter is about the literature study that has been executed. This study will answer the research question:

> *Which methods for optimizing the white-collar processes within a company are available in literature?*

In this study, the focus is on lean management. First, the principle of lean management will be explained, in the second part, the focus is on value mapping.

2.1 Lean management

According to the book "Lean Thinking" (1996), lean management is based on five principles. These principles are described in the book. The five principles (Do, 2017) are;

Value - What the customer is willing to pay for

Lean focusses on what the customer finds value, and is therefore willing to pay. This not only holds for the price, but the producer should also take the wishes of the customer for the product into account.

Value stream - Identify the value stream

The second lean principle is identifying and mapping the value. In this phase, it is determined where the value is added to the product, and how much time is spent to add this value. Activities that do not add value to the end customer are considered waste. This waste can be split into non-value added but necessary and non-value & unnecessary.

Flow – Smooth flow of operations

After creating the value stream, it is important to make sure that the remaining steps run smoothly without interruptions or delays.

Pull - Only produce based on demand

According to Do (2017), the biggest type of waste is inventory. A pull system strives to minimize the amount of inventory and work in progress items while ensuring that the requisite material and information are available for a smooth workflow.

Perfection - Continuous improvement

The last step is the most important step of all. After achievement of the first four steps, it is very important to continuously improve the processes. When processes are continuously improved, perfection is strived.

2.1.1 Waste

The main focus of lean is waste (Slack et al., 2016). Waste can be identified in three causes of waste. *Muda*, *Mura and Muri* are Japanese words conveying three causes of waste that should be reduced or eliminated.

Muda - are activities in a process that are wasteful because they do not add value to the operation or the customer. Decreasing Muda can be done through the elimination of non-valuable processes.

There are eight types of waste (Theisens, 2018):

1. Over production

When over producing, a company is producing more than demand. This is an important factor for Muda, because it creates inventory. This inventory leads to storage costs and the inventory could become obsolete if the demand of the customer changes.

2. Waiting

Waiting is also considered as waste. With this we mean the waiting of a product and not of an employee. Waiting also includes waiting for information, idling or defect equipment.

3. Transport

Each time a product is transported from one process to another, it can be seen as waste. The transportation does not add value to the product, but it can be necessary to do. Next to that, during the transport it is possible that a product is damaged or lost.

4. Over-Processing

Over-processing happens when not useful adaptations are added and developed. These adaptations do not add value to the customer and the customer is also not willing to pay for these adaptations. For example, if making use of parts that are more complex or accurate and therefore more expensive than a customer needs. Over-processing also includes the unnecessary over engineering of products. Quality control is also seen as over-processing, only if it does not improve the needed products quality.

5. Inventory

Inventory is seen as waste, because it contains a surplus in raw materials, components, work-in-progress or warehouse. Inventory waste can be caused by poor purchasing or poor forecasting. It is therefore very important to not only focus on lean in production, but also on supporting activities.

6. Movement

With motion, not only the motion of materials, but also the motion of data files should be considered. Unnecessary file motions from one people to another is non-value adding and could be considered as waste. It is therefore very necessary to design the supporting activities in a logical and efficient way.

7. Defects

Defect products cannot be delivered to the customer and should therefore be repaired or replaced. Products that are not ‘first time right’ should therefore be considered as waste. If a product needs to be repaired or replaced, it costs time and resources to fix it. Another defect is that documents are not immediately clear to the user of the document. This can also be seen as waste.

8. Unused expertise

The last type of waste is not using available knowledge or expertise. For example, a young employee can learn from an experienced one. If this does not happen, this could be considered as waste. Another example is that the managers are not involved in the processes that play within the departments. In this case, the expertise of the manager is not used.

Mura

Mura has to do with unevenness, non-uniformity and irregularity (Do, 2017b). This means that the workload is unequally divided among the resources. Mura can be avoided by dividing the workload so, that there are as less fluctuations as possible in workload during the processes.

Muri

Muri has to do with the overburden of equipment or people. Overburden is the long-term usage of machines and employees above an acceptable level. Within the company, a lot of work is done by the lead engineer.

2.2 Business process mapping

To get an overview of the current processes within the company, a technique called “Business process mapping”or “Business process modelling” is used. “A business process model consists of a set of activity models and execution constraints between them” (Wekse, 2012). This means that a business process model contains the different activities that play a role within a process. The language we use to create these models is the Business Process Model and Notation, version two (BPMN 2.0).

2.2.1 BPMN

Business process modelling notation (BPMN) was developed under the coordination of the Object Management Group (Wekse, 2012). There are two sets of elements for modelling with BPMN. The basic BPMN set enables simple modeling figures, while the complete element set allows to make expressive impact. Aspects on the organizational side are represented in the BPMN by pools and swim lanes. Within the swim lanes there is some hierarchy within a given pool: lanes and arbitrarily nested sub-lanes. A lane represents an organizational entity such as a department, sub-lanes can be used to define an organizational entity within a department (Wekse, 2012). This is also used for the models of the processes within the company. Every department has its own lane within the diagram.

The elements of a business process diagram can be divided into four categories: Flow objects, Artefacts, Connecting objects and Swim lanes. These can be found in figure 3. The main elements of a business process map are the flow objects. These are the building blocks of the diagram. The flow objects include events, activities and gateways. Events can be described as anything relevant that happens (Wekse, 2012). Activities represent units of work performed during business processes. Gateways are used to represent the split and join behavior of the flow of control between activities, events and gateways (Wekse, 2012).

Artefacts show extra information about a business process that is not directly relevant for the flow of the process. Groups are, as the name says, used to group elements of a process. They just serve documentation purposes. An annotation is a document specific aspects of the business process in textual form. Data objects are represented by a name. Their purpose is to the documentation of the data used in the process (Wekse, 2012).

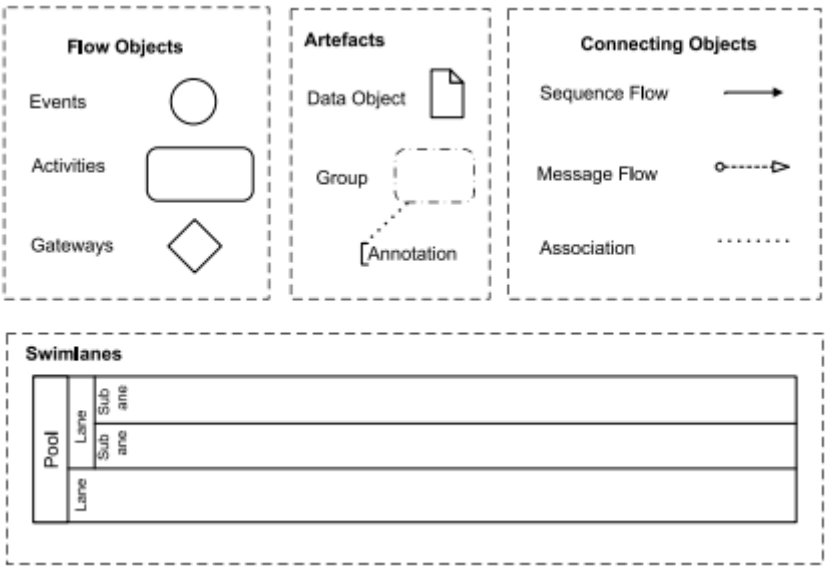

Figure 2: BPMN elements (Wekse, 2012)

The connecting objects connect flow all objects, swimlanes or artefacts. The sequence flow is used to specify the ordering flow objects. Message flow describes the flow of messages between the different pools. An association is a specific type of connecting object which is used to link artefacts to elements in bpm's (Wekse, 2012).

All these elements are used to create different Business Process Maps for both the current and the future processes that are going on within the company. These diagrams give an overview of each step in the process and can therefore be used to indicate which steps are useful and which steps are not.

2.3 Value mapping

In this section, the term value mapping will be elaborated, with focus on value mapping in product development departments. Value mapping during the product development stage has become increasingly important the past years (Hashmi et al., 2018). By mapping value, it is possible to identify value adding and non-value adding activities.

2.3.1 Value stream mapping

To improve the Product development (PD) processes, it is necessary to understand the PD system, especially PD information flow and the needs of the internal customer (Mayrl et al., 2013). VSM is a lean management method used to illustrate company processes in order to improve them, focusing on a value perspective. Value stream mapping consists of multiple steps (Mayrl et al., 2013):

1. **Goal**

   First, the goal of the improvement initiative has to be stated. This could be for example reducing the throughput times. It should be known what the scope is of the process, and so where the process starts and ends.

2. **Current state**

   When the goal is clear, the current state map can be created. In this map, the current state of the process is mapped. This can be done by observing the process from begin to end. The goal of this step it to understand how things currently operate. The whole process is walked-through from the beginning to end, usually in a kind of workshop (Gustavsson, Axelsson, 2010). The value stream map contains at least some values. These values are the inputs and

outputs, lead times (L/T) process times (P/T), number of involved people and completeness an accurateness (C&A) of the process (Mayrl et al., 2013).

There are different types of value stream maps. Two examples of a current state map are shown in figure 4 and 5. In figure 4, a kind of swim lane diagram is created, in which each step of the process is put in. In every step, the L/T, P/T and number of resources are shown. This diagram is used in a Product Development environment and is therefore called a Product Development Value Stream Map (PDVSM). In figure 5, a value stream map is created of a production process. In this map, the production planning control is put central in the diagram, with a strong relation to the production supervisor. From the production supervisor, there are several tasks, which together form the row below. For all these processes, the C/T and number of employees are stated. Together with the supplier and assembly unit, the value stream map is complete.

In this step, the processes that cause a problem or delay are indicated. In the next step, it is time to take a look at these problems and solve them.

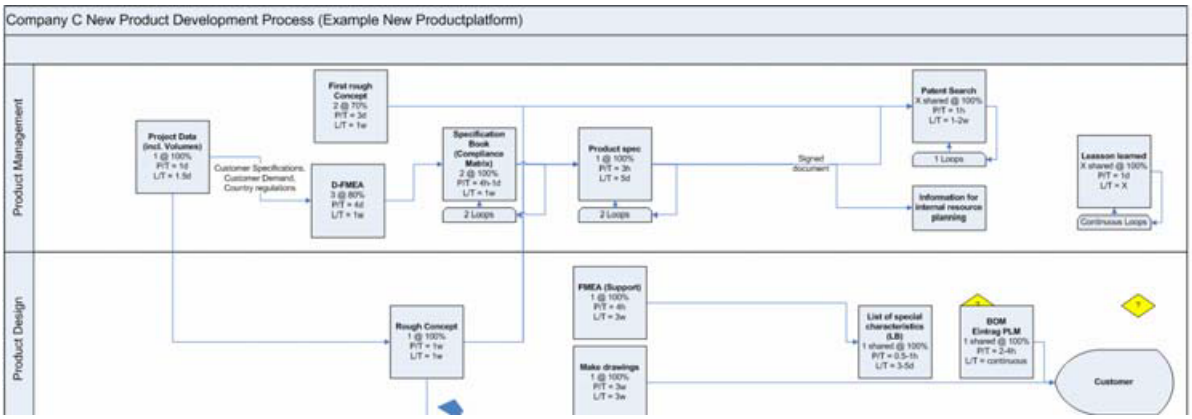

Figure 3: VSM example (Mayrl et al., 2013)

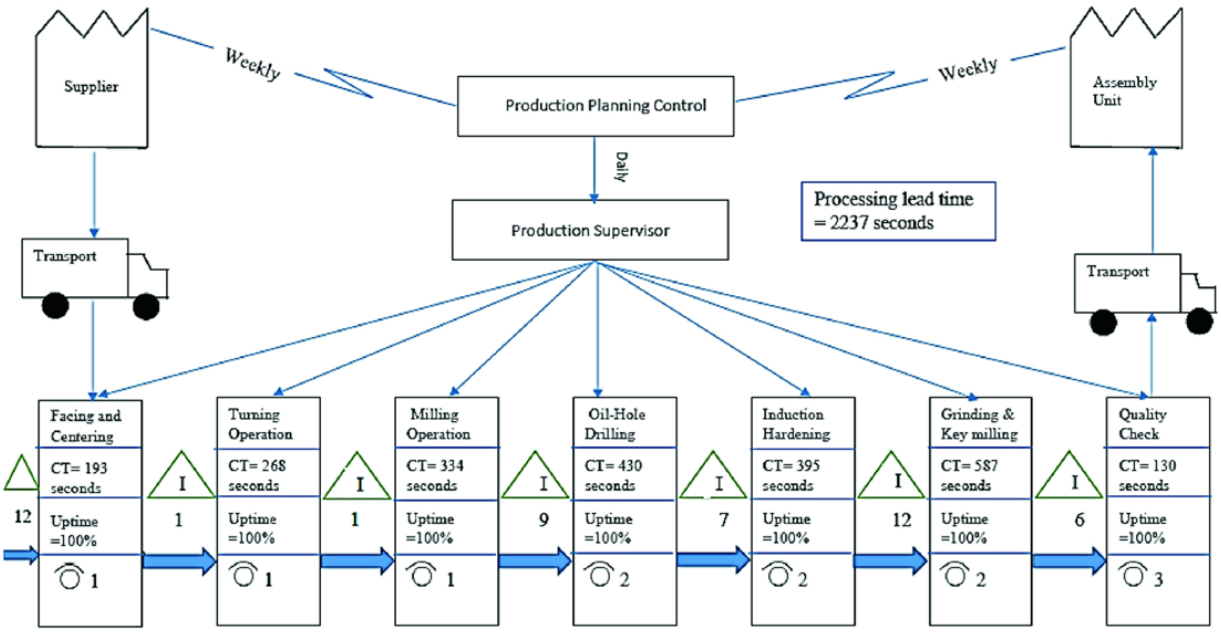

Figure 4: VSM Example (Deokar et al., 2019)

3. **Future state**

After the current state is mapped and the problems are indicated, it is time to think of solutions and the future state value stream map. The purpose of this step is to improve the process, I.e., to design a lean flow. This is done by analyzing the process with regards to the lean principles. There are a number of questions that can be asked to find those improvements:

- What does the customer really want?
- Which steps create value and which steps are waste?
- How can we design a flow of work with fewer interruptions?
- Are the interface description what the customer really wants or are some parts not necessary?
- Does the information need to be added to two different sources or would the database be enough?
- Can the task be done by the same person and thereby reduce the lead time?

By answering this set of questions, the value can be identified and waste can be eliminated. This has to be indicated in the value stream map.

2.4 Ways to improve a new business project

In literature, there are several ways to improve a business process for a new business project are described. One thing that the new business department is using is Scrum. Every day, they have a meeting during which they manage a scrum board. On this board, every employee has a row on the board, and there are three columns. One “To do” one “doing” and one “done”. Every day, they discuss what every team member did and what he or she is going to do this day. A picture of the scrum board can be found in figure 6.

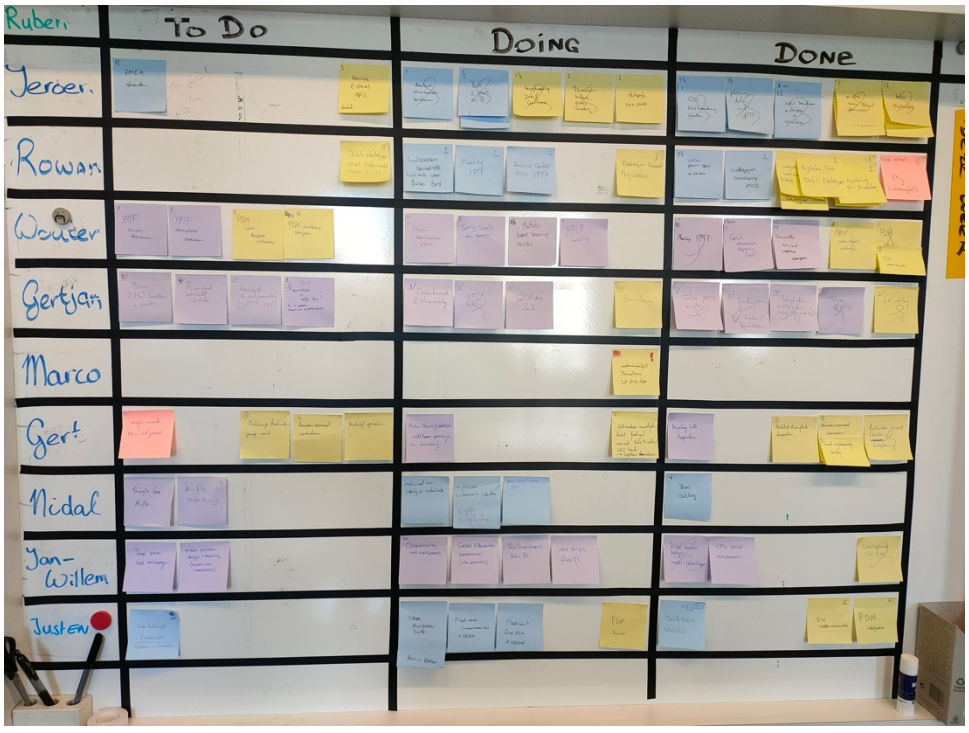

Figure 5: day to day scrum board

The company wants to investigate how they can cause scrum during their product development projects further, therefore we have taken a look at what literature says about using scrum in product development processes.

The scrum framework

Scrum was originally designed for the software industry, but it became increasingly attractive to use for the product development community (Sommer et al., 2015). According to *the scrum guide* (Schwaber and Sutherland, 2013), the scrum model consists of three stages: product backlog development, main sprint and daily sprints.

The product backlog should contain a list of requirements that the product should have. The product backlog should initially be set up with both external and internal stakeholders.The companyis currently busy with implementing scrum in their way of working. They are currently busy with other R&D projects for a hydrogen generator and a bigger BESS. For these projects, the lead engineers have made a planning which contains all requirements the product should have. This planning is functioning as product backlog.

Next, the product backlog is broken down into a number of *sprints* (Sommer et al., 2015). Each sprint forms a sprint backlog, which contains a set of priorities that need to be developed the current sprint. Within the company, they do this through a whiteboard that contains the tasks that need to be done the coming four weeks (figure 7).

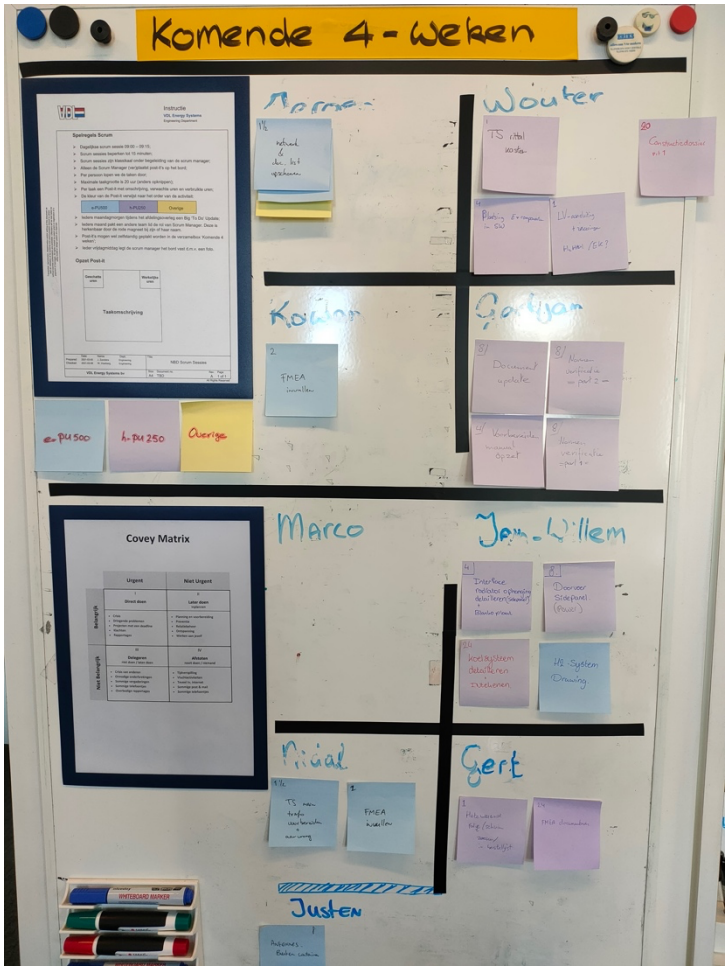

Figure 6: sub activities scrumboard

The activities required to produce the product are divided in small sub-tasks. These tasks do in principle not require more than two days to complete. The sub-activities are put on a scrum board (figure 14). Once every day, there is a short session with the whole team, called a daily sprint. During this meeting, every team member indicates what he or she has been doing since the last daily sprint, what he or she will be doing the before the coming meeting and he or she discusses problems that are encountered.

According to Sommer et al., 2015, the progress is monitored using a *burn down chart*; a two-dimensional graph with the sprint time period on the x-axis and the remaining sprint task ties on the y-axis. With this graph, the progress of the project can easily be made visible. When the number of finished tasks stocks, the graph will immediately become more flattened.The companyis not using this burn down chart, but this is something they could use in the future to make even more clear what they are doing.

All with all,The company is on the right way of creating more structure in their new business projects. From experiences with people in the new business team, the amount structure and clearance about what they are all doing and what should be done has increased a lot the past months. However, even more structure could be implemented by making the finished tasks visible by a burn down chart, for example.

3. Current system analysis

In this chapter, the current situation will be explained. This will be done by answering the first research question of the research:

"How does the current development process of the product look like?"

The answer to this question can be found by observing, measuring and analyzing the process (section 2.1), with this information we can create a business process map (section 2.2) and a value stream map (section 2.3).

3.1 Business process model

To get an indication of the current processes, a business process model (BPM). A BPM consists of a set of activity models and execution constraints between them (Weske, 2012, p.15). This model should give an overview of the current way of working at the different departments of the company, when developing the product. The goal of this section is to give an overview of the processes within the different department, with a special focus on the communication between departments.

3.1.1 BPM current situation

In order to get an overview of the current way of working within the involved departments of The company, a BPM is made of the current situation. In which they have developed the first three *The product*'s. This model has been discussed and validated with the involved parties through interviews with the involved parties of the model. The BPM (**Error! Reference source not found.**) is based on planned models that are created in an earlier stage by every department at the company. During the interview, the Planned model is compared with practice during the development of the Battery Energy Storage System (BESS). The BPM in figure 3 shows the different department of the so called "white-collar" part of the company. In this model, the swim lane principle is used (Swim Lane Diagram - Learn Everything About Swim Lane Diagrams, n.d.). This means that every department of The company has its own "swim lane". The communication of data and documents between these departments is also indicated in the diagram.

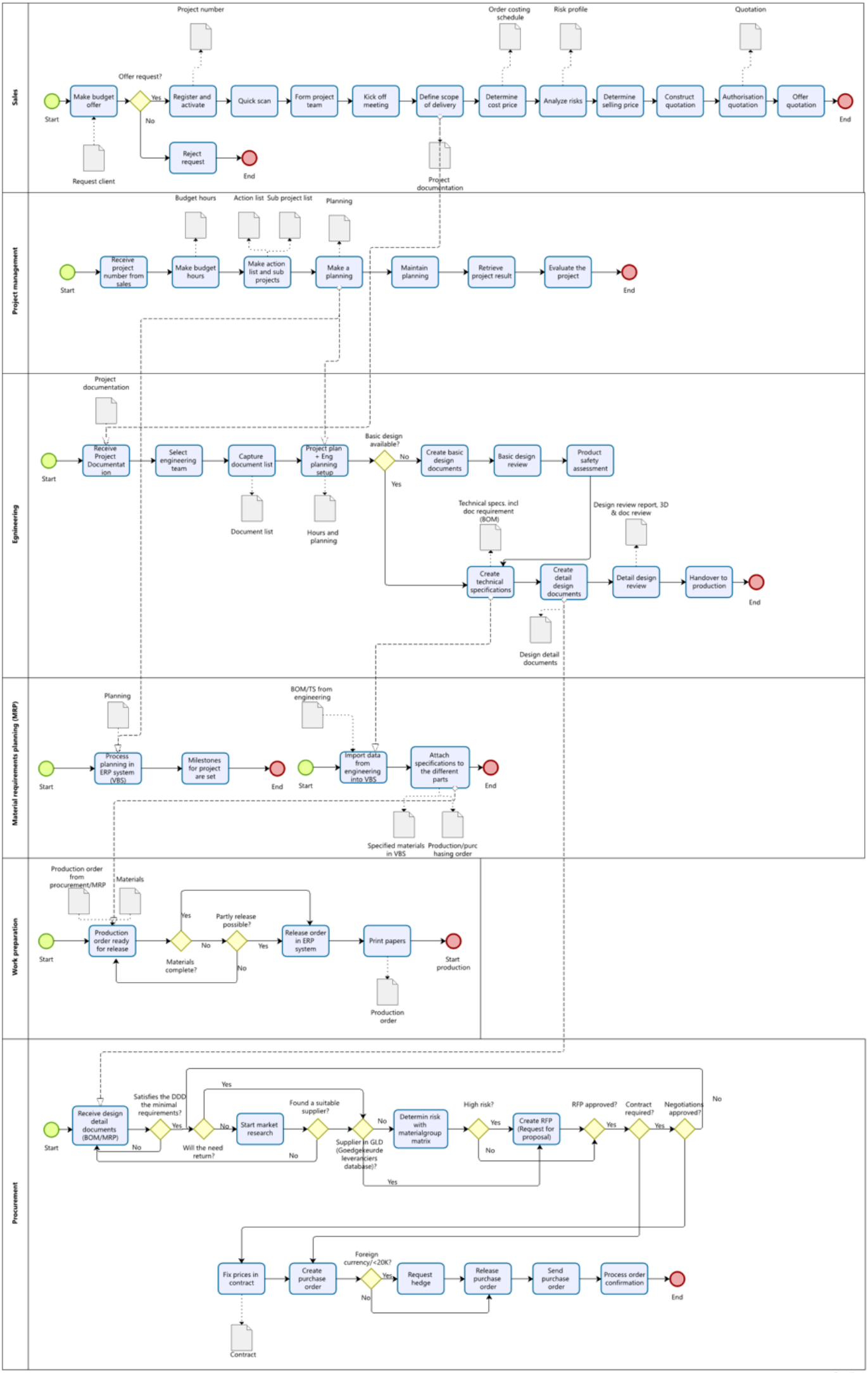
Sales
Project number
Order costing schedule
Risk profile
Quotation
Offer request?
Make budget offer
Yes
No
Register and activate
Quick scan
Form project team
Kick off meeting
Define scope of delivery
Determine cost price
Analyze risks
Determine selling price
Construct quotation
Authorisation quotation
Offer quotation
Start
End
Request client
Reject request
End
Project documentation
Project management
Budget hours
Action list
Sub project list
Planning
Receive project number from sales
Make budget hours
Make action list and sub projects
Make a planning
Maintain planning
Retrieve project result
Evaluate the project
Start
End
Egnineering
Project documentation
Receive Project Documentation
Select engineering team
Capture document list
Project plan + Eng planning setup
Basic design available?
No
Yes
Create basic design documents
Basic design review
Product safety assessment
Start
Document list
Hours and planning
Technical specs. incl doc requirement (BOM)
Design review report, 3D & doc review
Create technical specifications
Create detail design documents
Detail design review
Handover to production
End
Design detail documents
Material requirements planning (MRP)
Planning
BOM/TS from engineering
Process planning in ERP system (VBS)
Milestones for project are set
End
Start
Import data from engineering into VBS
Attach specifications to the different parts
End
Start
Specified materials in VBS
Production/purchasing order
Work preparation
Production order from procurement/MRP
Materials
Production order ready for release
Yes
Materials complete?
No
Partly release possible?
Yes
No
Release order in ERP system
Print papers
Start production
Start
Production order
Procurement
Receive design detail documents (BOM/MRP)
Satisfies the DDD the minimal requirements?
Yes
No
Start
Will the need return?
Yes
No
Start market research
Found a suitable supplier?
No
Yes
Supplier in GLD (Goedgekeurde leveranciers database)?
No
Yes
Determin risk with materialgroup matrix
High risk?
Yes
No
Create RFP (Request for proposal)
RFP approved?
Yes
Contract required?
Yes
Negotiations approved?
No
Fix prices in contract
Create purchase order
Foreign currency/ <20K?
Yes
No
Request hedge
Release purchase order
Send purchase order
Process order confirmation
End
Contract

Figure 7: BPM

In the sections below, a comparison between the theoretical and the actual process is made for each department. First the planned model is described, after that, the changes in practice will be discussed. These changes will be clarified with the figures. If a certain aspect is indicated with red, it is removed, if it is green, it is added.

Sales/project management

The current situation for the sales and project management is that these departments did not play a role in the first project that was executed. The new business manager of the company took care of the sales, and the lead engineer was also the project manager. Therefore, it is unclear what actions are taken by who and to make a process map of it.

MRP

The processes for the new business for the MRP department consist actually out of two relatively simple sub-processes. The first process is about setting milestones for the project. A milestone is set when a certain material is available to use in practice. This was hardly done at the product project because they simply did not know what the milestones were going to be. Therefore, this process is removed. Besides that, the specified materials in VBS (the ERP system) is not the only output of the department. They also create production and purchase orders. The planned and practical process can be found in Figure 8 and Figure 9, respectively.

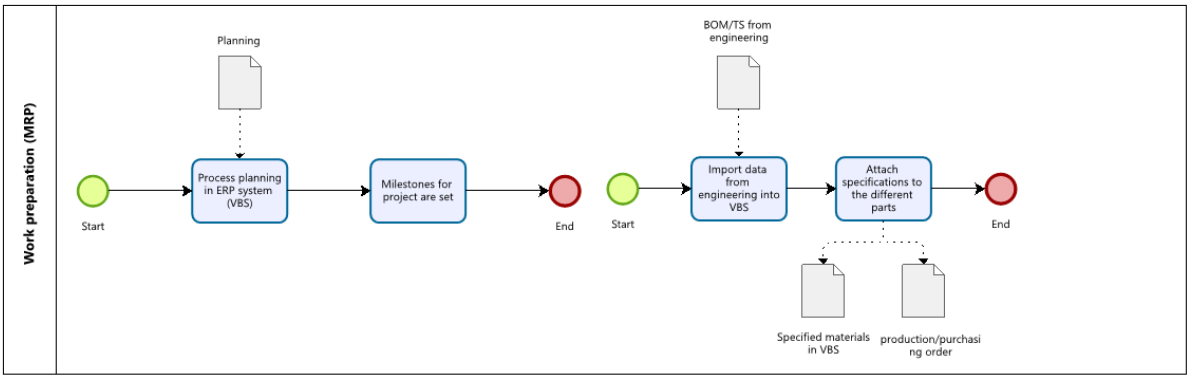

Figure 8: MRP planned

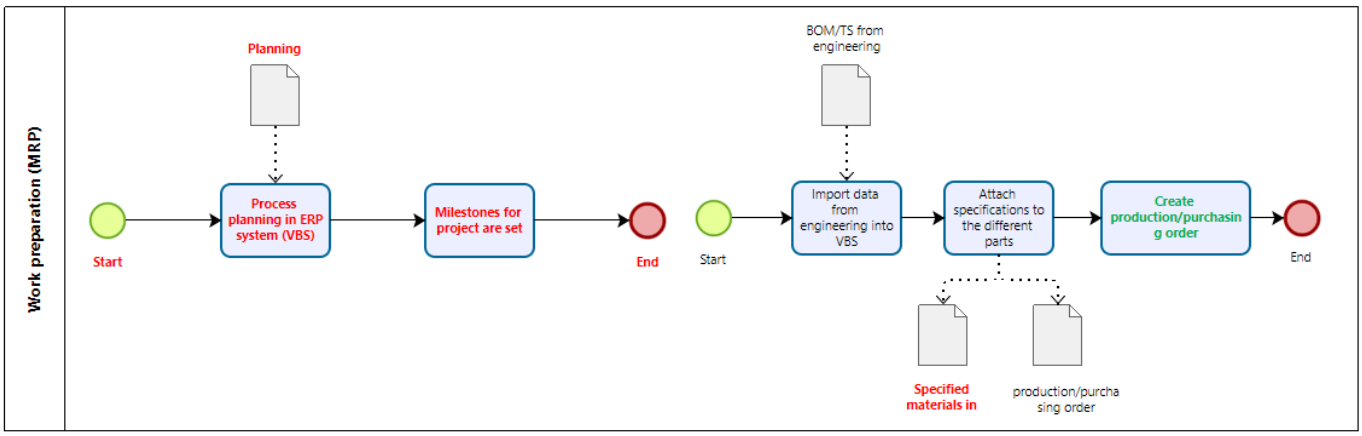

Figure 9: MRP in practice

Engineering

The process of the engineering is a much more complicated process. The process starts at the receival of the project documentation. When this is received, by a lead engineer, an engineering team is selected and a documents list should be made. After some other steps, a choice has to be made based on whether there is a basic design available or not. If there is not, a basic design has to be created and this design needs to be reviewed. After that, the product safety assessment should be executed.

With all these steps, the technical specifications and detailed design documents can be made. Out of these steps, the Bill of Materials (BOM) or technical specification (TS) is created. These documents are reviewed during the detailed design review, which often is combined with a Failure Mode and Effects Analysis (FMEA). When all documents are approved, the process can be handed over to the production department.

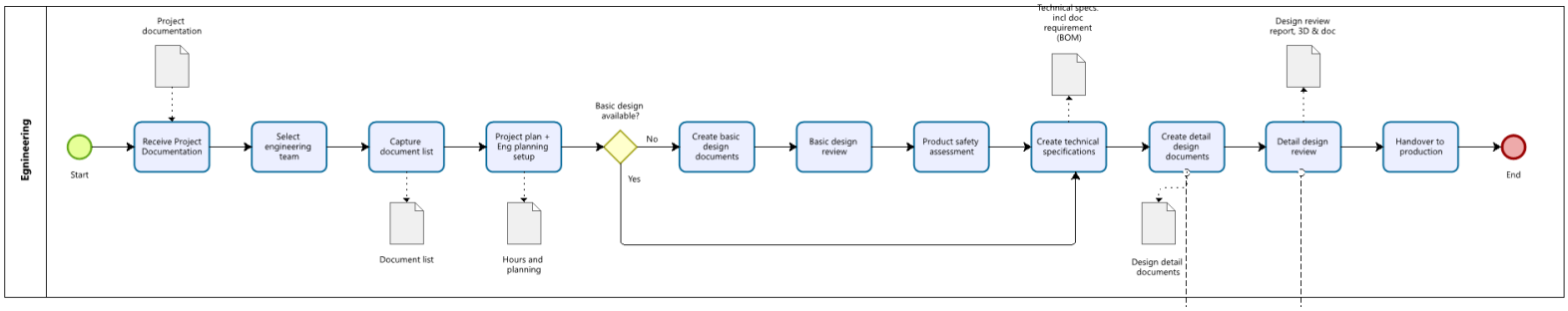

Figure 10: Engineering planned

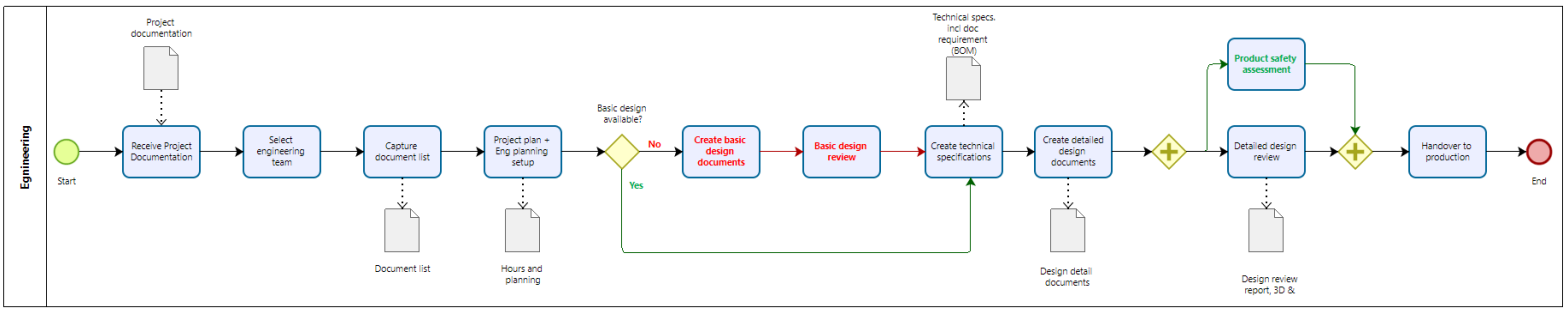

Figure 11: Engineering in practice

From the interview with the engineering representative, it became clear that this process was not exactly how the process in practice has been applied. There was already a basic design available,The companyreceived these documents through the partner they are working with. Therefore, the steps where the basis design is created and reviewed can be skipped. The product safety assessment is done in the same session as the detailed design review. The planned and practical process can be seen in Figure 11 and Figure 12.

Procurement

The procurement department is the department that is responsible for finding the right suppliers for the different parts. Their planned process consists of a series of choices and, depending on those choices they have to take certain actions. Their process starts with the receival of the detailed design document or BOM. Depending on the choices that are made for the requirements of the DDD and whether the need will return, the market research will start. During this phase, the buyers are going to search for suitable suppliers at the market. This is a very exploratory process which takes a lot of

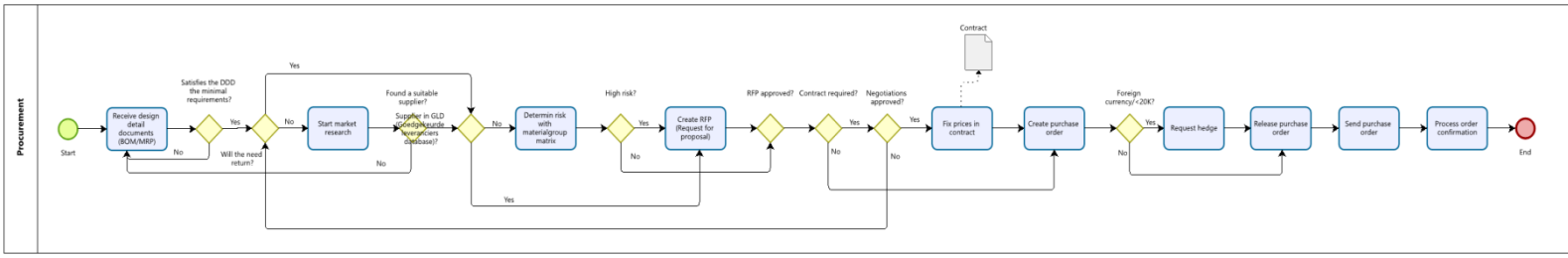

Figure 12: Procurement planned/in practice

time. When a suitable supplier is found, it is checked whether the supplier is stored in the approved supplier database. When this is not the case, the risk of the supplier is determined with help of the material group matrix. If everything is okay, a request for proposal is requested and when a contract is required, this contract in which the prices are fixed is made. From this contract a purchase order is created.

From the interview with the procurement representative, it became clear that this process is followed quite accurately. Nevertheless, this process was designed for the procurement of high value parts, from which a lot of profit could be obtained. But for the development of the relatively lower value parts of the product. This, in combination with the fact that this process takes a lot of time, makes that the procurement process is not efficient.

Work preparation

The planned model for the work preparation can be found in figure 9. The process starts with input as production order and incoming materials. The production order is ready for release. The work preparation department checks whether all materials for the production order are complete. If this is the case, the order is released in the ERP system of the company. If this is not the case, the work preparation department checks whether the order can partly be released. If this is the case, the order is partly released. If this is not the case, they have to wait until one of the two checks is positive. When the order is released, the papers that are needed for production are printed, and the production can be started. The output of the process is the production order.

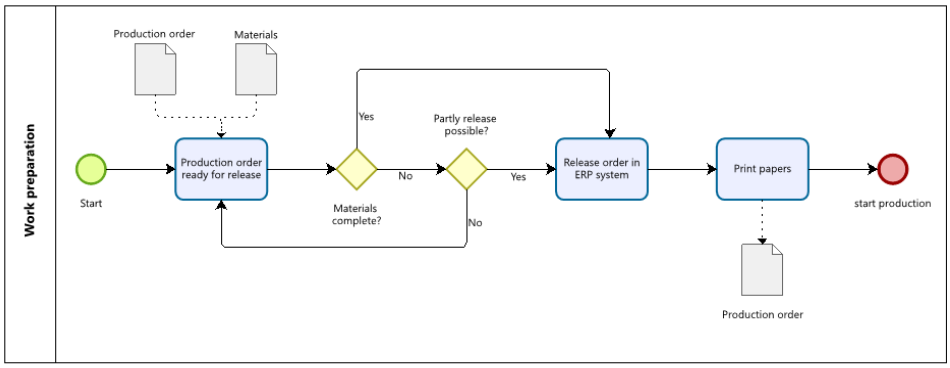

Figure 13: Work preparation planned/in practice

From the interview with the work preparation, it became clear that their role during the first project was very small. The lead engineer took care of the work preparation and prepared all documents by himself. The only thing the work preparation did was the release in the ERP system. The process can be found in Figure 13.

3.3 Value stream map

In this section, the value map that is created is presented and discussed. In the value stream map, the process is visualized in a higher level of detail and the process time and lead times are also indicated. The goal of this section is that the process per department is visualized in detail, and that the steps in the process that take a lot of time can be identified. With the value stream map, it becomes visible where the bottlenecks are in the whole development process at the departments that is taken a look at.

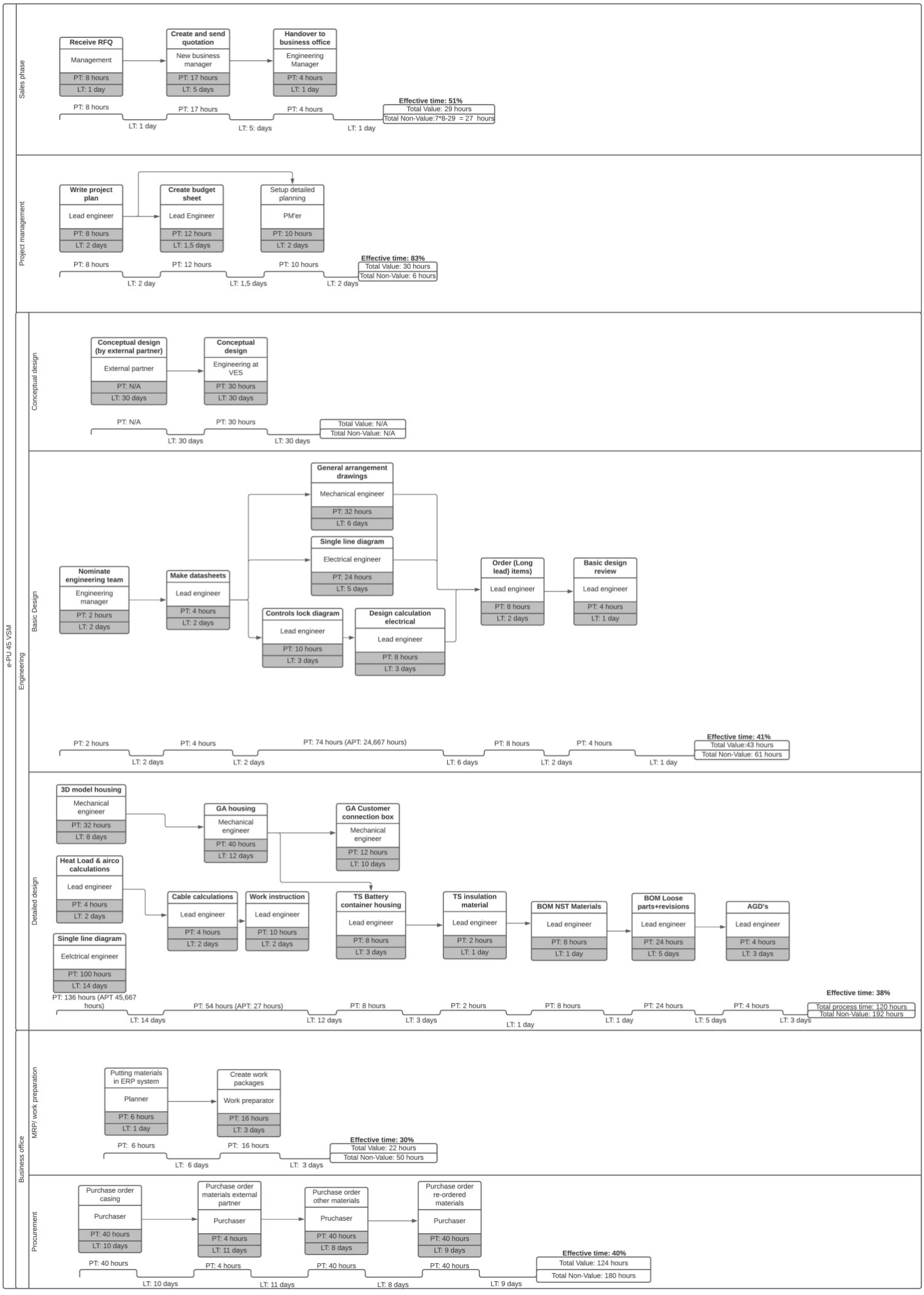

Figure 14: VSM The product process

The value stream (Figure 15) is built up of swim lanes of the different departments. For the engineering and production control departments, the lane is once again split up in different swim lanes. This because the tasks of these departments are divided into different sub-tasks. For the engineering department these are the conceptual design, basic design and detailed design. The production control can be divided into the Material Requirements Planning (MRP) and Procurement. The VSM is based on the planning that was made for this project. In this planning, every sub task is described for each department. Out of this data the VSM has been created.

Sales

The development and production process starts at the sales phase. The management ofThe companyreceived a request for quotation from a customer. This request was sent to the new business manager, who created and sent a quotation to the customer. This means that the new business manager was also busy with other things while he wrote the quotation. After the quotation is received back and approved, the order will be sent to the business office. The total value adding time for this process is 30 hours, which was in total divided over 4,5 days, or 36 hours.

Project management

The second lane is the one of the project management. In theory, this is a separate department, but in practice for this project the project management was done by the lead engineer. This is something that should not happen in a future project. He wrote a project plan, a budget sheet, and a project manager created a detailed planning. Making the budget sheet cost 12 hours, divided over 1,5 days. So, he worked on this the whole time. And therefore, the efficiency was 100%. The total time spent on creating value for project management took 30 hours, and during this process, there were 6 hours of non-value adding time.

Engineering

Next is the engineering department. The process at the engineering department consists of three phases. The conceptual design, basic design and detailed design phase. The conceptual design was for the biggest part executed by an external partner. The company bought this design and developed it further to build the battery energy storage system (BESS). The further development of the conceptual design cost 30 hours and was divided over 30 days. The total value of the conceptual design cannot be calculated, because it is unknown how much time the external partner spent on the conceptual design.

The basic design starts with nominating the engineering team by the engineering manager. After the team is set up, the lead engineer is making datasheets. Now, the process is split up among the engineering team. The first task is for the mechanical engineer, which will make the general arrangements drawings. Parallel to that, the electrical engineer is designing a single line diagram. This diagram contains the whole electric scheme of the product. He has finished this job after 5 days and has worked 24 hours on it. The lead engineer is during this time working on two tasks, the controls lock diagram and the design calculations for the electrical components. For the controls lock diagram, he needed 10 hours, divided over 3 days and the design calculations for the electrical components took 8 hours, divided over 3 days. When all these processes are completed, the lead engineer can order mostly long lead items. This took 8 hours and took place in 2 days. Finally, the basic design was reviewed by the lead engineer. This took 4 hours and was finished in one day. The total number of hours where value was created in the basic design is 42,667 hours per person. The total time the basic design cost was 13 days, which is equal to 104 hours.

The detailed design starts after the basic design and is divided among three people. The mechanical engineer is going to work on the 3D model of the housing. This took 32 hours to make and was finished after 8 days. At the same time, the lead engineer was busy with the calculations for the heat load and air conditioning after this this took 4 hours, divided over two days. The last parallel task was executed by the electrical engineer. He made a single line diagram, which took him 100 hours, divided over 14 days. This task was very time consuming and caused a bottleneck in the process.

After the single line diagram was finished, the lead engineer has made cable calculations and the mechanical engineer made the general arrangement (GA) for the housing. This took 4 hours and 40 hours, and was finished in 2 and 12 days, respectively. The mechanical engineer continued with the GA of the customer connection box. This took him 12 hours and was finished within 10 days. The lead engineer continued with the work instruction for the factory. This task took 10 hours and was divided over 2 days. The lead engineer continued with some technical specifications (TS). One for the battery container housing and one for the insulation material. These took 8 and 2 hours and were finished after 3 and 1 day, respectively. The last part of the detailed design consists of two BOM's, which were made by the lead engineer. The first one took 8 hours and was finished in one day, the other one was bigger and took 24 hours, divided over 5 days. The final step of the detailed design was making the AGD's. This task took 4 hours and was finished in 3 days.

All with all, the process time for the basic design took 118 hours. The total time during which the engineers were working on the detailed design was 39 days, or 312 hours.

Business office

The next department is the business office, which is divided into two parts: the MRP/work preparation and the procurement. The MRP/work preparation department is responsible for putting the BOM's they receive from the engineering department into the ERP system. For the *e*-PU 45, the MRP part took 6 hours and was finished within one day. The work preparator has to create work packages for the people in the factory. This task takes 16 hours and was divided over three days. All with all, the total time spent on this project by the MRP/work preparation was 22 hours, divided over nine days, which is equal to 72 hours.

The purchasing department took care of multiple purchasing orders. Three of them took 40 hours, divided over ten, eight and nine days. This includes finding the right supplier and making a contract. The purchase order for the materials of the design of the external partner was a lot less time consuming, this task took 4 hours, but was divided over eleven days.

3.4 Conclusion

From this chapter, we can conclude that the process of developing the product took a lot of time. The efficiency is about 40%, which is relatively low. From literature, it can be stated that the efficiency of a product development project should be around 60%. The efficiency is calculated by the time spent on the project of *The product*, divided by the time it took before the task was finished and a new task can start. A lot of time gets lost by the communication between departments. When an employee of a certain department has a question to a colleague of another department, he or she has most of the times to wait more than a couple of days. This is mainly because the process and way of working is not clear for everyone and therefore there is no structure on how communication between departments should go.

When the company wants to produce the product on a larger scale, the efficiency number should increase, because the process time of the whole process should be as short as possible.

4. Standardization of the product

In this chapter, we dove into the solutions and answers to the research questions

"How should the development process of the product be standardized?"

and

"How can the current process be optimized?"

In section 4.1, we will discuss the process of developing the product when it will be a standardized process. With this standardization, developing the product will be suitable for serial production, so production in larger numbers. In section 4.2, we will discuss the road towards this standardization. Because it is a complex change in way of working, it is important that the transition from a prototype to standardized production goes smoothly and that it is a well taught process. This will be discussed in this section.

4.1 Standardized process of *The product*

In this section, we will discuss how the standardized process of the development of the product will look like. To create this BPM, several interviews and feedback sessions are conducted to get this map as realistic as possible.

The company recently built three *The product*'s. The design process of these products took a lot of time, because it was the first time they built an The product and it was therefore very unclear how the company had to design and build those products. The goal of the company is that they move towards a serial production of the product, where there are almost no adaptations to the design of the product and that they can produce the products very efficiently. To be efficient, it is necessary that a lot of time will be saved at the engineering department, and that the engineering department is only needed when the customer has special wishes for design of the product.

To formulate a goal for the future process, we have made a business process map of the standardized situation as it should be in the future. In this map, we can see that some departments only act when certain requirements are met. This has to do with the special wishes of the customer. In principle, the people at the sales department should offer the customer options to configure the product. The way of working should therefore change from an engineer-to-order to a configure-to-order basis. This means that the company offers a certain configuration for a sharp price and that there is almost no engineering involved in the development and production of the product. The business process map can be found in Figure 16.

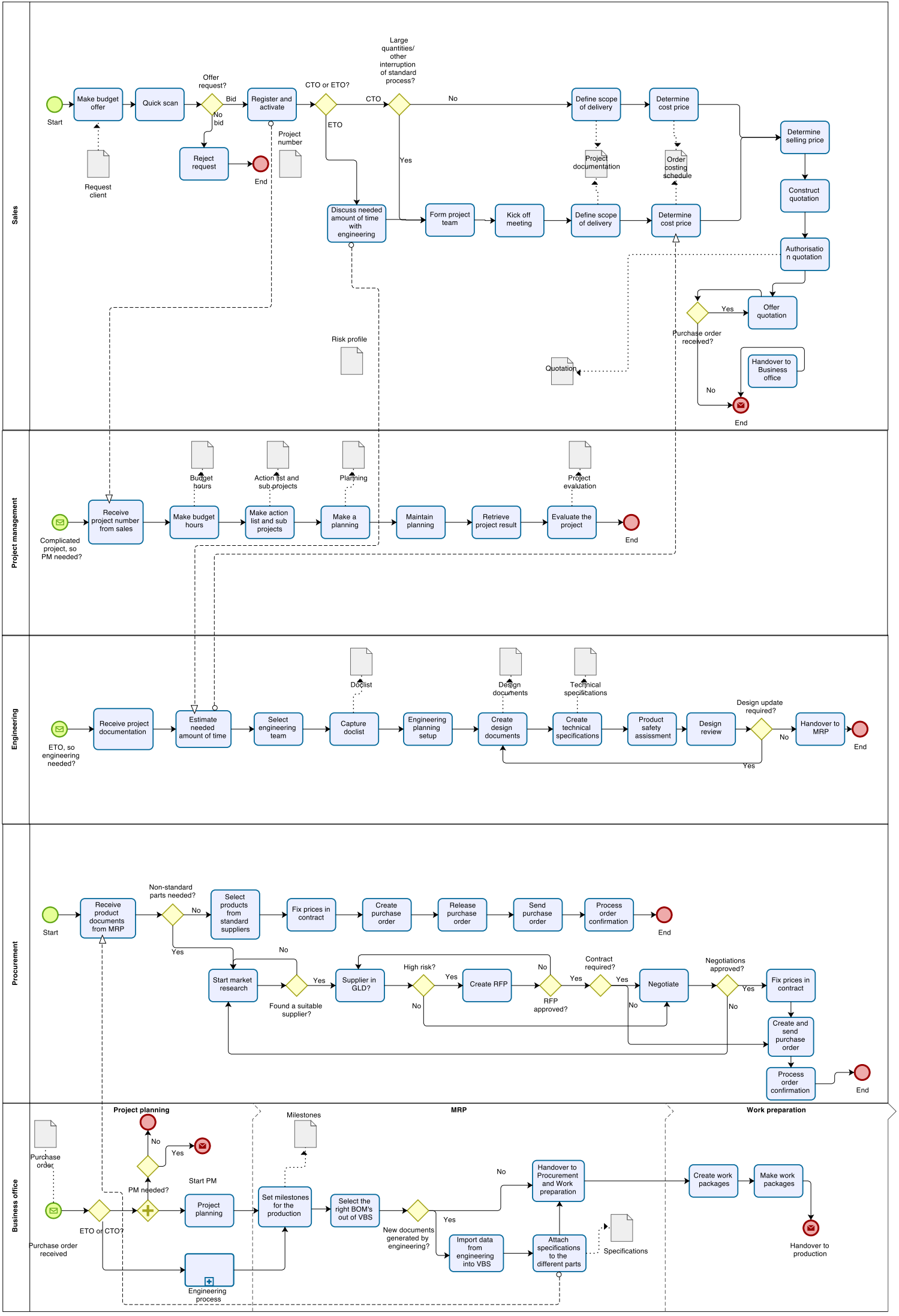

Figure 15: BPM future situation

4.1.1 BPM

In figure 16, we can see that this process is less complicated than the process as it is right now. This figure does contain the steps when a customer has special wishes. To make clearer how simple the process becomes on the 'white collar' side when a customer only orders a configurable option, this process is shown separately in figure 17. In this figure, we can see that the processes within all departments are a lot shorter, because when the standards that are set up are used, the communication between departments is much simpler and less people are involved in the process. Besides that, the business office and project management are not involved in the process anymore. This is because the sales department took over the project management and when the order is completely CTO, the business office is not needed anymore through the fact that the work packages are already known for the people in the factory. Less parties involved means that less time is spent on communication and discussion issues and therefore the process will take less time. How much time exactly will be discussed later this section. Besides that, the number of steps that needs to be taken has decreased by half.

We can see that this process is even more simple than the process where the customer has special wishes. Also, the project management and engineering department are not involved in the process at all. A bigger role lies at the sales department, which offer the configuration options to the customer and are responsible for the communication with the business office. This is direct communication, with no other department involved.

To give the reader an overview of the changes compared to the current process (figure 3), we have made a bullet list which provides all changes made in comparison to the current process. In this list, hours that will be spend are stated. These numbers are based on experiences of the previous project, given by the representatives of the different departments. The list is shown below:

Sales

- At the current process (figure 3), the role of the sales department is very small. The new business manager sold the product to the customer and finished all sales related jobs by himself. In the proposed process (figure 16), sales is going to sell the product on a Configure-To-Order (CTO) basis to the customer. The sales representative goes to the customer and the customer chooses the options he or she prefers. This is not visible in Figure 16, because it differs for every project how this exactly will look like.
- The sales representative makes a budget offer and checks whether the order is correct. He makes a project number and dependent on the wishes of the client, the sales goes through different processes. When the order is completely CTO, the process will continue with defining the scope, delivery and cost price. After that the process is handed over to the business office. If it is a process that is not completely CTO, so when the customer requires specific elements/parts that need to be engineered, it is checked whether it is needed to form a project team or involve engineering and project management in the project. This will cause the process to slow down a lot, 16 to 40 hours, dependent on the wishes of the customer. We advise the company to strive to have as low ETO orders as possible, because this causes extra costs.
- The process differs with the current process in the fact that there now is a process through which the sales representatives can work. This was not the case for the current process and the sales were totally done by the new business manager. With this new process, the sales representative becomes an important person in the process.
- The sales department will for most projects be responsible for the project management too. A project sales manager can maintain communication between departments when a CTO type of order is ordered. When this type of order is the case, it is more beneficial to have a sales project manager instead of selecting project management department.

- All the changes and adaptations described above will result in a process that will on average take 16 hours. And so the number of hours for the sales will decrease form 30 to 16.

Project management

- During the past project, the project management was all done by the lead engineer (figure 3). The past project was the first time the company has made the product and therefore the engineering department was very important and had a big role. It is therefore logical that the lead engineer was also the project manager of the project. However, at projects following the proposed process, the engineering department should have a small or even no role in the process. The project management should therefore be done by another department.
- From an interview with the head of project management, it became clear that the project management department will be hardly involved in a project where only an *The product* is involved. These products will be standardized in such a way that the work that belongs to the project management is divided over other departments.
- Only when a project is really complicated, project management (PM) is involved. Otherwise, the project will be managed by the sales department. This means when a customer orders only *The product* products, sales will be responsible for the project management, but when a customer also orders a *e*-PU500 and an electrolyzer, for example, PM will be involved in the project. It is yet unknown how often projects of this scope will take place, because The company is still in the development phase for other products than the product. For the first project, the total time spent on project management was 30 hours (figure 15). When PM is no longer needed, it will therefore save this amount of hours for the project management. It should be noted that a part of these hours will be executed by other departments, particularly sales. However, it will still result in a reduction of hours (Table 2), because the number of communication lines and needed meetings will reduce because less people are involved.
- If a project is complicated in such a way that PM is needed (as described above), the main task of project management is making and maintaining the planning and keep an overview of all the tasks that are and need to be done. Besides that, the project management is responsible for the project result and that this result will be evaluated.
- The average hours spent by the project management department will be approximately 4 hours. This is a decrease from 30 to 4 hours.

Engineering

- The first project, the engineering department plays an important role. As said earlier, this was because it was the first project The company had for this product, and therefore a lot had to be engineered. In total, the number of hours spent by engineering has gone over 400, which is way too high for serial production. For future projects, dependent on the type of project, engineering is not or rarely needed for the product.
- In the proposed situation, engineering is only needed if the project for the product is engineer to order (ETO). This means that the customer has specific wishes for the product, outside the standard options that are offered in the first place. These wishes need to be processed and probably the design needs to be adapted. This will start the engineering process, as can be seen in figure 16. The wish of the customer depends how far the product needs to be redesigned. The costs for these extra hours can passed on to the customer, so that he or she has to pay for it.

Procurement

- The procurement department had to put a lot of effort during the first project in finding the right suppliers with the right lead times. All with all, this took them the large number of 124 hours. With a standardized process and standard suppliers, this number will reduce a lot, to 16

hours. This number is based on estimations and experiences of the representatives of the procurement department, and are checked and verified by the procurement manager. However, this number is not based on hard data and therefore not 100% reliable.

- When there is an order with special wishes from the customer or an order that contains products that are not standard available, the procurement department should find a suitable supplier to receive the product.

Business office

- In the current process, the business office is not explicitly mentioned in the process, because the processes that normally take place within the business office took so much time that it was not beneficial to put them on one lane. In the future process, the business office will consist out of three sub processes/departments. The project planning, material requirements planning (MRP) and work preparation. These sub processes all contain a little amount of steps and are all executed by the employees at the business office.
- The business office is in principle responsible for the internal planning, MRP and work preparation of the project. Dependent on whether project management is needed, the process starts with the planning. After that, the MRP is going to select the right BOM's out of the ERP system and, if there are any documents generated by the engineering department, these documents need to be processed in the ERP system. Finally, work preparation creates work packages and distributes them to the production stage.

Now that we have compared the old with the future situation, it is time to investigate how much time will be saved in the future, compared to the old situation. To give an overview, a table (table 2) is made which shows the times it took per department that is involved in the old and new situation.

Table 2: Difference in hours between old and new situation

Department	Spent hours old situation (hrs.)	Spent hours future situation (hrs.)	Difference (hrs.)
Sales	30	16	-14
Project management	32	4	-28
Engineering	400*	16	-384
Procurement	124*	16	-108
MRP	25	4	-21
Work preparation	16	4	-8
Total	**627**	**60**	**-567**

*Because it was the first project and therefore a prototype, these hours are logically extremely high compared to a future project

In Table 2, we can see that the number of hours spent per department is decreasing significantly. The numbers stated in this table are all based on the interviews conducted, and are further explained in the bullet list at the beginning of this section. This decrease will ultimately result in a decrease of costs needed to develop and produce the product.

4.1.2: VSM

If the company has implemented standard processes in their organization, the efficiency of the process will increase. In this section, we will explain what changes and how the efficiency will increase.

When an order is a CTO order and no PM is involved, the process for the "white-collar" part of the organization will look like it is shown in Figure 17. In this figure we can see that only the Sales, Procurement and Business office are involved. This figure is based on the BPM that is shown in Figure 16 and on the interviews conducted with the representatives of the different departments.

In the VSM we can see that the efficiencies that was calculated by the process time divided by the lead time has increased a lot in comparison to the VSM of the current situation (Figure 15). The efficiency in figure 15 was 40%, while the efficiency of Figure 16 is 80% on average. The efficiency will therefore double when using standardized processes.

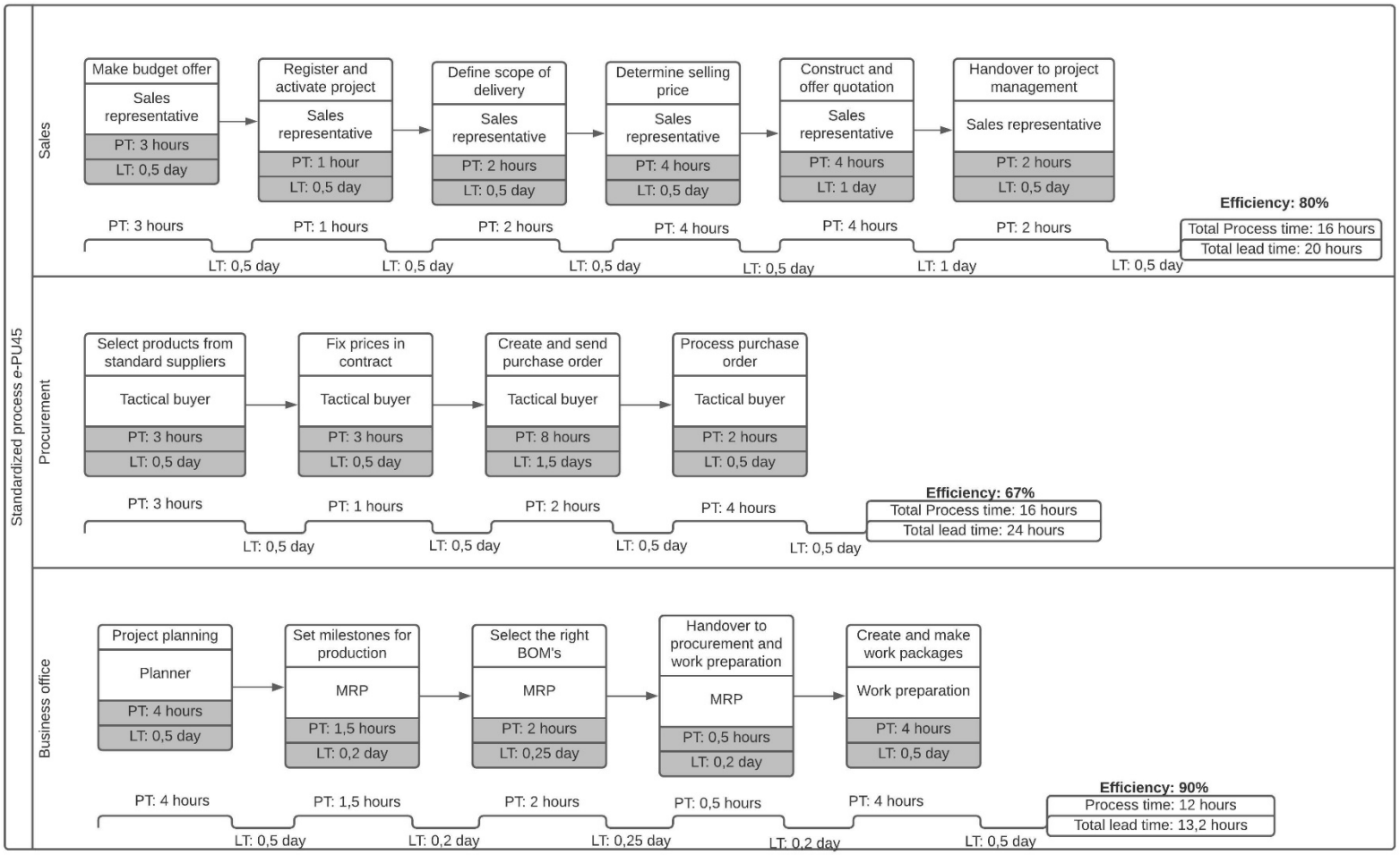

Figure 16: VSM CTO process

4.2 Towards standardization: development process

4.2.1 From ETO to CTO

Nowadays, The company is an engineer-to-order company. This means that they have a lot of engineering work for every customer and every order a customer places at the company. Usually, the projects they have are about gas turbines and compressors. The prices for these products are way higher as for the product. The price of one order of a gas turbine or compressor is therefore about a tenfold of the order price of an *The product* order, on average. It is therefore possible to have a lot of specialized engineering work for an order. For the product, this is not the case. The company should find a way to offer the product for the sharpest price possible. However, the customer should be able to choose out of certain options to configure the products to its wishes. The process of handling these orders should therefore change from engineer-to-order to configure-to-order. Configure-to-order means that the company offers the customer a basic design, from which the customer can choose a couple options to add. These options are standard available and worked out within the organization of the company.

By applying the CTO principle, it becomes very easy to run the operation smoothly through the organization and production. With this it is possible to produce the product in larger numbers and for lower costs. However, The company should make a change in their way of working when they want to apply CTO to their products. We have therefore generated a development plan to come to a standardized process for the development and production of the product. This plan was generated by conducting interviews with the people that were involved in the past project on the product, and will be involved in the future projects.

4.2.2 Investments

For the engineering, MRP and procurement department, a real investment in hours needs to be made to come to a standardized process. With the representatives of these departments, a list of actions is set up with all action points that need to be taken for a standardized process. We will go through them for every department.

Engineering

The main job of engineering is to make the drawings and BOM's suitable for configure to order. To realize this, they need to make standardized drawings, BOM's and other documents that can be used by other departments, for example sales to show to the customer, but also procurement to show which parts need to be ordered. These drawings can be put in the ERP system, so that they can be easily accessible when they are needed. Besides that, engineering is needed to set up a configuration tool that sales and MRP can use to offer and sell a product. An example of a tool that can be used that was proposed during the interview was Tacton. This is a tool that is commonly used when companies want to offer a product through a configure-to-order environment (Hansen, 2021). Based on the experiences the company has with the design of Tacton, the design of this program will probably take 12 hours for an engineer.

If a product will be offered through CTO, there should also be a price matrix for the different options. Engineering is involved when this price matrix is set up. This will take them about 12 hours too.

Finally, the lead engineer has functioned as project manager during the first off project of the product. It will take him about 40 hours to distribute all his knowledge among the colleagues that will be involved in future projects. The numbers and hours it take for the engineering to transfer from ETO to CTO are provided in Table 3

Table 3: Investment for engineering

Activity	Hours	Costs
Std. Drawings (incl. options)	56	€ 4.816,00
Std. BOM's (incl. options	20	€ 1.720,00
Std. Documents (incl. options)	32	€ 2.752,00
Configuration tool for CTO	12	€ 1.032,00
Price matrix+ PM discussion	12	€ 1.032,00
Process supervision	40	€ 3.440,00
Total	**172**	**€ 14.792,00**

MRP

The MRP department should connect the drawings and BOM's to the right products that are needed. By doing this, it becomes very easy and smooth to see what materials are needed per order and also whether it is on stock or that it needs to be ordered. To do this, they have to create all material numbers, and connect the options that can be chosen through CTO in VBS (ERP system). In total, this will take them 56 hours. A list with activities for the MRP department with the connected costs is provided in Table 4.

In a future state, when the sales of the product are increased, the MRP should also think of what materials should be on stock and which products need to be ordered per project. For example, wirings can easily be purchased per roll, but batteries are more likely to be bought per order/project.

Table 4: Investment for MRP

Activity	Hours	Costs
Create material numbers	16	€ 1.440,00
Create options in VBS	40	€ 3.600,00
Total	**56**	**€ 5.040,00**

Procurement

For the standardization of the procurement department, they need to find standard suppliers, or a total supplier for all parts. If they have found these, it will become very easy to order the parts they need. Besides that, the company can make a special offer and reduce the price of the products when they have arrangements with the suppliers.

During the first project, the procurement department found several suppliers for the parts of the product. There was a lot of time pressure on this project. It could therefore be that the supplier the procurement found is not the optimal supplier to deliver the part that is needed. Procurement should therefore go through the suppliers they selected for the first project and check whether the found supplier was the optimal one.

Next to that, when all the configurations are set up, there will be new products for which there is no supplier found yet. Procurement should find a suitable supplier for the new products, this will take about 45 minutes per product. However, it is not known how many products will come out of the configuration options and therefore this number needs to be estimated. Together with engineering and MRP, this number is set on 12 parts and therefore it is estimated that the procurement department will be busy for 9 hours with this task. An overview of the needed hours and the connected costs can be found in Table 5.

Table 5: Investment for Procurement

Activity	Hours	Costs
Check whether suppliers are optimal	20	€ 1.460,00
Find and register new suppliers	24	€ 1.752,00
Find suppliers for new products	10	€ 730,00
Total	**54**	**€ 3.942,00**

The other departments do not need a significant investment to come to the standardized process. Sales, the business office and project management should follow the process as it is stated in Figure 16. For these departments the process looks mostly like the process they are used to follow and it depends on the type of project whether they are involved or not.

4.3 Conclusion

At the beginning of this chapter, two research questions were stated that will be answered this chapter. These questions are:

"How can the current process be optimized?"

and

"How should the development process of the product be standardized?"

The first question is answered in Section 4.1. The current process is optimized. This is done through interviews during which a look has been taken at the steps that are waste, and the steps that are necessary to produce the product. From these interviews we have created a BPM which shows the process as it will be in the future (figure 16). In comparison with the previous project, this new process should result in a reduction of 567 hours for the "white-collar" departments. With this should be noted that the previous project was the first project of the company where they produced the product. Therefore, the hours spent by the engineering and procurement departments were very high.

The second question was answered in Section 4.2. The development process of the product should be standardized through an standardization project during which the departments that need to set up standards are setting these up. This standardization project needs an investment in spent hours to realize the standards. For the engineering department this will be 172 hours, which equals €14.792,-. For the MRP department, this requires 56 hours, which equals €5040,-. And for the procurement department this requires 54 hours, which equals €3942,-. The total investment to standardize the process will therefore be €23.774,-.

4.4. Validation

In this section, we will discuss the validation of this research. We can divide validity into internal and external validation. Internal validity refers to the degree of confidence that the causal relationship being tested is trustworthy and not influenced by other factors or variables. External validity refers to the extent to which results from a study can be applied (generalized) to other situations, groups or events (Streefkerk, 2021).

4.4.1 External validation

For this research, it is hard to have a strong external validation. The research that has been executed is one for the specific products of The company. When we question whether this research can be applied to other situations, groups or events, this is hardly possible. The models that are made during this research are so specific, that it is hard to generalize them. Nevertheless, the conclusion that standardization of products, when scaling up production leads to lower costs is something that can be applied to many other cases.

4.4.2 Internal validation

The solutions that were generated in the previous sections are based on interviews conducted with the representatives of the involved departments. In the optimal situation, this process can be tested on the next project the company has for the product. Unfortunately, this is not the case during the time this research is conducted. Therefore, the generated solutions need to be validated in another way.

At the time the solutions were generated out of the interviews, we have visualized them in diagrams and tables. The diagrams and tables are checked by managers and other involved colleagues. This is done through a small questionnaire which is answered and things that eventually pop up out of these questions are discussed and at least one colleague from each “white-collar” department, so at sales, project management, engineering, procurement and the business office. The questionnaire used for these discussions can be found in Appendix A.

Besides this, the researchers have held an intermediate presentation for the lead engineers of the company. This group is chosen because these employees have a lot of experience and can give feedback on the things we want to change. The outcomes of this presentation were that the things brought up during this research were quite in line with the vision of the lead engineers, with some minor changes. They also brought up that ifThe companywants to scale up the production of the sustainable energy products, the culture within the company should also change, and asked if this could also be taken into account in this reseach, however, that is beyond the scope of this research and will therefore only be mentioned as recommendation.

The most important causal relationship that we make in this research is that standardization will lead to a reduction of costs. We have tried to make this relationship as trustworthy as possible, by validating the findings with the managers of the company. With this, we are trusting on the experiences and expertise of them. However, it was not possible to test the relationship in practice. This means that there could be other factors or variables that have an influence on the causal relationship made in this research.

5. Conclusions and recommendations

In this research, Business Process mapping has been used to provide an overview of the current process of developing and producing the product. Based on this current process, a new process setup has been created to increase the efficiency of the "white-collar" departments from 40% to 80%. Each chapter of this thesis has answered a sub-research question, derived from the main research question. This chapter will be about answering the research question:

What conclusions and recommendations can be drawn from conducting this research at The company?

Section 5.1 will provide the conclusions and in section 5.2 the recommendations for further research will be discussed.

5.1 Conclusions

In this section, the main conclusions of this research will be stated. After the chapters 2, 3 and 4, a temporary conclusion are already drawn. We will provide the main conclusions of this research in this section.

The main research question of this research is:

How can the difference between the budget and actual costs of the production and development of the product be minimized?

The answers to this question will be enumerated below.

1. The difference between the budgeted and actual costs of the production and development of the product can be minimized through standardization. By standardizing the process, it will become easier to predict the needed number of hours and therefore the difference between actual and budgeted costs can be minimized
2. To standardizeThe companyshould transfer from ETO to CTO projects. Through CTO, it is possible to work through standards that can be set up. This will make it possible to decrease the throughput time significantly and increase the efficiency of the process from 40% to 80%.
3. An investment is needed to set up the standards to work through CTO. Engineering, MRP and the Procurement departments have some work to design and setup the standards they need. This investment will be about €23.774,-.
4. The efficiency of the "White-collar" part of the company will increase from 40% to 80%. If we take the increase in efficiency into account, we can calculate the earn-back time of the investment for the standardization project. Per project, €3800,- will be saved for the Sales, MRP and procurement departments. The investment of €23.774,- will therefore earn itself back in 6 á 7 projects for the product.

5.2 Recommendations

In this section, recommendations for further research and developments atThe companywill be provided. These will be enumerated below.

1. This thesis is focused on the "white-collar" departments that are involved in the development and production of the product.The companyis also developing a larger BESS, the *e*-PU500. And an hydrogen generator, the *h*-PU250 .Parts of this research can also be implemented in the processes that play within the production and developments in these products too. It is recommended to take a look at this.
2. When the sales of the product increase, it will be beneficial to have more parts of the product on stock, instead of ordering them per order, as happens now for most parts. Especially the

MRP department should consider from which point on it will be more beneficial to have a part on stock instead of ordering per order. This should be done for every part.

3. To offer the product through CTO at the customer, the sales department should create a nice tool to show the options to the customer. During this research, it became clear that Tacton could be a suitable program to use for this. It is recommended that sales will investigate this program as option to use.
4. The company is trying to set up a new business part of the company. This research is conducted at the engineering department of the company. Within this department, a team is working on different new business projects. It is recommended to treat these departments more as Research and Development departments. as Engineering department.

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Appendix A: validation questionnaire

1. Which activities are needed in the standardized process?
2. Which activities are needed to come to that standardized process?
3. How many hours does it take to complete the standardized process in your opinion?
4. How many hours does it take to come to the standardized process in your opinion?

I've also discussed these questions with your colleague, from this discussion I created the following diagram and table.

5. Do these figures match your expectations about the development process and the standardized process?
6. Are there any things you would change on the models?