

Reducing working hours at VDL Energy Systems

How lean can be used to re-design a process from start to finish



Bachelor Thesis Industrial Engineering & Management

14 September 2020

**UNIVERSITY
OF TWENTE.**



REDUCING WORKING HOURS AT VDL ENERGY SYSTEM

How lean can be used to re-design a process from start to finish

NOTE:

This is a publicly available report. Because of the confidentiality of the company data, the numbers and data in this report have been multiplied by a certain factor. This means that the presented data is not the real data. Next to that, certain images and appendices have been shielded.

AUTHOR

Jelle Peter Rik van Pijkeren
S1802674
j.p.r.vanpijkeren@student.utwente.nl
Bachelor Industrial Engineering & Management

UNIVERSITY OF TWENTE

Dr. Ir. L.L.M. van der Wegen
Dr. Ir. P. Hoffmann

VDL ENERGY SYSTEMS B.V.

A. Schut

Drienerlolaan 5
7522 NB Enschede
(053) 489 9111

Industrieplein 1
7553 LL Hengelo
(074) 240 2000

FOREWORD

Dear reader,

In front of you lies the bachelor thesis *“Reducing needed working hours at VDL Energy Systems”*. This research has been performed at VDL Energy Systems in Hengelo as a final assignment for my bachelor Industrial Engineering & Management.

Writing a bachelor thesis is a challenge and an adventure in itself. It becomes even more challenging if a pandemic comes looking around the corner. Although I could not continue with graduating for almost two months, I am very grateful to everyone at VDL who made it possible for me to continue my project from the moment the first lockdown measures were lifted. The employees of VDL Energy Systems have always been very cooperative and helpful to me and always were available for my questions.

A special thanks to my company supervisor André Schut, who was always available and willing to help with any issue I ran into. His feedback and advice were always helpful, especially at the moments that I was making things too complex for myself.

I also want to thank Leo van der Wegen and Petra Hoffmann for the feedback they provided. Without that feedback, the report in front of you would be of a considerable lower level.

Lastly, I want to thank everyone else who was willing to listen to my endless dragging stories and analyses during the project, especially those in my inner circle.

Although challenging at sometimes, I have enjoyed my stay at VDL Energy Systems and am proud of the result of my project. I hope VDL can create a lot of advantage out of my findings.

Have fun reading!

Jelle van Pijkeren

Enschede, 8 September 2020

SUMMARY

In this section, we will give a short overview of the contents of this report.

Problem Context

This research has been conducted at VDL Energy Systems in Hengelo. The company was part of Siemens until it was acquired by the VDL Group in 2018. Because of this transition, the big profit margins of Siemens are gone and thus a different focus on their own operations is needed. As part of the transition, VDL ES has set itself the goal to reduce 30% of the total costs over a three year period. In this research, a specific group of products is analysed, the labyrinth seals. These labyrinths are relatively simple, although there is a lot of variation, so VDL ES wants to produce them so cost-efficient as possible. Because of the cost reduction, we researched the possibilities to make the process from order to delivery of a labyrinth take less working hours. Therefore, in compliance with the goal of a 30% cost reduction, the problem statement that needs to be solved is the following:

The number of working hours it takes from receiving an order until shipment of a labyrinth needs to be reduced by 30%

To solve the problem stated above, the following main research question has been constructed:

How can the process of labyrinth production be redesigned, using lean management theory, such that 'waste' is reduced so that the number of needed working hours is reduced by 30%?

Current process

The first thing we did was create a full overview of the process. The process consists of process steps (e.g. Sales) and the process step consists of actions, the things employees do (e.g. receive order, determine sales price, confirm order).

The process steps can be divided into two groups: 'support', which consists of all tasks apart from the modification of the product, which is done by the second group 'production'.

In addition, we wanted to know what the duration of each action is so that we know how many working hours the process, each process step and each action takes. What we did to find this information was 1) observe employees doing their tasks to see which actions they perform; 2) analyse historical ERP data to get an average duration per process step; 3) measure the duration of each action so that we could use the relative contribution of each action in the measurement to make an estimate of the average duration based on the ERP averages. E.g. if we measured that the 'receive order' action took 10% of the total time at Sales of that measurement. Then we assume that on average 'receive order' takes 10% of the average Sales duration.

Process step	Group	Hrs.
Planning	Support	0.16
MRP	Support	0.21
Technical Support	Support	0.40
Engineering		
Project	Support	0.19
Management		
Q MDB	Support	0.18
Sawing	Production	0.32
Turning	Production	1.46
Milling	Production	0.41
Eroding	Production	0.59
Glowing	Production	0.09
Benchwork	Production	0.12
Quality Inspection	Production	0.12
Packaging & Shipment	Production	0.17
Total		4.42

Current average durations per process step.

We found that the process takes 4.42 working hours in total, of which 1.14 are support hours and 3.29 are production hours. Next to this, we did some relevant observations which indirectly cause too many working hours:

- Deviations in planned and needed hours (Section 2.3.1).
- Quality Issues (Section 2.3.2).
- Manual Checks(Section 2.3.3).
- Inaccurate registration of hours in the ERP system (Section 2.3.4).

Waste in the process

The theory with which we will analyse the process is lean manufacturing. We have classified all the actions that we found as value added, necessary or non-value added according to the following definition:

“A value adding activity should comply with the following requirements:

- *The customer is willing to pay for it.*
- *It should be done ‘first time right’.*
- *The activity should change the product or service in some way.*

If an activity does not meet one of these requirements, it is classified as either necessary, actions that add no value but are inevitable, or non-value adding, also called ‘waste’.”

	VA (hr.)	%	N (hr.)	%	NVA (hr.)	%	Pot. (hr.)	%
Support	0.11		0.53		0.49		0.65	
		10%		47%		43%		-43%
Production	1.55		0.93		0.81		2.48	
		47%		28%		25%		-25%
Total	1.66		1.47		1.30		3.13	
		38%		33%		29%		-29.29%

Division of value-added, non-value added and necessary time in the process and the potential improvements

After identifying all the actions in the labyrinth process as either value adding (VA), non-value adding (NVA) or necessary (N), the following division of working hours became clear. This means that the process could take (potentially) 29% working hours less than it does currently.

Solutions

With the analysis of the process done, solutions could be drafted. The solutions are divided into three categories: solutions for a specific process step, solutions for the whole process and long term solutions. These solutions aim to either eliminate and reduce the time spent on non-value added or necessary activities.

Because of the other observations, additional criteria have been set up which solutions must fulfil. Every project should result in that the process becomes:

- More **standardised**, always the same procedures and no room for deviations.

E.g. the implementation of the generator tool outputs, which are standard production routings in the EPR system instead of manually entering them.

- More **dependable**, meaning the quality of the products improves.

E.g. installing better tools for producing and measuring to decrease variation and thus increase the quality of the products.

- Better **'analysable'**, so that more and better data can be measured.

E.g. implementing scanners to sign process steps on and off so that a very accurate registration of the needed hours is done, based on which analyses and adjustments can be made.

- More **controllable**, making sure all information that is needed is available and that the hours that are being sold are accurate.

E.g. creating a more detailed planning which assigns not only deadlines for a product but also deadlines per process step per product, so that the progress of a product can be monitored in more detail interventions can be done earlier if needed.

All the 24 solutions that are drafted are summarised in Section 5.5 on page 5-51. Next to that, they are prioritised with the help of the impact-effort matrix (Section 5.2.4).

Result

When these 24 solutions are implemented, the new process will take 0.80 working hours less.

	Current Process (hr.)	New Process (hr.)	Reduction (hr.)	Reduction (%)
Support	1.14	0.69	-0.45	-39.48%
Production	3.29	2.94	-0.35	-10.57%
Total	4.42	3.63	-0.80	-17.97%

The expected decrease in needed working hours in the labyrinth process after implementation of the solutions

Process step	Group	Hrs.	Change (%)
Planning	Support	0.16	0%
MRP	Support	0.18	-15%
Technical Support Engineering	Support	0.13	-68%
Project Management	Support	0.18	0%
Q MDB	Support	0.05	-73%
Sawing	Production	0.33	+2%
Turning	Production	1.46	0%
Milling	Production	0.35	-14%
Eroding	Production	0.36	-39%
Glowing	Production	0.10	+7%
Benchwork	Production	0.08	-32%
Quality Inspection	Production	0.13	-4%
Packaging & Shipment	Production	0.14	-19%
Total		3.63	

Future durations per process step and the whole process

A lot of these solutions affect the process in a broader way because they aim to tackle the other observations mentioned earlier, this makes it hard to quantify the decrease that these solutions will cause. However, if we add up all these solutions of which we can quantify the average reduction, we can draw some (preliminary) conclusions about the reductions that follow from the solutions. With these solutions taken into account, the new process will take 0.69 working hours for support and 2.94 for production. Bringing the total number of working hours the process to produce a labyrinth

will take to 3.63, which is a reduction of 17.97%. This is less than the 29% reduction that is possible, this is mainly due to the mentioned fact that the effect of most solutions is hard to quantify.

Recommendations

Firstly, we recommend VDL ES to implement the solutions as drafted in Chapters 5 of this report. Also, we recommend to look at the impact-effort matrix and the division we made of our solutions in the matrix to determine the order of implementation.

Secondly, we recommend VDL ES to take a good look at the preconditions as described in Chapter 6 of this report. Especially Section 6.1, which gives additional theory on change management/Kotter's 8-step model. Change management is important to keep in mind when going to implement the solutions to make sure that the implementation will succeed and results will be sustained.

TABLE OF CONTENTS

Foreword	1-4
Summary	1-5
Table of Contents	1-9
1 Introduction	1-11
1.1 About VDL Energy Systems.....	1-11
1.2 Problem Context.....	1-12
1.3 Problem Identification	1-12
1.4 Stakeholders.....	1-13
1.5 Theoretical Background of Lean Manufacturing.....	1-14
1.6 Research Design.....	1-16
1.7 Deliverables	1-17
1.8 Limitations	1-18
2 The Current Labyrinth Process.....	2-19
2.1 Observations & ERP Data.....	2-19
2.2 The Process.....	2-24
2.3 Other observations	2-25
2.4 Conclusion.....	2-27
2.5 Discussion with regard to the conclusion	2-28
3 Methods To Map Waste In A Process.....	3-29
3.1 Value Stream Mapping	3-29
3.2 Manufacturing Critical-Path Time.....	3-31
3.3 Time Value Map	3-32
3.4 Conclusion.....	3-33
4 Waste In The Process	4-34
4.1 Value Adding and Non-Value Adding activities	4-34
4.2 Mapping Waste.....	4-34
4.3 Conclusion.....	4-37
5 Possible Solutions.....	5-39
5.1 Drafting the Solutions.....	5-39
5.2 Solutions	5-40
5.3 New Process	5-49
5.4 Conclusion.....	5-50
5.5 Overview of all solutions.....	5-51



6	How to implement the solutions	6-53
6.1	Cooperation of the employees/Change Management.....	6-53
6.2	The ERP system.....	6-56
6.3	Standardised procedures.....	6-58
6.4	Employee(s) responsible for improvement.....	6-58
7	Conclusion.....	7-59
7.1	Answers to the research questions.....	7-59
7.2	Recommendations	7-61
7.3	How can lean be used to reduce the number of needed working hours by 30%?	7-61
7.4	Discussion	7-62
	Bibliography	7-64
	Appendices.....	7-65
A.	The Current Process Steps	7-65
B.	The Future Process Steps	7-74
C.	Calculations	7-81
D.	Manual for the analysis of production hours.....	7-86
E.	Systematic literature review	7-88

1 INTRODUCTION

In this Chapter, we will give some background on VDL Energy Systems (Section 1.1), sketch the context, identification and stakeholders of the problem this research will solve (Sections 1.2, 1.3 & 1.4). In Section 1.5, we will give some theoretical background on lean manufacturing, which will be used as framework for this research. In Section 1.6, we will describe the research design. Lastly, we will discuss the deliverables and limitations (Sections 1.7 & 1.8).

1.1 ABOUT VDL ENERGY SYSTEMS

This bachelor thesis is conducted at VDL Energy Systems in Hengelo. The company is located in the historic site of the former factory of the 'Gebr. Stork & Co.'. Since the year 1868, the Stork company build steam engines and later steam turbines in Hengelo. The main occupation remained in the field of engines and turbines, even after the merger with Delaval in 1971 and the acquisitions of Mannesmann Demag (1995) and Siemens AG (2001) (Wikipedia, 2018).

In July 2018, the VDL Group bought Siemens Hengelo, splitting it into two different divisions. VDL Energy Systems continued with producing and assembling gas turbines, compressors and parts. The other part of Siemens Hengelo was brought under at VDL ETG Technology & Development, which works for ASML (VDL Group, 2018).

At the facility of VDL in Hengelo the occupation contains the development, production and sales of systems and components aimed at the production, transition, transport and use of energy. They have three main working areas. The first is the production of big gas turbines and compressors (so-called packages). The second is the testing/calibrating of (used) parts. The last area is the production of smaller parts. These smaller parts can be used for service, production in own packages or direct sales.

The focus of this bachelor thesis will be on a specific type of the smaller parts, the labyrinth. Labyrinths can be used for multiple applications. Labyrinths are used as seals to contain fluids (oil) or gas, and they are always placed on or around a rotating shaft. In a compressor, the labyrinths are used to maintain the air pressure that is build up by the compressor.

Such a compressor consists of a shaft rotating at high rpm and around that shaft multiple 'chambers'. In each of that chambers, more pressure is built, the labyrinths are placed in between these chambers and the outer sides of the shaft to contain this pressure. The 'teeth' of the labyrinth let through a bit of gas which will spin in the cavities of the labyrinth, this makes sure that the velocity of air is decreased over multiple cavities so that eventually the compressor becomes airtight (Figure 1). The labyrinth seals do not actually touch the rotating shaft, which means that they wear very slowly.

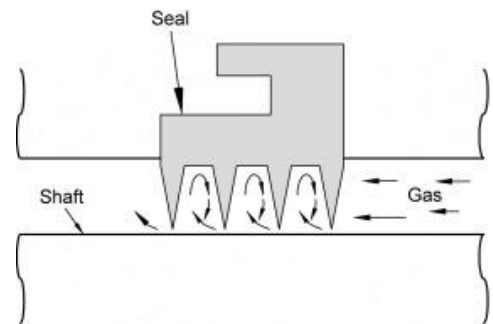


Figure 1 Application of labyrinth seals (Stewart, 2018)

There is a great variety of possibilities in designing the labyrinth, think of the number of teeth, the gap between teeth and shaft (split) or material types. Next to that, the needed accuracy of production

is very high. Therefore, VDL needs to spend a significant amount of time in the preparation of the production of the labyrinths.

1.2 PROBLEM CONTEXT

In November 2018, the facility in Hengelo was taken over by VDL from Siemens. Since then, the company has been very busy to process the change from Siemens to VDL. The change of ownership has big implications for the way working at VDL Energy Systems. Before they were a production facility for Siemens, meaning they could benefit from the advantages that come with a big concern such as Siemens. Now, the margins do not count over the bulk, but over each individual product. Although Siemens is VDL's biggest customer, their relationship is much more competitive. VDL has to 'earn' their orders instead of just getting them from Siemens.

This change of roles means that VDL Energy Systems is doing a self-assessment to their processes, both at the office as in the factory. The goal is to make them more efficient so that VDL ES is put in a more competitive market position. This self-assessment forms the reason for this research.

As said before, the focus of this research will be on the production of labyrinths. Management concluded that at this moment the costs per unit are too high. This means in the first place that not even all labyrinths are profitable to produce, as costs rise above the sales price. Secondly, this means that the sales price VDL is offering is far above market standards, making them too expensive compared to competitors.

In the process of self-assessment, the goal has been set to reduce the costs, companywide, by 30% over a period of three years. For the smaller parts, and especially the labyrinths, they want to reach high volumes with minimum effort. This means that these small parts can be ordered in a very easy and standard way, in which it won't take much effort and time from VDL employees to process these orders. This way of working is comparable to a webshop.

The goal of this research is to redesign the process in such a way that this target can be achieved for the labyrinths in particular. When this goal is achieved, VDL will obtain a much stronger competitive position in its market segment.

1.3 PROBLEM IDENTIFICATION

Having talked to a lot of staff involved in the production of labyrinths it turned out that there are a lot of little steps that are carried out by different individuals, and that there is a high number of working hours spent on producing a labyrinth, especially in the 'support' phases before and after production. This led to the formulation of the following **core problem**:

"There is too much human input in the process."

The variable 'human input' can be measured through the following indicator:

- 'Number of hours a human has to perform actions during the process.'

As explained in Section 1.2, a 30% cost reduction is the goal for VDL operations. There is a strong linkage between the total cost of a product and the needed working hours to complete that product.

By solving this core problem the actual problem, the **action problem** can be solved:

“The number of working hours needed from order reception until shipment for the labyrinth product group should be reduced by 30%.”

The action problem is in line with the target of 30% cost reduction in three years. However, since this problem is measured in the number of needed working hours I have changed costs by working hours (in reality these two are very closely related since a very big part of the costs come from the labour costs).

1.4 STAKEHOLDERS

With this research, multiple stakeholders at VDL are involved. They all have some different interest in the outcomes of this research, I will address them all individually.

1.4.1 Management

The management is mostly concerned with the big picture. They have set the goal for the whole organisation to reduce costs by 30% in three years. Their main concern is the number of sales that they want higher. The management wants to attain a more competitive market position.

In order to meet the 30% cost reduction target, they want the process to be assessed by the lean concepts to remove the non-value adding activities so that the process can be performed faster.

The exact way and details of this redesign process are not very important to them but they are ultimately responsible for the process. Therefore, it is necessary to keep them informed and involve them in the decision making but not very intensively in the rest of the process.

1.4.2 Support

The support contains all stakeholders that perform the processes other than production. These roles are, for example, sales, work preparation, planning and financial controlling.

Their main interests are a smooth process. At this moment issues arise often which create a lot of extra work. For them, the solution must provide clarity in procedures and responsibilities.

They are the people who will directly execute the process. Next to that, a lot of them have done their jobs for a long period and are very experienced in their profession. Therefore, it is important to involve them in the construction and development of the solutions that will be proposed because they can easily say whether or not solutions are feasible.

1.4.3 Production

Production contains the people who operate the machines, do the transport, maintain the warehouse/inventory, do the quality checks and do the shipment.

Their main interests are clear instructions. So, what type of operation has to be done when, and detailed explanation (accompanying drawings) of how the operation should be executed.

Similar to support, they are the ones who actually perform the operations. Therefore, it is important to involve them in the construction and development of the solutions proposed.

1.5 THEORETICAL BACKGROUND OF LEAN MANUFACTURING

Lean is a philosophy that has its origins in the Toyota Production System and that formalised by James Womack, Daniel Jones and Daniel Roos in the book *'The machine that changed the world'* (1990). The focus of lean is to achieve a flow of materials, information or customers that delivers exactly what customers want, in exact quantities, exactly when needed, exactly where required and at the lowest possible cost (Slack et al., 2016).

1.5.1 Principles of Lean

In the book *'Lean Thinking'* (1996), Womack, Jones and Roos (Womack & Jones, 1996) describe five principles of Lean based on their observations at Toyota, which are described in the Greenbelt book by Theisens (Theisens, 2018):

- **Value** *Define what is of value to the customer.*

Lean focusses on what the customer finds of value. The producer should adapt its product or service to this value and not to his own vision. This holds not only for the product but for example also for price and lead times.

- **Value stream** *Identify the value stream; eliminate waste.*

Secondly, there should be focus on how processes, both within the organisation as the supply chain, perform from start to finish. The performance of the whole value stream depends on the worst-performing process. The goal is to identify all steps that do not add value and eliminate these.

- **Flow** *Create a constant flow.*

When all waste is out of the processes, the next step is to create flow. By designing all process steps such that they take the same amount of time, products can flow evenly through the process. This way, no queues or inventory is created. By producing per product instead of per batch the ideal flow can be achieved, this is called 'one-piece-flow'.

- **Pull** *Produce only based on demand.*

When the first three principles have been implemented, there is flow in the process that only contains value adding steps. The next step is to produce based on demand, meaning products are only produced when there is a demand for them. The counterpart of pull is push, where large batches of products are 'pushed' through the process. Sometimes in pull production, some inventory is still needed. This inventory is minimal and gets replenished 'just-in-time'.

- **Perfection** *Continuous improvement.*

There should not only be defect-free production, the product should be delivered exactly to the customer's wishes, when the customer wants it and against a fair price, all without waste. By continuously improving the processes, perfection is achieved bit by bit.

1.5.2 Waste

The most significant part of lean is its focus on the elimination of all forms of waste. Waste can be defined as any activity that does not add value. (Slack, Brandon-Jones, & Johnston, 2016)

Within lean three sorts of variation are defined, the 3Ms: Muda, Mura and Muri. Decreasing these three types of variations is critical to increase effectiveness and profitability (Theisens, 2018). From these three, Muda is most relevant for this research as it contains waste.

1.5.2.1 **Muda** - Activities that do not add any value, waste.

The goal of decreasing Muda is making sure that the process uses not more than the minimal resources needed to make the product the customer actually wants. This is achieved by eliminating the activities that do not add value. A **value adding activity** should comply with the following requirements:

- The customer is willing to pay for it.
- It should be done 'first time right'.
- The activity should change the product or service in some way.

If an activity does not meet one of these requirements, it is classified as either **necessary**, actions that add no value but are inevitable, or **non-value adding**, also called 'waste'. Non-value adding activities should be eliminated whereas necessary activities should be minimised.

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

1. **Over-production**

Producing more than is asked for by internal or external customers. Over-production is considered the worst type of Muda. It creates unnecessary inventory, which leads to storage costs, and when customer demand changes, this inventory becomes obsolete.

2. **Waiting**

When products are not being processed, they are waiting. Waiting is seen from the perspective of the product and not from the employee. This also includes waiting for information, idling or defect equipment.

3. **Transport**

Each time a product is being transported between processes can be considered waste. When in transport, no modification is done to the product, which the customer is not willing to pay for. Next to that there is the risk that products get damaged, lost or slowed down while in transport.

4. **Over-processing**

Over-processing happens when too much modifications/activities are done to a product that a customer is not willing to pay for. For example, making use of tools or parts that are more accurate, more complex and therefore more expensive than what is actually needed. This also includes excess and redundant information and unnecessary inspections. Quality control is seen as over-processing if it does not modify or improve the quality of the product.

5. **Inventory**

Inventory contains a surplus in raw materials, components, work-in-progress or the warehouse. This inventory takes up resources without returning revenue. In service organisations, this includes the 'pile' of documents that wait between process steps. Often, inventory is necessary to maintain flow, however, this should be minimised.

6. **Movement**

Moving consists of all the movements the operators make from one activity to the other. Searching for information is also considered movement. During these actions, no value is created.

7. **Defects**

A product with faults cannot be delivered to the customer. Not producing 'First Time Right' is classified as a defect. If a product needs to be repaired or even thrown away, it will cost extra resources without yielding revenue. Documents or information that is not immediately clear to the customer/user is classified as a defect.

8. Unused expertise

Not using expertise or knowledge is also waste. For example, young employees can learn from the experienced ones. Another example is the management not involving the operators that actually work on the floor in an improvement process.

1.5.2.2 *Mura* - Lack of consistency in the processes.

The goal is not to approach each activity as a sprint and to finish it as quick as possible. Lean is not about increasing speed, but about reducing variation of speed to increase the predictability of the process. This way, a solid basis is created for further improvement initiatives.

1.5.2.3 *Muri* - Overburden of equipment and people because lack of understanding of requirements.

Overburden is the longer-term usage of machines and employees above an acceptable level. Doing extra hours for a longer period, bad ergonomics and postponing preventive maintenance will eventually lead to unexpected downtime and sick leave.

(Theisens, 2018)

1.6 RESEARCH DESIGN

To solve the core problem as described in Section 1.3 the main research question and accompanying sub research questions have been formulated and can be found in [Table 1](#). The main research question is as follows:

How can the process of labyrinth production be redesigned, using lean management theory, such that 'waste' is reduced so that the number of needed working hours is reduced by 30%?

To answer this main research question, the following sub-questions have been formulated:

1. *What does the current process for labyrinths look like?* (Chapter 2)

Before any improvements can be made to the process, we first have to get a detailed overview of how the current process operates. To do so, we will take a closer look at each individual action in the process to find answers to the following questions:

- a. *How much time does each step take?*
- b. *How much time does the process take on average?*

To find these answers, we will observe the employees while they are doing their jobs, one step at a time. During this observation, we will closely write down all the actions that are taken and measure the time each action takes. Secondly, during observation, we will discuss with the employee which steps are important and why they are. Next to that, we will take a look at the data in the ERP system, which should provide more insights on the average needed time per process step.

2. *Which mapping methods are there that identify waste in a process?* (Chapter 3)

When the process is fully mapped, it is time to analyse it. In Section 1.5, theoretical background is given on lean manufacturing and especially on waste, activities that do not add value. With this

knowledge value-adding activities (VA), non-value-adding activities (NVA) and necessary activities (N) can be identified.

Knowing the definition of VA, NVA and N activities is one thing, being able to identify them is another. Therefore I will look into methods or tools that give insights which activities in a process add value, which do not and which are necessary. Important sub-questions are:

- a) *How to apply the methods?*
- b) *What are the advantages and disadvantages of different methods/tools?*

With the answers to these questions, a method/tool will be chosen to gain insights into the added value of activities in the process.

-
3. *Which steps in the process are value-adding, which are not and which are necessary?* (Chapter 4)

Now it is time to combine the theoretical knowledge gained in Chapter 3 and the insights in the process from Chapter 2. To determine which steps add value and which do not, the method chosen in Chapter 3 will be used to analyse in the process. With the outcome of this analysis, the activities that do not add value can be identified. These activities are called 'waste' and will be the focus of Chapter 5, possible solutions.

-
4. *What are possible solutions to reduce the number of working hours needed in the process of labyrinth production?* (Chapter 5)

With the waste in the process known, possible solutions should be created. These solutions will be created with the help of lean theory and with the help of the people who perform the actions. The solutions will be prioritised/categorised with the impact-effort matrix.

-
5. *How should this solution be implemented?* (Chapter 6)

In Chapter 5 a suitable solution(s) has been chosen. Implementing this solution will not be a part of this research. However, good implementation is of great importance to the relevance of this research. Therefore, some thought has to be put in what the conditions are so that the proposed solutions can successfully be implemented. When these conditions have been found, they will be combined in a list of requirements, which VDL ES can use to successfully implement the solutions found.

Table 1; Research (sub) questions

1.7 DELIVERABLES

The final outcome of this research will be a new list of the process steps, in which it is stated per process step which actions need to be done, and what the expected amount of time is that is needed to complete that actions. This final outcome will become clear from the following deliverables:

- Insights in the number of hours needed to produce a labyrinth.
- Insights in value added, necessary and non-value added activities of the current process.
- Solutions to eliminate non-value added activities and improve the process.
- Explanation on how to implement the proposed solutions.

1.8 LIMITATIONS

Due to the time limit of ten weeks, the research design has some limitations. These limitations have to be taken into account when using the outcomes of this research for either further research or replication.

1.8.1 Labyrinths

In this research, the only process that is being researched is that of the production of labyrinths. For other product groups certain procedures might be different or are more important than they are for labyrinths.

Therefore, when doing further research or expanding the findings of this research, it should be taken into consideration that not every statement or assumption can be copied one-on-one, but should be rethought whether or not it holds for this new situation as well.

1.8.2 Lean perspective

The goal of this research is to decrease the needed number of working hours in labyrinth production. For this research, a lean perspective is chosen and the focus is put on waste and how to map that waste. This does not necessarily mean that the lean perspective is the best perspective to choose, so maybe other theories/perspectives can achieve better results although they are left out of this research. For example, Quick Response Manufacturing or Theory of Constraints.

2 THE CURRENT LABYRINTH PROCESS

In this chapter, we will answer the question “*What does the current process for labyrinths look like?*”. To answer this question we started with observing, measuring and analysing the process (Section 2.1), with which we recreate the whole current process (Section 2.2). After we have the (basic) process defined, we will discuss other relevant observations which influence the process (Section 2.3).

2.1 OBSERVATIONS & ERP DATA

The process has been (re)created via the combination of three pieces of information. The first is observations of the actual employees and operators that execute the process to create a detailed overview of the process steps and underlying actions. The second is the analysis of the historical data from the ERP system to determine average durations of the process steps. The last is the observed time per action so that a relative contribution of each action to the total time per process step can be determined. It was not possible to do many measurements, therefore only the ratio of measurements is used and not the measurements themselves to determine the average durations. The results of these approaches as well as an overview of the whole process as it currently runs is given in the remainder of this chapter and will serve as input for Chapter 4.

Important to note is that ‘process steps’ and ‘actions’ can seem the same, however in this context ‘process steps’ consist of actions. As an example: the process step ‘Sales’ consists of the actions ‘receive order’, ‘check delivery date’ and ‘confirm order’. This distinction is needed because actions can be classified as waste, as process steps consist of too many steps to classify the whole step as waste.

The observations were done by sitting or standing next to someone, on a safe 1.5 m distance, and noting every action and measuring the time that action took with a stopwatch. In case multiple labyrinths were processed, the ‘product-specific’ steps were averaged so that in the end a time estimation per process step per labyrinth was made.

2.1.1 Observations of the process steps

The first piece of information to find out is the process itself. Which process steps are followed to make a labyrinth? Which actions are needed in each process step? How is it managed? To find answers to these questions, the employees were observed doing their regular work and all actions they did were registered and combined in one big map.

2.1.1.1 Characteristics of the process

Firstly, it is important to understand the nature of the product and therefore the repeatability of the process. Although labyrinths are relatively simple products, each and every one of them is a unique product that needs to be built according to customer specification. This is done based on technical drawings supplied by the customer. This characteristic implies that it is very hard to say “step X takes Y hours” as processing time depends completely on the drawings, material, and dimensions, which are different each time.

Apart from the differences in time between two labyrinths in a single process step, there are also different routes through the factory for a labyrinth depending on its specifications. For example,

when a labyrinth needs to have a split (two separate halves), it needs to be eroded or if it has certain specifications, too much tension might build in the product during modification, thus it needs to be glowed to reduce the tension. This means that we must be careful with ‘just’ adding up all the averages per process step and get a universal total time for the process. However, to be able to analyse the process, not every possible route of the process can be taken into account, so we made one process containing all the steps.

2.1.1.2 Order routing cards

The support part of the process makes sure that the right documents are gathered and evaluated, orders are planned, sales is done and a routing for the production is made. The result is a folder with a routing card. This routing card tells the operators which steps have to happen in which order, what the deadline is, how much time they have to complete the setup (SU) and to do the modification (UPS) and it contains remarks/instructions for the operators.

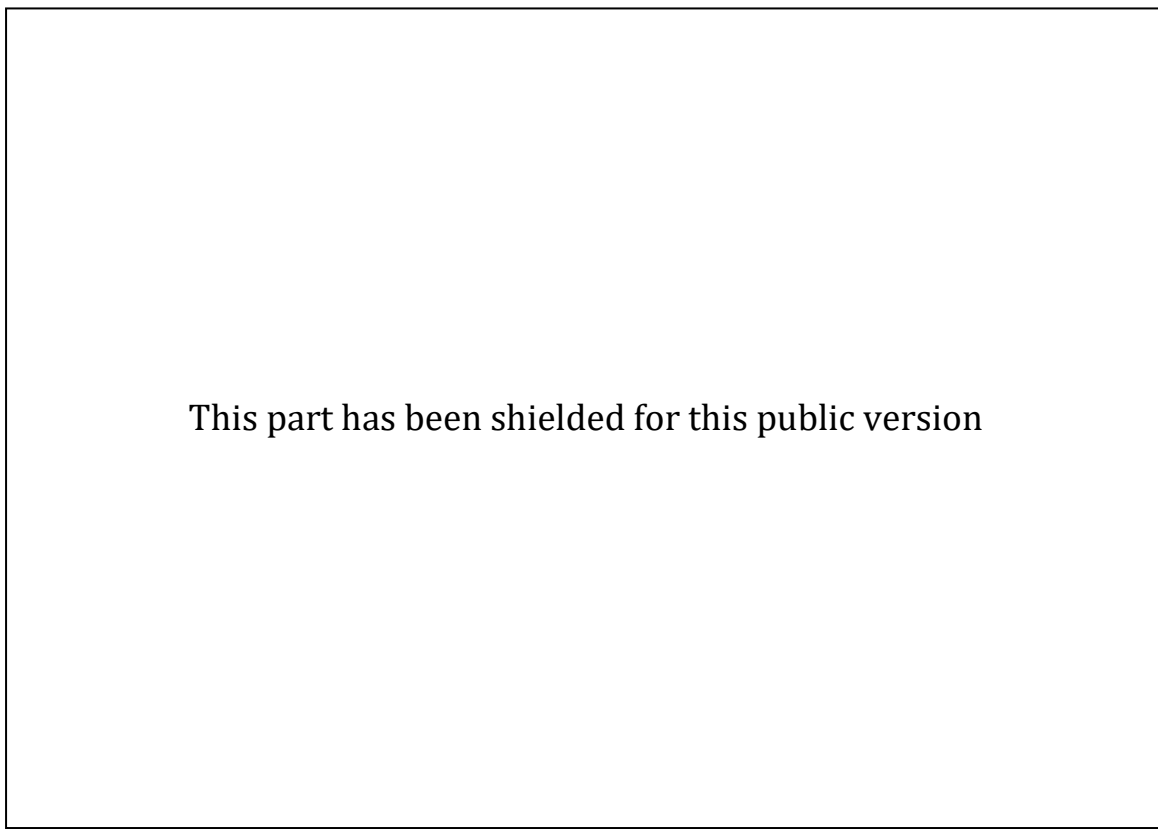


Figure 2 An example of a (empty) routing card

These routing cards are the means to steer production. The card travels along with the product and is the first source operators use to prepare and install their machines. Therefore, the routing card is a very powerful document in the process of labyrinth production.

2.1.1.3 The process steps

From the observations became clear that the process of producing a labyrinth basically consists of two parts, the support part and the production part. The support part contains all the steps that are done to make the production of labyrinths possible where the actual product is not modified. The production part then consists of all the steps that do modify the product in the factory.

While going through the process to map it, the following process steps were looked at. In **Table 2**, an overview of what each step contains is given. Next to that, Appendix A contains the process flows of each individual step and all the actions that are performed during the process step.

Process step	Type	Description
Sales*	Support	Sales receives and confirms the orders, they make cost estimations and, based on that, sales prices. Next to that, they create the hour booking orders and the projects in the ERP system.
Planning	Support	Planning is responsible for the machine planning. They decide if a delivery date is feasible and determine which product is worked at which time and when production starts.
MRP	Support	MRP is responsible for the transfer of the order into the ERP system by creating production orders. For each, they make the Bill of Materials (BOM), upload relevant documents into orders, and determine if material needs to be purchased or which needs to be sawed.
Technical Support Engineering	Support	The Technical Support Engineers (TSE) create the dimensional protocols, in which operators fill in the (actual) dimensions they have produced. Next to that they create the routing of the product and make sure that the routing is uploaded into the production order in the ERP system.
Project Management	Support	Project Management (PM) is responsible for starting production, meaning they bring the printed routing and needed documents to the first process step. After that, they continuously check what the status of the product is and whether they are on schedule. If mistakes happen, they are responsible to contact the customer to determine further steps.
Q MDB	Support	The Q MDB department is responsible for collecting and checking all the documents that are needed to verify quality requirements. For labyrinths, these are the dimensional protocol and a material certificate.
Controlling*		Controlling checks the difference between what was budgeted and what the actual costs turned out to be. If there are great deviations, they go searching for the cause of the deviation. They also send the invoices.
Sawing	Production	Sawing saws the needed amount of raw material from the stock material.
Turning	Production	Turning creates most of the product, they create the shape of the labyrinth.
Milling	Production	Milling does small modifications, they make paddles or threaded holes in the products.
Eroding	Production	Eroding cuts the product in two halves with an electrified wire.
Glowing	Production	Glowing glows the product in an oven to remove tension from the product so that it can be further modified.
Benchwork	Production	The benchwork for labyrinths contains deburring (making sure no scratches or 'impurities' remain) and engraving serial numbers.

Quality Inspection	Production	The quality inspection measures the dimensions of the products, checks the outer surface on damage, and fills in/completes the dimensional protocol.
Shipment	Production	Shipment prepares the products for shipment by treating them with conserving spray and packaging products.

**Sales & Controlling hours are not invoiced directly to the customer, and therefore not registered in the ERP system. Meaning no data can be retrieved and analysed for these process steps.*

Table 2 Short descriptions of each process step

The process flow of all these activities can be seen in **Figure 4** in Section 2.2.

2.1.2 ERP Data

Because it is hard to do a lot of measurements and single observations do not say enough about the process to build conclusions on them, a different source should be used to get valid data. Therefore, for the abovementioned process steps the historical data from the ERP system is used to give a good impression of how much time the process takes. Next to the average time per process step, more interesting variables can be retrieved from the ERP data: the (average) difference between the time planned and time spent during a specific process step, the spread of the processing time per step, and average waiting time per step.

Although there is a lot of variation in the specification and routing that a labyrinth can follow, it was not possible to distinguish different types or categories of labyrinths in the ERP data. Therefore, it is not possible to research the relation of, for example, the material or number of modification steps on the number of needed working hours.

The modification hours that were registered are therefore combined into one data set. The outcomes are thus an average over all the different types of labyrinths and routes.

2.1.2.1 Design of the ERP database

A problem with analysing the ERP data is the design of the database (**Figure 3**). This problem applies only to the support process steps. An order that VDL ES receives can consist of multiple parts, of which not all are labyrinths. This order, a so-called ‘purchase order’, is entered into the ERP system as a ‘project’ with a unique project number. The individual parts in that purchase order are entered in the ERP system under that project as so-called ‘production orders’, again with their own unique order number. The issue is that the hours for the support process steps are registered in a separate ‘hour booking order’, which is the same type of entity as a production order in the ERP system.

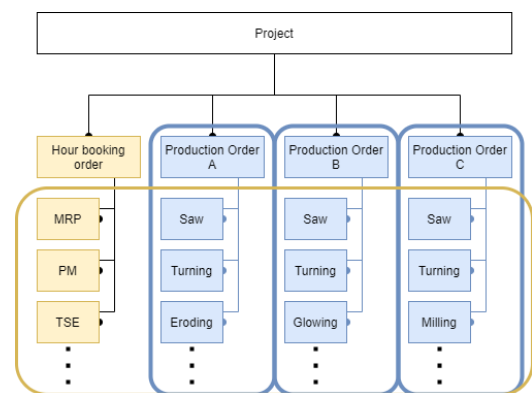


Figure 3 The build of the ERP system' database

Therefore, it is not possible to connect a single support process step and the registered amount of time to a specific production order or labyrinth as all the hours in the ‘hour booking order’ hold for the whole project.

How can we then still make a good estimation of the number of support hours that are needed to make a labyrinth? We will make the assumption that all production orders have an equal contribution to the number of hours in the ‘hour booking order’. But is this a reasonable assumption?

If we take all 527 production orders (labyrinth and non-labyrinth) in our data set and for each order we calculate its relative contribution to the total number of hours in its project. If we then take the squared difference compared to the average contribution of orders in that project, we get a deviation for that order. To illustrate, if project X has orders A,B,C with contributions 20%, 50% and 30%, then the average is 33,3% and the squared deviations are 1.8%, 0.1% and 2.8% respectively. The average deviation for this project X is 1.6%. The sum of all average squared deviations over all 527 orders is 0.82%, making the assumption a reasonable one, as on average the deviation from an equal distribution of hours over the project is less than 1%.

When we make the assumption that all production orders have an equal contribution to the support hours in the 'hour booking order' we will be able to calculate a number of hours per support process step per labyrinth. There are some things to keep in mind when doing so:

- Not all production orders in a project contain labyrinths
- A production order can contain more than one labyrinth

To counter the first issue, we first calculate the average time per production order. After that, we multiply it again with the number of labyrinth production orders. Then we have the number of support hours spent on labyrinths. To calculate the time spent on a single labyrinth, we simply divide by the total number of labyrinths that together form the abovementioned production orders. This results in the following formula:

$$\begin{aligned} \text{Support Hours per labyrinth} &= \frac{\text{hours per production order} \cdot \#\text{labyrinth orders}}{\text{Total number of labyrinths}} \\ &= \left(\frac{\#\text{hours registered}}{\#\text{production orders in project}} \right) \cdot \left(\frac{\#\text{labyrinth production orders}}{\#\text{labyrinths in project}} \right) \end{aligned}$$

Equation 1 Calculating Support hrs. per labyrinth

Although this allows us to make an estimation of how many hours are spent on a single labyrinth, it is not very accurate. In this calculation, the number of registered hours is “divided” twice, among production orders and among individual labyrinths. Therefore, it is just a “rough” estimation that allows us to say something about the number of support hours that is used on average.

2.1.2.2 Analysis of the ERP data

Based on the ERP data it was possible to analyse the production process steps for each order. Then, with the use of [Equation 1](#), it was possible to calculate the number of support hours per piece for each order. The number of working hours that is needed, on average, per process step, per labyrinth is summarised in [Table 3](#). These hours are the registered working hours, so not the total time a labyrinth spends at that step.

As can be seen, the average total number of working hours it takes to process a labyrinth is 4.42 hours. To reach the goal of a 30% reduction the number of hours that is needed should decrease with 1.33 to a total of 3.09 hours.

2.1.3 Measurements per process step

Now, we know which steps and actions form the process and how much time each step takes on average. Because we were not able to do enough observations to find the average duration per action, we have to use the average times from the ERP system in some way. So, to be able to determine the average duration of each action we will assume that the relative contribution to the total time a step takes is always the same. With this assumption, we can observe each process steps once or a few times and use the time each action takes to determine a relative contribution of that action to the total duration of that process step.

Process step	Hrs.
Planning	0.16
MRP	0.21
Technical Support Engineering	0.40
Project Management	0.19
Q MDB	0.18
Sawing	0.32
Turning	1.46
Milling	0.41
Eroding	0.59
Glowing	0.09
Benchwork	0.12
Quality Inspection	0.12
Packaging & Shipment	0.17
Total	4.42

Table 3 Average working time per process step from ERP data (hrs.)

To find this relative contribution, we measured the time that was needed to perform each action in each step. However, due to circumstances and the effects of the COVID-19 measures, it was not always possible to measure the exact times. In these cases, the steps and needed times were discussed with the operators to construct a general ‘time path’ for their process step. For a total overview of all the steps and their relative contribution, see Appendix A.

These relative contributions of each action are then multiplied by the average from the ERP data as an estimation of the time the action takes, and ultimately how much time can be saved. The results of multiplying the contributions with the ERP averages can also be found in Appendix A.

To give an example, milling consists of the six actions ‘install clamps’, ‘install tools and write modification programme’, ‘pre-milling’, ‘measure depths’, ‘final milling’ and ‘fill in dimensional protocol’. These actions were measured 4.8, 4.8, 2.2, 1.6, 1.0 and 3.2 minutes respectively, with a total of 17.51 minutes. The relative contribution of each step is then 27%, 27%, 13%, 9%, 5% and 18% respectively. With the average duration of 0.41 hour for milling and the assumption that the same contribution holds on average, the average duration per action is calculated by multiplying the contribution with the average duration from the ERP data. This results in 0.11, 0.11, 0.05, 0.04, 0.02 and 0.07 hours per action respectively.

2.2 THE PROCESS

Now we know which steps there are, what actions are needed and based on measurements and historical averages we can estimate the average duration of each action. The process consists of many more smaller actions. For a more detailed overview of the actions per process step and the flow between individual steps, see Appendix A.

We know that there are thirteen steps in the process, that together, on average take 4.42 of working hours. Based on the historical averages, we also know how long each step takes. All the information we have now can all be combined in one process flow (Figure 4)

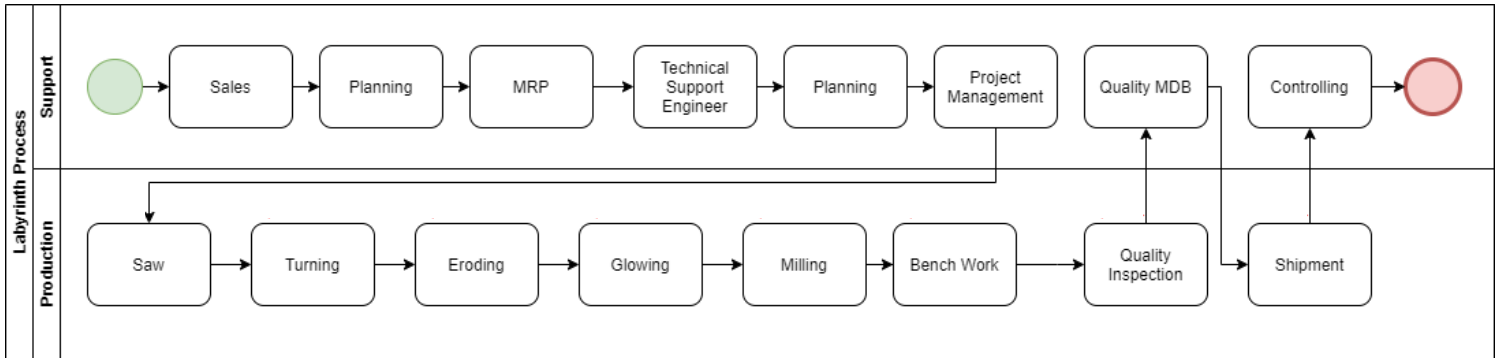


Figure 4 High-Level overview of the labyrinth process

2.3 OTHER OBSERVATIONS

Apart from the observations about how the process looks like and how long the process takes, more observations were done that contribute to the number of needed working hours being too high.

2.3.1 Deviations in planned and needed hours

There are three things that stood out with regard to the difference between the planned number of needed hours (VC) and the actual realised number of hours (NC). First, the average of the differences ($=VC-NC$) per process step is negative for almost every process step. This implies that the number of hours that is needed is structurally estimated too low and production has to do with too few hours from the beginning (Figure 5).

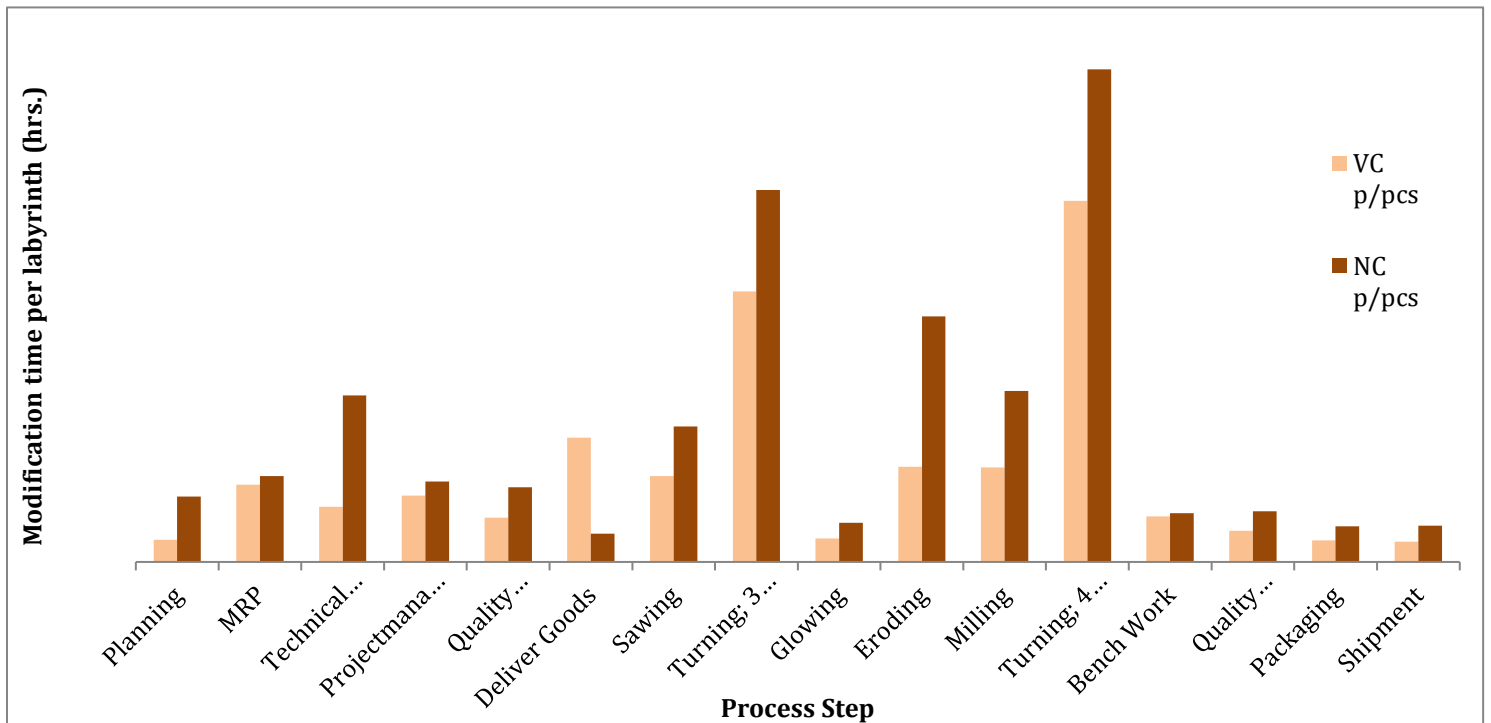


Figure 5 Overview per process step VC and NC

The second thing is that when we count the times that the planned amount of hours is either enough ($VC > NC$), just enough ($VC = NC$) and not enough ($VC < NC$), we see that for most production steps, the estimated amount VC is right only 30% of the cases and just enough about 40% of the cases (Figure 6).

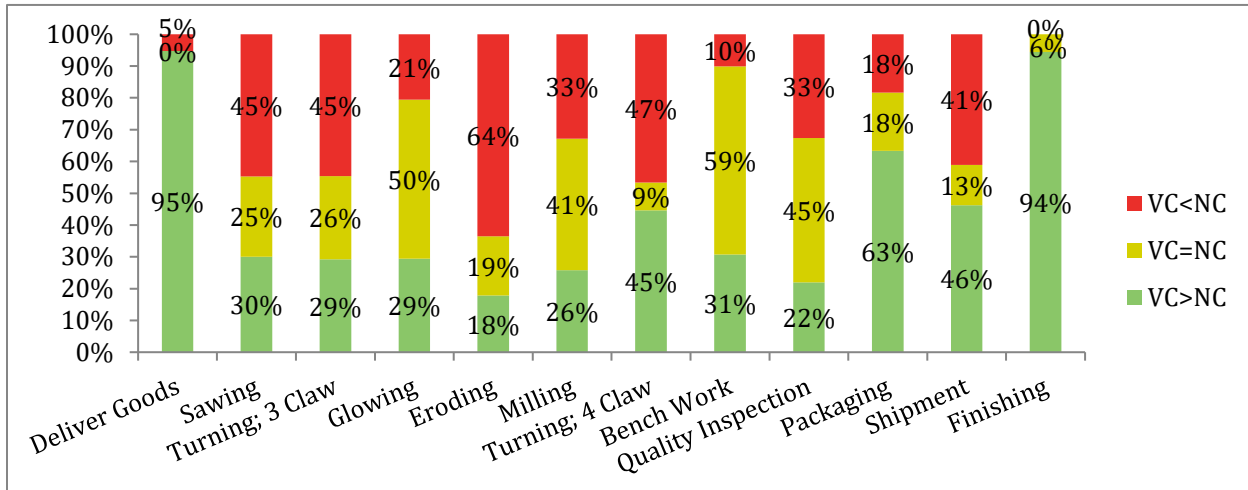


Figure 6 Ratio per production step whether planned hours are enough or not

This might seem quite alright, 70% the NC is not more than the VC. However, it still means that about 30% of the time, VDL ES fails to estimate the needed amount of time to produce their products accurately. If we keep in the back of our heads that the margins are also not that big, then those margins disappear rapidly when estimations are too positive.

Lastly, when we look at the sample standard deviation of the difference $VC - NC$, then it is often greater than an hour or even two hours. Meaning there is a lot of spread in the difference between VC and NC.

These three things imply that it is very difficult at the moment to be able to plan the needed number of working hours accurately, depending on the different specifications of the product. This means that a lot of times the production takes longer than scheduled and sold to the customer. So, when the NC is too often bigger than the VC VDL ES loses (too much) money. To fix this issue, a method must be constructed to iteratively estimate production times (VC) more accurate.

2.3.2 Quality Issues

Another interesting observation that we made, is there are relatively a lot of errors made with regard to quality. These errors can be, amongst others, damage to products, products produced wrongly, products that are produced out of dimensional specifications. Although a lot of these errors can be fixed in some way, they cost a lot of extra time. When an error is found at the inspection, it costs the quality inspector extra time; the project manager must contact the customer whether or not they accept the product with the error made or after a little modification, which is often the case. Additionally, if extra modification is needed the planner must adjust the planning.

If the error is so bad that rework must be done, MRP and TSE must redo their work since rework means a new production order. On average, when rework is needed, more than 5 hours of extra work are needed.

Concluding, an error (minor or major) can easily cause extra hours of support and production work, evaporating the already small margins. So if a method can be constructed to reduce the number of errors that is made to get closer to 'First Time Right' producing, it will reduce the number of unforeseen extra working hours.

2.3.3 Manual Checks

In both production and support, a lot of manual work is done. Especially for turning and milling, checks need to be done during modification because the tools and calibration of the machines are not accurate enough to be able to trust the machine to produce 'first time right'. But also separate saving locations or excel sheets are used to keep an overview. This causes extra working hours.

2.3.4 Inaccurate registration of hours in the ERP system

An issue that was both mentioned by operators and came clear from the ERP data itself is that the registering and signing off of process steps is not done consequently. The "earlier" step was signed off later than the "latter" step in 21% of the times it was possible to retrieve the difference in 'sign off time' between sequential steps.

If it is indeed the case that orders are not signed off directly after they have been processed, the number of hours booked on that order may very well be less accurate, as then the operator has to make an estimation of how much hours it took him. Next to that, it is likely that if an operator is not sure how much hours it took, that he will look at how much he got planned for it (VC) and base his NC on that. This gives inaccurate NCs and that is a poor basis to improve your process on.

2.4 CONCLUSION

Based on observations and the analysis of the historical ERP data, we were able to map the current process that is used to produce a single labyrinth. We know, although the needed time is very dependent on individual product specification, the process takes on average 4.42 working hours to complete. Next to that, we now have a clear target for the 30% reduction, namely 1.33 working hours.

By combining the process steps, the historical average duration and the measured duration of each action we were able to make an estimation of the average duration of each action that is carried out in the process. This enables us to quantify the improvements of possible solutions.

Also important to keep in mind are some other observations that were done:

- There is a structural (negative) difference between the hours that are planned to do a task and the hours that are actually needed, implying that planning the process is quite hard at the moment.
- There are a significant number of minor and major quality issues, that take up extra working time, time that is not available.
- A lot of checks are done manually, causing extra time and the possibility for errors.

- The registration of hours in the ERP system seems to be not very accurate. This means that it is hard to adjust the process as the data to base conclusions on is not representative of the reality.

2.5 DISCUSSION WITH REGARD TO THE CONCLUSION

There are a few things to keep in mind while reading this chapter.

The COVID-19 pandemic caused some threats to validity. First of all, the demand decreased significantly, making it impossible for quite some time to observe labyrinth orders as there were simply none. The second issue is that because of the measures normal observation was not possible. Especially for the support process steps, to adhere to the 1.5 m distance rule we had to sit in meeting rooms. Because of this different situation, the employees had some difficulty finding the right information and buttons as they now only had one screen, further away, compared to the two they would normally have. This caused the measured times to differ from the “real” ones.

As mentioned under 2.3.4, the booking of hours in the ERP system is presumably not very accurate. Therefore, the quantitative data as presented in this chapter do not represent the actual process, but only the “registered process”.

As mentioned under 2.1.1.1, each order is different. To be able to draw conclusions, not all different types, setups or routes are evaluated. And the process is simplified somewhat to make analysis feasible. This means that for individual labyrinths the actual times might differ significantly from the process presented in this chapter. Although, for the bulk of all labyrinth orders the data presented will be right.

Lastly, there is a lot of variety in the labyrinths and thus in the process, they follow and working hours that they cost. However, it was not possible to make some sort of categorisation based on the ERP data to analyse different routes or specifications. Therefore, all data was combined into one process for one labyrinth. This excludes the possibility to examine the effect of e.g. route or material on the number of working hours. If the data in the ERP system would be altered such that it is possible to identify and filter the data based on the labyrinth specification, it will be possible to make a more detailed analysis of the needed working hours.

3 METHODS TO MAP WASTE IN A PROCESS

In this chapter, the third research question, ‘*which mapping methods are there that identify waste in a process?*’, will be answered. A closer look will be taken into Value Stream Mapping (3.1), which originates from Lean Manufacturing, Manufacturing Critical-Path Time (3.2), which originates from Quick Response Manufacturing, and Time Value Mapping (3.3).

3.1 VALUE STREAM MAPPING

Value stream mapping (VSM) is a mapping method that focusses on value creation. The process of mapping includes four steps:

1. Set a **value stream scope** to determine what process (value stream) is to be improved and to create a common view of the process analysed. It has to be known where the process starts and ends, what are inputs and outputs and what are its control parameters (e.g. strategy or business goals). These parameters are visualised in an Input-Output view (Figure 7).
2. In the **current state** step, the aim is at getting to know how the process actually currently works (Figure 8). This is done by observing the actual processes from beginning to end. Demands of internal and external customers must be identified. The flow of materials and information is then mapped, identifying each process time and lead time.

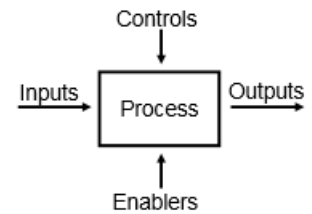


Figure 7 Input-Output view of a process (Gustavsson & Axelsson, 2010)

Rother and Shook established a sequence for the construction of the current state map, identifying which data is required and indicating that they must be collected from the end of the process toward the beginning. Mapping should start by customer demand, then data should be collected. Thereafter, the cycle time, the number of people needed to operate, the available work time per shift, the operation time, and the size of production batches should be obtained for each process. Next to that, initial, in-process and final inventories must be determined, besides determining the flow of information on the shop floor. (Rother & Shook, 1999)

3. Then comes the **future state** step (Figure 9). The purpose of this step is to improve the process. This is done by analysing the process according to the lean principles. There are a number of questions that could be answered: *What does the customer really want? Which steps create value and which are waste? How can we design a flow of work with fewer interruptions?* With the help of the questions to these answers, a future state can be made.

Rother and Shook also constructed some guidelines for creating a future state map:

- What is the takt time (Available working time (sec) / Customer Demand)? *This number says how long one product may be at an activity in order to meet demand.*
- Will you build to direct shipping or to a ‘supermarket’ from where a customer pulls?
- Where can you use continuous flow processing?
- Where will you need to use supermarket pull systems in order to control the production of upstream processes?
- At what point in the production chain will you schedule production (the pacemaker)?
- How will you level the production mix at the pacemaker process?
- What increment of work will you release and take away at the pacemaker process?
- What process improvements will be necessary for the value stream to flow as the future-state design?

(Rother & Shook, 1999)

- The last step is the **work plan and implementation**. The goal is to implement the improvements. It is done by describing the specific improvements that are chosen to be implemented. A work plan is made to show what will be done by whom at what time.

(Gustavsson & Axelsson, 2010)

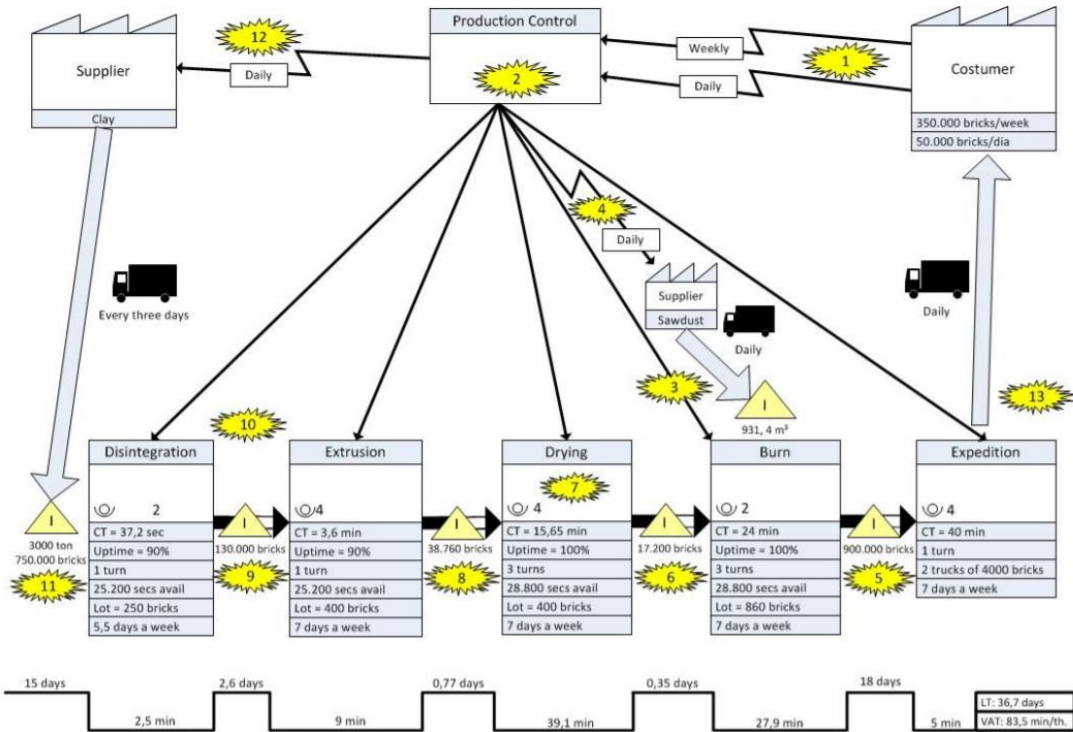


Figure 8 A Current state map (Luna, Klökner, & Ferreira, 2013)

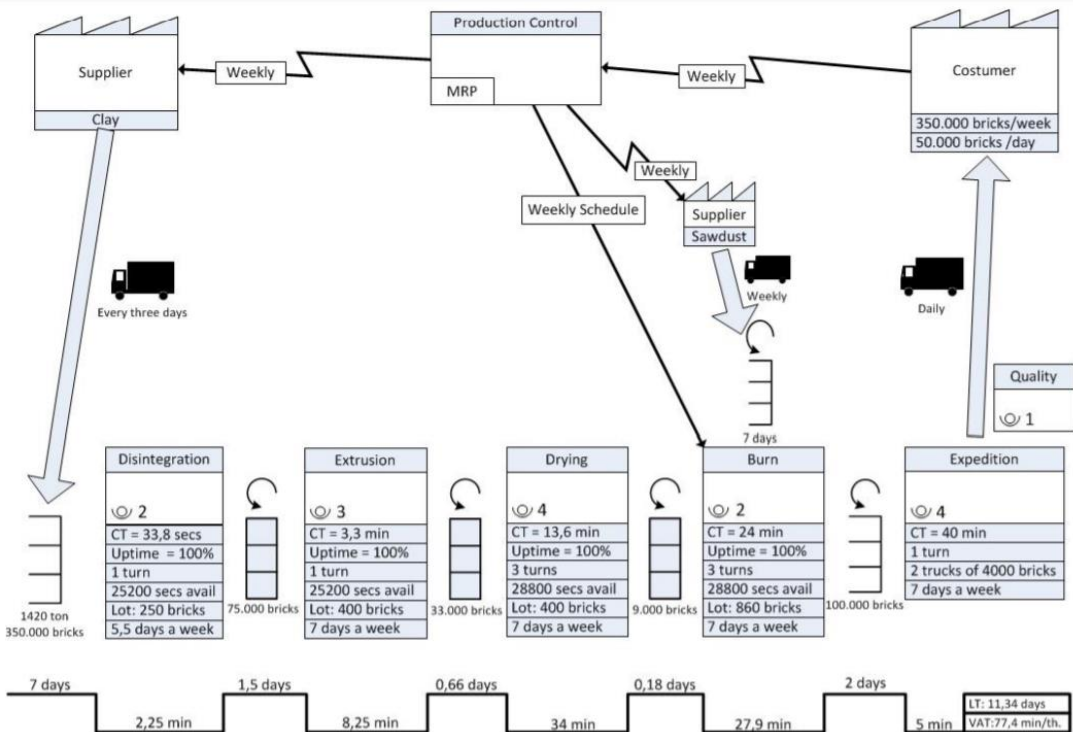


Figure 9 A future state map (Luna, Klökner, & Ferreira, 2013)

3.2 MANUFACTURING CRITICAL-PATH TIME

Manufacturing Critical-Path Time (MCT) is a time-based metric that defines lead-time so that it properly quantifies system-wide waste (Suri, A Timely Metric, 2015). MCT is part of Quick Response Manufacturing (QRM), a companywide strategy developed for reducing lead times, both internally and externally (Suri, Beyond Lean: It's About Time!, 2011). The external aspect involves rapidly designing and manufacturing products for specific customer needs. The internal aspect focuses on reducing lead times for tasks within the enterprise.

3.2.1 Quick Response Manufacturing

QRM defines two types of variability:

- **Dysfunctional variability** caused by errors and poor systems.
- **Strategic variability** introduced by a company to maintain its competitive edge.

Whereas the core of lean is to get rid of all variability, QRM only gets rid of dysfunctional variability, since you may want to keep strategic variability as it gives you competitive advantages. Thus QRM aims to exploit strategic variability (Figure 10). This is done by designing the organisation to effectively cope with this variability and still achieve a quick response.

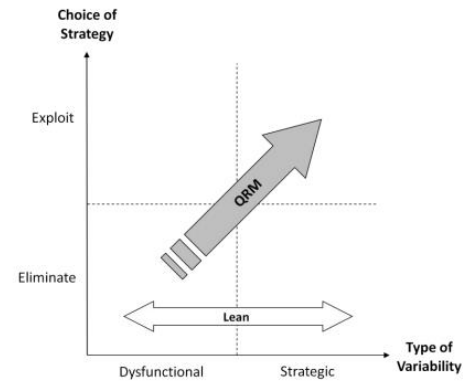


Figure 10 QRM strategy enhances lean programs (Suri, Beyond Lean: It's About Time!, 2011)

3.2.1.1 Reducing Lead Time

QRM is based on four core concepts:

- Realizing the Power of Time.
- Rethinking Organizational Structure.
- Understanding and Exploiting System Dynamics.
- Implementing a Unified Strategy Enterprise-wide.

(Suri, Beyond Lean: It's About Time!, 2011)

3.2.2 Manufacturing Critical-Path Time

“MCT is the typical amount of calendar time from when a customer submits an order, through the critical path, until the first end-item of that order is delivered to the customer.”

The ‘typical amount’ indicates that MCT is about highlighting the biggest possibilities for improvement, thus focusses less on details. The ‘calendar time’ refers to the view of customers that is in terms of delivery at a specific calendar date, so it is not important in which calendar the organisation works. For determining the ‘critical path’ there are some rules to observe:

- All activities must be completed from scratch; time to make components must be included.
- Include all normal queuing, waiting and moving delays that jobs incur, do not use values for rush jobs.
- Time spent by material at any stage, including all inventory holding points, must be added into the MCT value.

The gray rectangles in the map indicate when someone is actually working on a customer's order.



Figure 11 Simple MCT map (Suri, A Timely Metric, 2015)

- If there are multiple paths involved (e.g. subtasks), then MCT is the value for the longest path from start to finish.

Even though the customer might have ordered a batch of parts, use the term ‘first end-item’ as it sharpens the focus on the first end-item. Here end-item is the ‘first usable set of items’. Lastly, ‘is delivered’ means that the order is delivered to the customer’s point of receipt.

3.2.2.1 The MCT map

The MCT map provides a high-level picture of opportunities for improvement. The grey spaces mark the total time someone is working on the order, the grey shaded rectangles are placed at the end of the operations for which this time occurs. The white space illustrates the remaining time spent by the order in a particular area, time when nothing is happening. The map is drawn roughly to scale, so the magnitude of different elements is apparent.

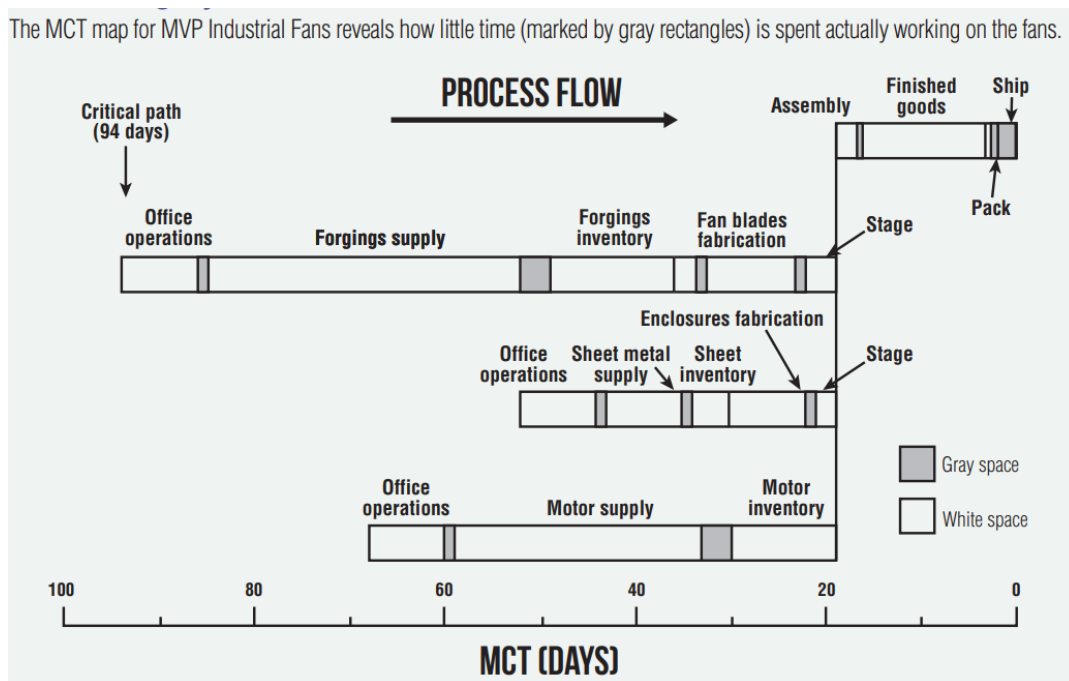


Figure 12 An example of a MCT map (Suri, A Timely Metric, 2015)

3.2.2.2 MCT mapping versus Value Stream Mapping

VSM is a popular tool for improvement projects. However, in the initial stages, MCT mapping has some advantages over VSM. First, an MCT map is simpler and provides a high-level, easy-to-see, view of the operation. Secondly, an MCT map represents time proportionally so that big amount of white space visually highlight versus the small amounts of grey. Lastly, an MCT map identifies the critical path, ensuring that improvements are targeted at processes that will make a significant difference.

3.3 TIME VALUE MAP

A Time Value Map is a tool that tracks how a specific process spends its time. It’s a graphical description of value-added and non-value added time in a process. The aim is to eliminate waste and streamline the process whenever possible (CIToolkit, 2020).

The map is created by drawing a line, above that line, only that value-added activities are drawn, below the line, the necessary and non-value added activities are drawn. Each activity is represented

by a bar of which the colour represents its type (green, orange and red resp.) and its width represents the time the activity takes.

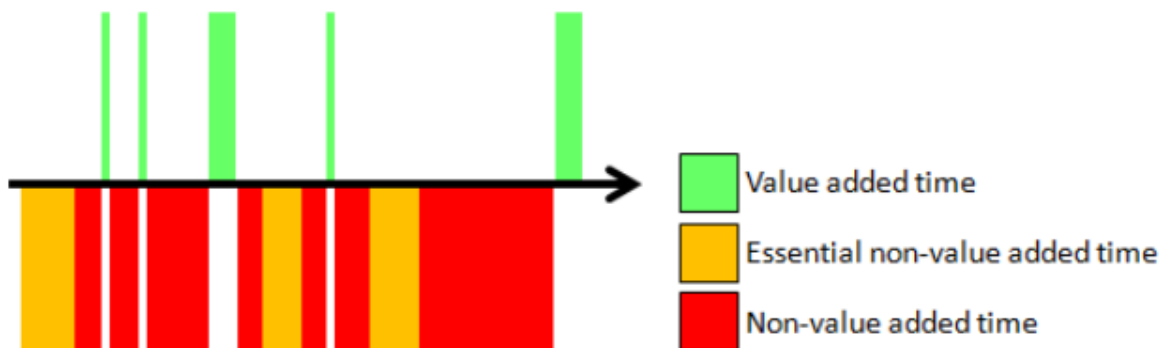


Figure 13 An example of a Time Value Map (CIToolkit, 2020)

There are almost no articles that mention time value maps, let alone explain and evaluate it. However, some comparisons with VSM and MCT can be easily made by ourselves. Most of all methods, time value mapping lays the focus in value-added and non-value added time. Next to that, with its three colour scale, it is the most detailed representation of waste of the three methods.

However, with a long process, the time value map might become too big as one big arrow with coloured blocks does not provide that much of an overview. Also, it does not capture the information and product flows as a VSM does.

3.4 CONCLUSION

The choice of method to map waste in the process will be a Time Value Map. The advantages of both an MCT and Time Value Map over VSM are that they focus more on time, which is more suitable for our problem statement since we are focussing on the number of working hours. Next to that, both show a simple high-level view of the process, which makes it easier to analyse and see where value is added and where not. The MCT map gives the best overview of activities over time, especially with parallel processes, but it only considers touch time and non-touch time. Since this research is specifically looking into the time that is spent by operators in the process a more detailed distinction between process steps is more useful. Therefore, we will use the three colour scale of the TVM to create a complete overview of the process in VA, NVA and N activities.

4 WASTE IN THE PROCESS

Now it is time to combine the theoretical knowledge gained in Chapter 3 (Section 4.1) and the insights in the process from Chapter 2. To determine which steps add value and which do not, we will analyse the process with a TVM, as described in Chapter 3. With the outcome of this analysis, the activities that do not add value can be identified. These activities are called 'waste' and will be the focus of Chapter 5, possible solutions (Section 4.2).

4.1 VALUE ADDING AND NON-VALUE ADDING ACTIVITIES

As mentioned in Section 1.5.2.1, there are value adding, non-value adding and necessary activities. A **value adding activity** should comply with the following requirements:

- The customer is willing to pay for it.
- It should be done 'first time right'.
- The activity should change the product or service in some way.

If an activity does not meet one of these requirements, it is classified as either necessary, actions that add no value but are inevitable, or **non-value adding**, also called '**waste**'.

The eight types of waste are:

- Over-production
- Waiting
- Transport
- Over-processing
- Inventory
- Movement
- Defects
- Unused Expertise

4.2 MAPPING WASTE

Using this definition of a value added activity, all actions in the process have been evaluated. Every action that did not change the product in any way is considered non-value adding, or necessary if it is a specific request of the customer.

For the support hours, there are no actions that literally change the product. Therefore, an action in support process steps that 'makes a change to the product' is considered an action that changes the minimal needed entities, e.g. in the ERP system, to enable the process to move one step closer to making the product. For example, the uploading of the routing into the ERP system, since the routing is needed to steer production.

4.2.1 Waste Map of the whole process

With all the actions, that form the working hours, classified as either value adding (VA), necessary (N) or non-value adding (NVA) we can create a waste map of the process (Figure 14). With this map, we create a visual overview of the process that shows the ratio between the three types of activities.



Time (hr.)

Figure 14 Waste Map of the whole labyrinth process

From the waste map, it is clear to see that there is a lot of waste at the beginning of the process, and some big parts at the end of the process. The presence of 'little' blocks of non-value added time indicates that there are a lot of small actions that could be eliminated from the process.

4.2.2 Ratio of VA, N & NVA per process step

The overall waste map already gives insights into the process and the ratio of value added and non-value added time. However, it is hard to see exactly what the ratio is per process step. Therefore, an overview of the ratio per process step is given in [Table 4](#).

	Total Hrs.	VA	N	NVA
Planning	0.16	0.00 <i>0%</i>	0.16 <i>100%</i>	0.00 <i>0%</i>
MRP	0.21	0.05 <i>26%</i>	0.11 <i>56%</i>	0.04 <i>17%</i>
TSE	0.40	0.06 <i>15%</i>	0.10 <i>24%</i>	0.25 <i>61%</i>
PM	0.19	0.00 <i>0%</i>	0.12 <i>61%</i>	0.08 <i>39%</i>
Quality MDB	0.15	0.00 <i>0%</i>	0.05 <i>27%</i>	0.13 <i>73%</i>
Sawing	0.32	0.25 <i>75%</i>	0.04 <i>13%</i>	0.04 <i>13%</i>
Turning	1.46	0.78 <i>54%</i>	0.30 <i>20%</i>	0.38 <i>26%</i>
Milling	0.41	0.07 <i>18%</i>	0.22 <i>55%</i>	0.11 <i>27%</i>
Eroding	0.59	0.23 <i>40%</i>	0.12 <i>20%</i>	0.24 <i>41%</i>

	Total Hrs.	VA	N	NVA
Glowing	0.09	0.07 73%	0.03 27%	0.00 0%
Bench Work	0.12	0.12 100%	0.00 0%	0.00 0%
Quality Inspection*	0.12	0.00 0%	0.09 76%	0.03 24%
Packaging & Shipment	0.17	0.03 15%	0.14 79%	0.01 5%
Total	4.42	1.66 38%	1.47 33%	1.30 29%

Table 4 Overview of VA, N, NVA time per process step

**Although quality checks that do not modify the product are considered waste by definition, we classified it as necessary because the customer demands a dimensional protocol, and thus the dimensions must be measured and registered at least once.*

From **Table 4** it becomes clear that the total amount of non-value added time in the process is 1.30 hours. The majority of this time comes from the Turning process step (0.38 hrs.), but also Eroding, TSE, Milling, PM and Quality MDB have a significant contribution to the total non-value added time.

For Turning, this time comes mainly from the fact that the machine contains too much unreliability in the turning process. For example, determining the reference point has tenths of a millimetre of slack, but if the turning machine has its reference point just a few tenths of a millimetre off, the machine will produce out of specification, which allows slack of only a few hundredths of a millimetre. Another example, the tools that are used wear over time, causing a difference in the dimensions programmed in the machine and the actual dimensions produced. To counter this issue, the turning is done in three rounds, first roughly to get rid of most of the material, and then operators measure the dimensions and manually adjust the machine's settings to turn outside of specification, then the operators measure again and turn within specification. Also, the operators often have to put a lot of effort into understanding the drawings they get, sometimes having to go back to the TSE to explain it to them. Additionally, at Turning the dimensions must be measured for the dimensional protocol.

For Eroding, there is a significant difference between what is measured and what comes out of the ERP system's data. Because it is easy for eroding to retrieve the modification time (the machine tracks it itself), the operator made an overview of the modification time per labyrinth he modified. This difference is not explainable, also due to a change in operator. Therefore, we assumed that the difference of 0.24 hours is non-value added time and therefore can be eliminated

For the Technical Support Engineer, the non-value added time comes from all kinds of manual steps that need to be done in the ERP system. There already exists a tool with which the TSE can determine the routing. However, this routing needs to be added in the ERP system manually, line by line. Because of this, the TSE spends most of his time manually changing and adding data in the ERP system that he has created in just a few minutes.

For Milling hold the same issues as with Turning, determining the reference point is too inaccurate and filling in the dimensional protocol takes extra time that is not used for modifying the product.

For Project Management, the first things to do are to gather and print all documents (routing card and drawings), which lie in different buildings and put them together in a folder. And after that, they must bring the folder to the starting point of the process, which is almost always sawing (which is located at the other side of the plant).

Lastly, the Quality MDB department is responsible for making sure that the right 'quality documents' are created and collected. To keep an overview, they use a big Excel list in which is stated per order which documents need to be created. Next to that, they check whether the right quality requirements are filled in on the routing card. However, they do not get a sign when the routing is ready, so they have to manually look for the routing, which is not always ready when they look so they have to look again. Lastly, when inspection has done their work, MDB gathers all the documents and uploads them to a separate system. This means that the Quality MDB step is spending most of its time retrieving information from different places, which is waste.

4.2.3 Potential improvements

With the non-value added activities identified and with the amount of non-value added time per process step determined, we can add up and see what the potential of the process is.

As can be seen from **Table 5**, when we would eliminate all the non-value adding activities, the total number of hours that will remain is 3.13 hours. This would mean a reduction of 29.29%, very close to the 30% target that was set beforehand.

	Average ERP (hr.)	Potential without NVA (hr.)	Reduction (hr.)	Reduction (%)
Support	1.14	0.65	-0.49	-43%
Production	3.29	2.48	-0.81	-25%
Total	4.42	3.13	-1.30	-29.29%

Table 5 Potential improvement of the process

Next to the reduction of non-value added time, the necessary time should be minimised. In Chapter 5 possible solutions to do this will be evaluated.

4.3 CONCLUSION

A total of 1.30 hours of non-value added time has been identified through mapping the waste. The process steps where the majority of this waste was found are: Turning, Eroding, Milling, Technical Support Engineer, Quality MDB and Project Management.

All this non-value added time must be eliminated from the process. To do this, solutions must be made to the following issues:

- Too much uncertainty in the machines to determine reference points accurately.
- The dimensional protocol has to be filled in and checked by multiple process steps if this could be done only once it would save time.

- TSE has to do a lot of manual actions, those actions do not add anything to the creation of the routing.
- Quality MDB is spending quite some time checking the process. If this were standardised it would save time.
- Eroding should be planned more accurately.

Additionally, all the time spent on necessary actions should be minimised, as it also does not add value.

5 POSSIBLE SOLUTIONS

After creating an overview of how the current process works, finding a method of mapping waste in a process and analysing the current process with the method we found, it is time to find an answer to the next research question ‘*what are possible solutions to reduce the number of working hours needed in the process of labyrinth production?*’. From Chapter 4 we know how much working hours are value adding and which are not. We also know now, where the areas for improvement lie in order to get closer to reaching the goal of 30% reduction in the number of needed working hours. In this chapter, we will discuss, both for individual process steps and the process as a whole, solutions that will either eliminate non-value adding time or decrease the amount of necessary time.

5.1 DRAFTING THE SOLUTIONS

Before we get to the solutions, we will first discuss how we are going to categorise the solutions and which criteria we have set for the solutions.

5.1.1 Impact-Effort Matrix

A way to categorise or prioritise possible actions is by evaluating them in an ‘Impact-Effort Matrix’ (Figure 15). This matrix consists of two axes. Horizontally, the effort axis, how much time, money or resources are needed to complete a task. Vertically the impact axis, how much value or impact the outcomes have on the business or project. These two axes divide the matrix into four quadrants to which one can assign tasks, or in our case solutions. The four quadrants are:

- **Quick wins:** These activities give the best return based on needed effort. These activities are also called ‘low-hanging fruits’.
- **Major Projects:** Activities that provide long term returns but are more difficult to execute and need more planning.
- **Fill Ins:** These activities are the everyday tasks, they provide little impact but also do not take much effort.
- **Hard Slogs:** These activities take a lot of time and effort but do not give much impact in return, these activities should be avoided.

(GroupMap Technology Pty Ltd, 2019)

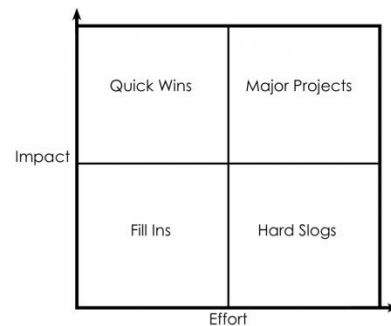


Figure 15 Impact-Effort Matrix (Hardwick, 2014)

The solutions drafted to reduce the number of needed working hours in the labyrinth process can also be classified in the four quadrants of the Impact-Effort matrix. Because of the transition from Siemens to VDL and the changed role, there is some urgency in improving the process. Therefore, the decision has been made to focus on solutions with short term gains. These are the solutions that require relatively low effort or are less complex to implement, for example, because it is clear what needs to be changed. Any room for improvement that remains after the proposed solutions will be highlighted so that it is clear to VDL ES where next or bigger improvement projects can focus on.

5.1.2 Criteria for the Solutions

In Chapter 2, we did not only gain insights in how the process works and how much time it takes, but we also did observations that have an impact on the process and the needed number of working

hours. These issues do not directly lead to more working hours as a non-value adding action would do. However, indirectly these issues cause the process to be hard to predict and undependable.

Therefore, we set ourselves the following set of criteria next to the criterium of making the process shorter. Each solution should make the process shorter and/or make sure that the process becomes:

- More **standardised**, always the same procedures and no room for deviations.
- More **dependable**, meaning the quality of the products improves.
- Better '**analysable**', so that more and better data can be measured.
- More **controllable**, making sure all information that is needed is available and that the hours that are being sold are accurate.

5.2 SOLUTIONS

In this section, we will explain possible solutions to reduce the needed number of working hours. First, we will give an overview of possible solutions specific for individual process steps. After that, we will elaborate on solutions that will apply to the functioning of the process as a whole. Each solution has received a number which stands behind the paragraph between brackets. With this number, the solution can be identified in the impact-effort matrix in Section 5.2.4. Next to that, behind each solution it is indicated with the letters S, D, A, C to which of the four criteria in Section 5.1.2 the solution works beneficial. The letters are the first letter of that criteria respectively (note that solutions that only make the process take less working hours did not receive a letter).

5.2.1 Solutions per process step

The process steps are ordered from most non-value added and necessary time to least, behind each process step this amount of time is noted.

5.2.1.1 Turning (0.67 hr.)

Turning is the process step with the biggest portion of working hours that do not add value. This is due to the fact that turning modification takes a lot of time. Next to that, turning operation contains a lot of uncertainty in the tools, setup, material and environment. To cover this it takes three turning rounds to turn a labyrinth within specifications, the first is rough-turning, the second is turning with some extra margins and the last round is turning to full specification. The dimensions that need to be produced are tenths or even hundreds of a millimetre. With the amount of variation that currently exists in the machines, it is impossible to turn in less than three rounds, so that they can manually adjust the machine each round to make sure it does not cut away too much in one round.

Some possibilities to reduce the working time where no value is added:

- There is too much variation in the operation which should be minimised. To lower the variation possible solutions are: better equipment to determine reference points, better tools that wear slower, redo the placement of the machine to reduce uncertainty through vibrations or create a more constant environment around the machines. These must increase the reliability of the turning process reducing the time needed for checking and more importantly improve the quality of the product. **D (1)**
- It was indicated that sometimes the diameter of the sawed product is significantly bigger than the diameter that the final product should have. So, a lot of material has to be cut away, causing longer turning times and more wear on the tools (which causes unreliability). To counter this, VDL could buy more different types of raw material that saves turning time and

wear. Of course, this will not be cost-efficient for the more rare diameters so it has to be further investigated if more types of raw material is cost-efficient. **D (2)**

- Every single product is produced from the technical drawings. It happens often that the drawing is not that clear. If this is the case the operators need more time to understand and check the drawing, or have to ask others what they have to do. This is all waste by definition. Therefore, there should be a system to improve the quality of the technical drawings that ultimately go to the factory. This also means that VDL can set requirements on the drawings they receive from customers. **D, C (3)**

5.2.1.2 Eroding (0.36 hr.)

Eroding takes on average 0.59 hours, however, because it was easy to retrieve the modification time from the machine we were able to create an overview of the actual times the whole eroding process took. From this overview it turned out that on average, with only very few outliers, eroding took 0.35 hours. Together with the operator we could not explain this difference. This makes us believe that it should be doable to plan, on average, 0.35 hours for eroding instead of 0.59 hours, and the gap of 0.24 hours is 'useless time'. **Saved time: 0.24 hours. (4)**

5.2.1.3 Technical Support Engineer (0.34 hr.)

The goal of TSE is to make the routings and enter them in the ERP system. In this process, there are a lot of manual actions that need to be done while the actual routing is made with just a few clicks in a separate tool. More manual actions also cause more actions for the ERP system, during observations quite some time went by where the ERP system had to process data and no adjustments could be done. Solutions for Technical Support Engineering are:

- Create the possibility to upload the routing directly from the, already existing, labyrinth generator tool. From this tool a file could be exported that then could be upload into a routing in the ERP system. This would save a lot of manual actions and also reduces possibilities for mistakes. **Saved time: 0.23 hours. S, D, A, C (5)**
- The dimensional protocol is made by the TSE. This protocol is a demand from the customer. If VDL ES would provide each customer with a blanc dimensional protocol in which they can fill in the demanded dimensions themselves, this saves working hours (and thus cost price) and possibilities for errors. **Saved time: 0.09 hours. D (6)**
- Both MRP and TSE connect drawings, one to the production order and the other to the routing. However, the production order and the routing are connected to each other, so why not make sure that the ERP system automatically connects the drawings from the production order to the routing? **Saved time: 0.01 hours. (7)**

5.2.1.4 Milling (0.33 hr.)

For the milling process step hold the same problems as for turning. The reference point cannot be determined accurately enough to modify within the very small margins and tools wear. Also, after milling the miller has to fill in the dimensional protocol.

A solution for milling can be, just as with turning, to get better tools so that the quality is increased and maybe the checking and the second milling round could even be shortened a bit. **D (1)**

5.2.1.5 PM (0.19 hr.)

For PM a lot of the time they have to go after products, they have to search them in the factory, check whether everything is going according to planning, and if not they have to contact the customer. All

these checks are a result of the process as it currently goes, so if the process would become more predictable, easier to control and more standardised it will mean that PM needs less time to do searches and checks.

5.2.1.6 Q MDB (0.18 hr.)

A big part of the current occupation of Q MDB is checking the order and checking that the right instructions are placed in the routing. This checking should not be necessary. For relatively simple products such as labyrinths, there is not that much variation in the documents that are needed or the instructions on the routing.

- In the generator tool that TSE uses there should be made an option to fill in the applicable quality plan, which automatically adds the right instructions on the routing. **Saved time: 0.04 hours. S, A, C (8)**
- Another document that needs to be searched for is the material certificate, that comes with a piece of new raw material. If the amount of material that needs to be sawed in the production order is connected to the raw material, and the certificate is in the ERP system, it should be possible to automatically connect the right certificate to the order. This means that the certificate will be directly available without needing to search for it. If all documents are “automatically” available, then it should not be necessary to make an overview of what is needed, saving time. **Saved time: 0.08 hours. S, C (9)**

5.2.1.7 MRP (0.15 hr.)

For the MRP process step, there are some small changes that could save a little bit of time:

- Save the documents directly to the right location on the server. **Saved time: 0.01 hours. (10)**
- Stop checking the availability of raw material, that is the responsibility of purchasing. **Saved time: 0.013 hours. (11)**
- The ERP system requires a manual change of the sawing line when a new production order is created. This is a useless change. **Saved time: 0.003 hours. (12)**

In order to be able to link a material certificate to the order, MRP should link a sawing line in a production order to a specific piece of raw material.

5.2.1.8 Packaging & Shipment (0.15 hr.)

Most of the non-value added time comes from making the label that should go on the package. This label should contain the project, order number, description and quantity. The label is currently created manually, but it should be possible to create it from the ERP system with a single push from a button, reducing the needed time from several minutes to only one. **Saved time: 0.04 hours. S, C (13)**

5.2.1.9 Quality Inspection (0.12 hr.)

At this moment there is not much that can be done to lower the number of needed working hours at the inspection step. If products are produced right, they can do their task in the time they get for it. The problem here arises when there are errors, because then a lot of extra actions have to be done. So to reduce the number of hours that quality inspection needs, the quality of the labyrinths should be increased. By reducing variation and enabling operators to use good measurement tools the quality can be increased. Eventually, if the quality increases enough, the inspection could be done not for every single product but by means of checking samples of all products. **S, D (14)**

5.2.1.10 Sawing (0.08 hr.)

For sawing it holds that the number of needed hours depends mostly on the diameter and type of material that needs to be sawed. So, if more types of material are in stock then smaller diameters could be used to reduce sawing time. Again, keeping more types of raw material in stock should be cost-efficient, so VDL ES should find out that first before implementing this solution. **D (2)**

5.2.1.11 Glowing (0.03 hr.)

For Glowing it should become possible to easily link the glowing operation or glowing run to a set of production orders. This way, the operator can upload his documentation into the ERP system and through the link that was made, these documents are automatically available to the Q MDB department. **S, A, C (9)**

5.2.1.12 Bench Work (0.00 hr.)

The benchwork is very simple for labyrinths. It is only making sure there are no scratches, no metal curls remain in tapped holes and the serial number is engraved. At the moment this is a separate process step. Where the turning, milling and eroding machines are positioned next to each other, the benchwork needs to be done somewhere else, meaning it needs to be transported there which increases the likeliness of the labyrinths being damaged, which again causes extra work. Therefore, a solution is to equip the eroding bench with the material needed to do this and go from there straight to quality inspection. **D (15)**

5.2.2 Solutions for the whole process

We have now evaluated several solutions to reduce the number of working hours for individual process steps. Next to these solutions, we also drafted some solutions that apply to the process as a whole and are meant to increase the control over the process so that the actual working hours can be decreased.

5.2.2.1 Labyrinth identification numbers

A project that is already worked on is that of the labyrinth generator tool. This tool creates a cost price and routing based on the parameters 'shape type', 'material', 'number of teeth', 'diameter', 'Split' and 'quantity'. This tool is already used by TSE as a source to create the routings in the ERP system. The tool uses the parameters also to create a special identification number. We suggest that the code gets an extra number that indicates glowing (0-1) and that the diameter parameter number gets more categories. **S, A, C (16)**

This number can be used for all kinds of analysis, for example how accurate the planned number of working hours (VC) is for sawing aluminium labyrinths. Also on the financial side, these codes can be used to determine cost prices accurately and adjust them if they turn out to be too low or too high. More on how to do this will be elaborated under Section 5.2.2.5.

Another useful application of this number is in the factory. All the machines need to be programmed before they can modify the product. These 'programmes' remain on the computer of the machine. Already, operators re-use the earlier programmes to reduce programming time. This can be done in a more structured way if the modification programmes are saved under the identification number. Because this number already contains a certain shape, the number of teeth, the material and the diameter, there is not much that needs to be adjusted after. When it is thoroughly checked that the programme is correct, it can be used multiple times after reducing the chance of errors.

5.2.2.2 ‘Signing off’ start and finish of process step

In a process where the margins are small, it is very important that the data that represents the process is as accurate as possible so that the process can be adjusted and fine-tuned to increase profitability.

Something that was observed in the process and described in Section 2.3.4 is that the registration of hours in the ERP system was not accurate. To increase the accuracy of the registration of the duration of production steps in the ERP system, there should be a clear and, above all, easy way to ‘sign off’ the step. This method must be easy and mistake-proof so that the data is accurate. **S, A (17)**

To make the procedure easy, a possibility is to include barcodes, that represent the order number, in the physical routing card and equip the operators with scanning tools with which they ‘sign on’ the product when they start modifying and ‘sign off’ again when they are finished with modification. This method means that there should be made a possibility in the ERP system to do this signing on and off.

To make it error-proof two things can be done:

- The ERP system gives pop-up notifications after the time of start + planned modification time + some margin, let’s say 15 minutes. When the operator is still busy, he can indicate he is still modifying and if he forgot to sign off, he can sign off by a click on a button. This way, the maximum error that the NC can contain is the margin X. If the operator is still busy, he could also indicate why it takes longer (for example “I miss a part”), this data then gives insights in bottlenecks in the process.
- The sequential step can only start, in the ERP system, when the previous step has been signed off. This also causes that operators will notify each other when they did not sign off properly because otherwise they cannot continue their own work.

If the implementation into the ERP system will take a lot of time, a temporary short term solution is necessary. To force operators to fill in the hours they needed directly after they finished modification, a short checklist can be placed on the routing card. In this checklist, operators should then check off that they filled in the hours and checked the product on damages and errors. When it is found that there are irregularities in the registration in the ERP system, there is physical evidence which can be used to track down the irregularity and address the responsible operator.

5.2.2.3 Planning the order of production

At this moment Planning determines whether a delivery date is feasible. If it is, a ‘factory done’ date is chosen a week before the delivery date, which is the date the labyrinth must be finished. Based on this date it is determined whether or not the production of a labyrinth is started or not. When it starts this ‘factory done’ date is put on the physical routing card so that operators can prioritize which order the process first. **S, A, C (18)**

Based on the ‘factory done’ date and the routing made by TSE it is possible to plan backwards through the process and determine when each individual process step must start and when it should be finished. The current software that is used to plan orders is capable of making such a planning. With the help of the labyrinth identification number, the planning could be adjusted a bit so that the same type of material or the same diameters are scheduled together to reduce set-up times.

With this new planning, there is a clear overview of where a labyrinth should be at a given time and it will become easy to check whether or not production falls behind schedule or not. This helps Planning and Project Management in keeping an overview of the process, so less working hours will be needed, and the operators have clear time windows in which they know what to manufacture.

5.2.2.4 Day starts/Stand-up Meetings

A technique that originates from 'Lean Daily Management' is stand-up meetings. These meetings take place every day at a set time for about ten to fifteen minutes, standing around a communication board, placed at a set location on the work floor. Displayed on these communication boards are 'Key Performance Indicators' (KPIs) that are relevant for the team and that the team has influence on. Examples of relevant KPIs are 'the amount of Work-In-Progress work', 'the number of rejected products' or 'the status of emergency orders' (Theisens, 2018).

VDL ES could implement a stand-up meeting at the start of or halfway each production shift to discuss things like orders that have to be produced during that shift (if needed put extra emphasis on emergency orders) or errors and complaints that occurred in previous shifts and how to prevent these errors. **S, C (19)**

The goal of this stand-up meeting is that all operators get involved in making sure that products leave the factory on time and problems are handled swiftly so that there can be some continuous improvement in the labyrinth process.

5.2.2.5 Analysis of VC and NC

To be able to continuously fine-tune the working hours you need to produce a labyrinth and thus to offer competitive prices, there should be a continuous analysis of the working hours that were needed. On a regular basis, the differences between the hours that were planned (VC) and the hours that were realised (NC) need to be analysed, so that the hours that end up in the routing are as realistic as possible. **S, A, C (20)**

The same kind of analysis has been done to analyse the current process in Chapter 2. Therefore, we have built a little tool with Excel and made a manual on how to use it (Appendix D). This tool gives an overview of the performance of all the process steps and will enable the analysers to sort on parameters such as material or diameter.

With this periodic analysis, the input for the labyrinth generator tool can be adjusted so that the routings become more and more accurate.

5.2.2.6 Reporting errors in order routing through standard form

The goal of the analysis of the VC and NC hours is to fine-tune the hours that are needed for certain steps under certain conditions so that the process can be planned accurately. The same goal holds for this solution. It happens that the instructions and hours that are given in the routing are way off.

If operators find such an error, they report that to their team leader, who then forwards that to the relevant persons. However, from interviews it became clear that mistakes that were reported reappeared in the routings and thus were not solved. This happened so often that the operators said

they became tired of reporting and thus stopped doing so. This is a problem as errors will not be exposed and thus not be solved.

To solve the above there should be a clear procedure for reporting errors that makes sure that the errors are solved and that the operators get feedback of what is done with their report. This will, next to solve errors, stimulate operators to contribute to optimising the process, which is needed to continuously improve. **S, A, C (21)**

To make sure that the procedure becomes clearer is by giving the operators a standard form in which they can state what the error is. The form includes relevant numbers, the labyrinth code, the number of VC hours, how much those hours differ from what is actually needed, and lastly why the number should be higher or lower. This form is then sent to a new mail alias with its own mailbox, to which all relevant people have access. Each month the responsible people go through the mailbox and check of each received form if they have solved the error or if an error needs follow up steps. If the error is solved the operator gets a reply with what is changed.

5.2.3 Solutions for the long term

The solutions mentioned so far are (almost all) solutions that fall in the category of 'Quick Win' or 'Fill Ins', meaning that they take relatively low effort to start/implement. However, as will be shown in Section 5.3, these solutions do not result in enough reduction of working hours to reach the 30% target or even the 29.29% potential that we found in Chapter 4. After the implementation of the solutions, there remains some non-value added time which should be eliminated in the long(er) run. Therefore, we have indicated what should be done (roughly) to also eliminate that waste from the process. These solutions are for (continuous) improvement projects that will need to take place.

5.2.3.1 Striving for 'First Time Right' and Improved Quality

As indicated before, there is uncertainty in the machines that are used for turning and milling. To reduce some of this uncertainty we have proposed some 'simple' solutions. These solutions do not eliminate all uncertainty. Therefore, uncertainty remains that needs to be eliminated to be able to reduce modification time and improve the quality of the products.

However, First Time Right production is not something one can achieve overnight. It takes time and asks the persistence and cooperation of everyone involved. If a culture of continuous improvement can be established and enough time and dedication are invested by both management and operators it should be possible to create a highly dependable process that saves time and delivers high-quality products. The time this can save is another **0.11 hours. S, D, A, C (22)**

Another aspect of the process that will improve due to first time right production and higher quality of the products is that the quality inspection department can go to checking sample-wise and not every individual product. If the number of labyrinths that will be checked drops to, for example, 10% because of sample-wise checking, then the number of hours needed to check labyrinths will be 10% of what it is now. Then the saved time will be, on average, about **0.10 hours. S, D (14)**

5.2.3.2 Optimising the dimensional protocol

Something that will remain to take non-value added time is the dimensional protocol. In the short term, there is not enough that can be done that could fully eliminate the time that is spent making and filing in the protocols. Therefore, it is needed to look into projects that can make the actions

regarding dimensional checking quicker, more accurate and/or even redundant. This could, for example, be a measuring method that saves time or a quicker way to digitally fill in the protocol. Eliminating this time can save approximately **0.05 hours** of working hours. **S, D, C (23)**

5.2.3.3 Stop collecting (quality) documents from different locations

A thing that takes a lot of non-value added time at multiple process steps but mostly at Quality MDB, is that documents or information must be searched for manually. This time does not add any value and should therefore be minimised and if possible eliminated. A lot of the information should be able to be embedded in the ERP system, earlier examples have already been given in the sections above. When all documents are linked to the right entities and operations, it should be possible to do the MDB part almost automatically and save a lot of time at other process steps.

Next to the digital searching of information and documents, there are also physical documents, such as drawings, that need to be picked up at someplace and delivered at the other. All this movement is non-value added time. The time that is saved by finding a way to get physical documents from place A to place B without someone having to collect them is approximately **0.05 hours**. **S (24)**

5.2.4 Impact-Effect Matrix for the solutions

In the sections above, a lot of possible solutions have been proposed. Before we discuss what the effect of them will be on the new process, we will categorise them in the impact-effort matrix. First, we will discuss the criteria that have been used to determine the position of each solution. Secondly, we will discuss how to interpret and use the impact-effort matrix and the division that we have made.

First, the impact axis. The biggest criterium was the number of saved hours of the solution. The biggest number of saved hours is 0.24 (4), so that solution received a high score on impact. For a lot of solutions, it was not possible to quantify the number of saved hours. Therefore, we looked at the extent to which a solution changed the process. For example, the labyrinth identification numbers (16) are not used yet in managing the process, but when they are it will significantly change the way the process is managed, and therefore it received a high score on impact. Also, the signing on and off of orders at the production process steps is a solution that has a high impact, as it will provide VDL ES with data that is a lot more accurate than it is at the moment, which will enable them to plan and analyse their process better and optimise it further.

Secondly, the effort axis. For effort, it is even harder to quantify, as it is hard to say for us how much time a solution costs to make or implement. Therefore, we have looked at two things that helped us give a score on effort for each solution. The first is how much work is needed to change the current machines or (IT) infrastructure. For example, other tools can be placed in the machine, that does not take that much effort, but making scanners compatible with the ERP system requires some coding and 'tailor-made' work, which obviously requires more effort. The second criterium was whether or not there was already a project worked on within VDL ES that leads to the solutions. For example, the labyrinth identification numbers are a project that has progressed quite far and has started to be implemented. Such a solution thus does not cost very much effort. On the contrary, doing several continuous improvement projects to optimise the process further in the future is more uncertain and requires effort from a lot of employees, these projects thus received a high score on effort.

In **Figure 16**, the division of all the solutions that have been made can be seen. Each solution in Sections 5.2.1, 5.2.2 and 5.2.3 has received a number with which they are labelled in the matrix.

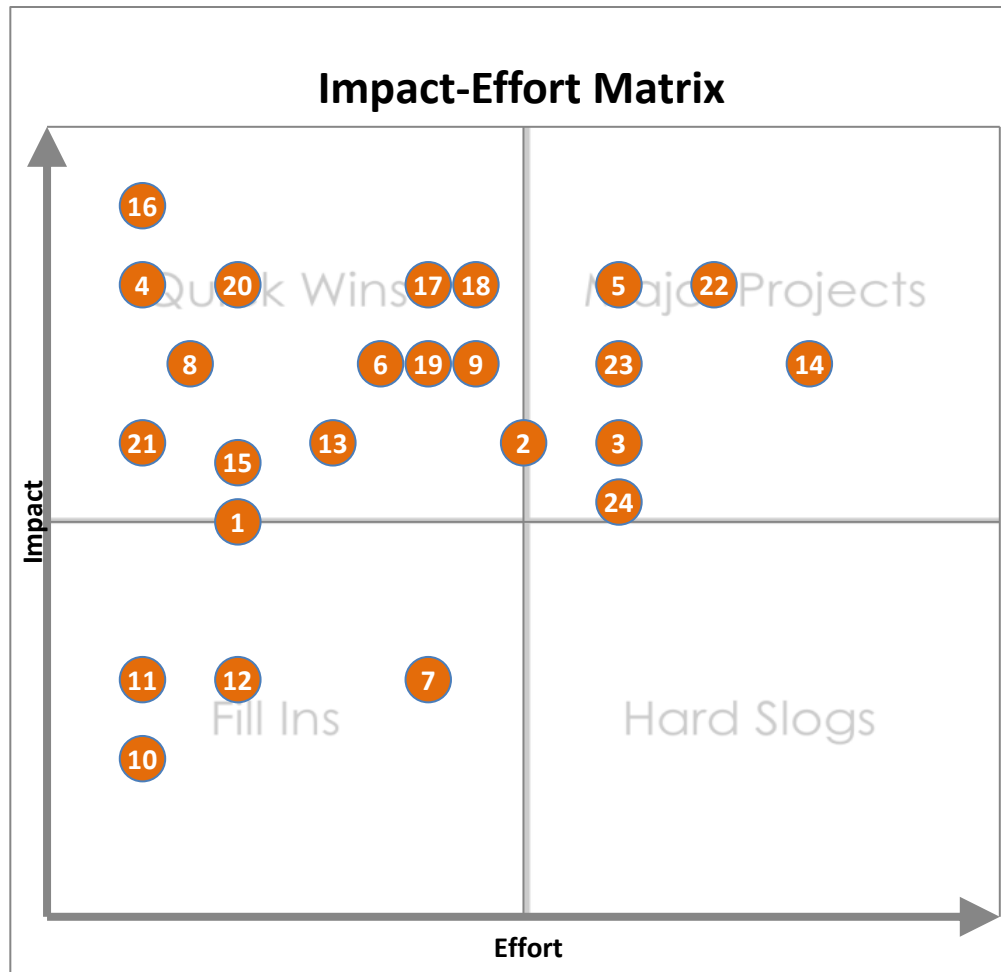


Figure 16 Impact-Effort Matrix of the solutions

When looking at this matrix, it is important to keep in mind that the location of these points should not be considered to be the 'absolute truth'. As explained above, we made the division ourselves and although we did our very best to make it as objective as possible, there still remains subjectivity in the allocation of scores on both axes. This is not necessarily a problem, since we think that the relative position the points have to each other is sufficiently accurate. In practical terms, there is not that much difference between a score of 9/10 or a score of 4/5, as long as the relative position changes with the same amount.

Next to that, we are confident that an employee of VDL ES who would fill in this matrix would get almost the same matrix as a result. Some points may change position a little, but the overall division would be roughly the same.

Lastly, how to use this matrix? The matrix is useful to show the ratio between the result and the needed resources of a solution. For VDL ES this overview can be helpful in determining the order of solutions to work on. The projects that are already worked on have a low score on effort, so they can start by doing the projects with low effort and high impact first. After that, they can look more to the right in the 'Quick Win' quadrant, and start on projects which take more effort and continue doing so

until the ratio between the needed effort and the impact is such that it might be more useful to do an easy task with a low effort from the 'Fill Ins' quadrant.

When all 'Quick Wins' and 'Fill Ins' are done, VDL ES can start on the major projects.

5.3 NEW PROCESS

We now have a long list of solutions both on the short as on the long term to improve the process so that the goal of 30% reduction in the number of needed working hours is achieved. With all these solutions it is time to create an overview of how many working hours this 'new' process will take on average, and the activities that remain for each process step.

5.3.1 New durations of each process step

With all of the quick win solutions taken into account, a number of actions could be eliminated from the process. Next to that, we adjusted some action durations because they were estimated unrealistically high. This results in a new process that is expected to take a total of 3.63 hours on average. In [Table 6](#), an overview is given of all the process steps and what the new expected duration is per process step, also the change with regard to the current duration is given.

Process step	Hrs.	Change (%)
Planning	0.16	0%
MRP	0.18	-15%
Technical Support Engineering	0.13	-68%
Project Management	0.18	0%
Q MDB	0.05	-73%
Sawing	0.33	+2%
Turning	1.46	0%
Milling	0.35	-14%
Eroding	0.36	-39%
Glowing	0.10	+7%
Bench work	0.08	-32%
Quality Inspection	0.13	-4%
Packaging & Shipment	0.14	-19%
Total	3.63	

Table 6 Expected duration per process step in the new process

Some process steps show an increase in the number of working hours they are expected to take in the future. This is due to the solution of implementing scanners to sign on and sign off the orders when an operator starts and finishes modification. Although this results in an increase at first, as the registration of the working hours becomes more accurate it is expected that a decrease in the needed number of working hours will show over time.

Furthermore, some steps show a decrease while the solutions described above do not cause a reduction. This is due to a correction that is done in which unrealistically high estimates are lowered to values that the operators indicated themselves. This has as a result that the above list can be used as a first starting reference for average durations.

The new process flows per process step and an overview of the actions that are needed at each process step are given in Appendix B.

5.3.2 Improvement of the process as a whole

With the new duration of each process step, we are also able to determine the new total duration of the process. How much do the solutions bring the process closer to the 30% reduction target? We already found that the new process takes 3.63 hours on average, this is a 17.97% reduction from the 4.42 hours it takes currently, as can be seen in [Table 7](#).

	Current Process (hr.)	New Process (hr.)	Reduction (hr.)	Reduction (%)
Support	1.14	0.69	-0.45	-39.48%
Production	3.29	2.94	-0.35	-10.57%
Total	4.42	3.63	-0.80	-17.97%

Table 7 Improvement of the process

You might think “but the potential reduction was 29.29%, why is the new process only 17.97%?” and that is a justified thought. As mentioned earlier, the solutions that are now implemented in this new overview are the quick wins, the solutions that can be easily implemented, that do not require great amounts of time and/or effort. However, after implementation, there is still non-value added time in the process which should in the long term be eliminated. When these non-value added activities are eliminated from the process, by for example achieving ‘First Time Right’ production, then it is possible to achieve the 30% reduction of the number of needed working hours.

5.4 CONCLUSION

With the insights about waste in the process, we have drafted multiple solutions that can be used to reduce the non-value added and necessary time in the number of working hours. The impact-effort matrix has been used to categorise these solutions as either ‘Fill Ins’, ‘Quick Wins’ or ‘Major Projects’ based on the impact the solutions have and the effort they take to implement.

Because it is important for VDL ES to improve the labyrinth process in the short term as it fails to be profitable in some cases already, a new list of process steps has been designed with the quick wins and fill in solutions taken into account. Next to these solutions, there are some areas of improvement that will take longer to implement are identified for further reduction of the number of needed working hours.

With the solutions taken into account, we get a process that requires 0.80 working hours less. This is a reduction of 17.97%. When VDL ES manages to also successfully implement the bigger projects then the potential of 29.29% reduction can be reached and even a bit more.

Overall the biggest task for VDL ES is to eliminate the variation in the process. It is important that they make sure that the employees at every process step know exactly what to do. Also, all possible causes of variation should be identified and eliminated as much as possible. This means that all needed information should be available and the collection of data should be as accurate as possible so that eventually it becomes possible to have complete control over the process.

5.5 OVERVIEW OF ALL SOLUTIONS

In this section, we give an overview of all the solutions drafted in this chapter.

Nr.	Short Description	Process Step	Quadrant I/E Matrix	Effect on criteria	Saved Time (hr.)
1	Better equipment to determine reference points, better tools that wear slower and redo the placement of the machine(s).	Turning, Milling	Quick Wins/Fill Ins	D	?
2	VDL could buy more different types of raw material that saves turning time and wear.	Turning	Quick Wins/Major Project	D	?
3	Make it clear on the drawings which dimensions are for turning to make and which are for milling. Quality of the drawings should increase in general.	Turning, milling	Major Projects	D, C	
4	Eroding must on average realise an NC of 0.24 hours.	Eroding	Quick Wins	-	0.24
5	Create the possibility to upload the routing directly from the, already existing, labyrinth generator tool.	Technical Support Engineer	Major Projects	S, D, A, C	0.23
6	If VDL ES would provide each customer with a blank dimensional protocol they could fill it in themselves, this saves working hours (and thus cost price) and possibilities for errors.	Technical Support Engineer	Quick Wins	D	0.09
7	Make sure that the ERP system automatically connects the drawings from the production order to the routing.	Technical Support Engineer	Fill Ins	-	0.01
8	In the generator tool that TSE uses there should be made an option to fill in the applicable quality plan, which automatically adds the right instructions on the routing	Q MDB	Quick Wins	S, A, C	0.04
9	If the amount of material that needs to be sawed in the production order is connected to the raw material, and the certificate is in the ERP system, it should be possible to automatically connect the right certificate to the order.	Q MDB	Quick Wins	S, C	0.08
10	Save the documents directly to the right location	MRP	Fill Ins	-	0.01
11	Stop checking the availability of raw material, that is the responsibility of purchasing	MRP	Fill Ins	-	0.01
12	The ERP system requires a manual change of the sawing line when a new production order is created. This is a useless change	MRP	Fill Ins	-	0.00
13	Be able to create a label from VBS with a click on a button	Packaging	Quick Wins	S, C	0.04
14	Increase the quality of the produced products so that in time, inspection goes through sample checks.	Q Inspection	Major Projects	S, D	0.10
15	Replace bench work to eroding or milling to lower lead time and reduce possibilities of damage	Bench Work	Quick Wins	D	?
16	Labyrinth identification numbers to steer production.	Whole process	Quick Wins	S, A, C	?
17	Signing on and off of process steps through a scanner system.	Whole process	Quick Wins	S, A	?
18	Use a more lean/pull way of planning the production based on ready date and routing.	Whole process	Quick Wins	S, A, C	?
19	Day Starts/Stand-Up meetings at the beginning of each shift	Whole process	Quick Wins	S, C	?

Nr.	Short Description	Process Step	Quadrant I/E Matrix	Effect on criteria	Saved Time (hr.)
20	Analysis of VC and NC to continuously finetune the process	Whole process	Quick Wins	S, A, C	?
21	Reporting mistakes through standard form	Whole process	Quick Wins	S, A, C	?
22	Continuous improvement of modification steps to achieve 'First time right'	Whole process	Major Projects	S, D, A, C	0.11
23	A more efficient way of filling in the dimensional protocol	Whole process	Major Projects	S, D, C	0.05
24	Stop collecting (quality) documents from different locations	Whole process	Major Projects	S	0.05

Table 8 Overview of all solutions

6 HOW TO IMPLEMENT THE SOLUTIONS

In the Chapters 2-5, we have mapped the current process, found a method to map waste in a process, analysed the current process, and drafted a lot of solutions that will make the process take less working hours. For the last chapter, we will answer the last research question *'how should these solutions be implemented?'*. Because there are a lot of solutions, we will not address every solution with an implementation plan. What we will do is give an overview of preconditions, starting with the cooperation of the employees (6.1), the ERP system (6.2), standardised procedures (6.3), and an employee responsible for improvements (6.4). These preconditions need to be arranged in order to be able to implement the solutions of Chapter 5.

6.1 COOPERATION OF THE EMPLOYEES/CHANGE MANAGEMENT

Under Siemens, there was a different atmosphere and a different role for the employees. Under VDL the time it takes to make a product is much more important than it used to be. This means that for the employees and operators that they have to change the way they do their work, although the products do not change. The challenge for VDL ES is to guide this process of change to a success.

6.1.1 Change Management

With regard to change management, there exist a lot of models that can help a company manage change projects, think of McKinsey's 7s model, Kotter's 8-step model, the ADKAR model, Change Acceleration Process Model (CAP) or Kurt-Lewin's Unfreeze-Change-Freeze model.

From all these models it becomes clear that no matter the model, change will only be successful if communicated and accepted by employees or project team members. Next to that, it is critical that an organisation or project team should be able to manage change management effectively with appropriate support, knowledge and resources. Change management is complex, so management should understand all resistant forces. Failure to do so can be costly, decrease loyalty, reduce the probability of reaching goals, waste money, or squander resources (Galli, Change Management Models: A Comparative Analysis and Concerns, 2018).

Each of the models contains the basic concept of change management. Which is starting at a current state, realising the need for change, entering the transition phase, implementing the change, and then getting to their desired state. The CAP, McKinsey and Kotter models are detailed on the beginning, managing and sustaining change, whereas the ADKAR model puts a lot of emphasis on the people dimension (Galli, Change Management Models: A Comparative Analysis and Concerns, 2018). From another article of Galli in which he compares the Lewin, ADKAR and Kotter model it became clear that Kotter is useful for change projects where urgent/quick change is needed in contrast to the other two that are more useful for gradual change over time (Galli, An Engineering Manager's Guide for Commonly Used Change Management Approaches - From One Practitioner's Experience, 2019).

Because it is detailed and useful for a short-term change, we will describe a possible approach to the change within VDL ES from the perspective of Kotter's 8-step change model.

6.1.2 The 8-Step Kotter Model

Kotter's model is an expansion of the theory of Lewin. Kotter states that leadership must create and sustain the kind of changes needed for successful organisations to compete in the current competitive

world (Kotter, 1995). The model consists of eight steps that, in total, take a long time. However, skipping steps never produces satisfying results.

Below we go by each step of the model, first explaining the purpose of the step and secondly we come up with possible actions that VDL ES can take to complete that step. These proposed actions are mainly meant to give an idea or direction of the actions that are needed. It is up to VDL ES management which actions to take.

6.1.2.1 Create a sense of urgency

The process starts with creating a sense of urgency among the employees that a change is needed. This usually starts with a person or team that analyses the company's competitive position, market position, trends or financial performance. It is important to make sure that this is done thoroughly, rushing to the next step to quickly will result in resistance among the employees and will threaten a successful change. The most successful approach is to initiate a discussion by presenting potentially unpleasant facts (e.g.: new competition, shrinking market share, lack of revenue growth). The other way around is also possible, by showing the huge benefits and possibilities that will be opened up by the change.

What does this mean for VDL? The discussion as described above should be facilitated. Therefore, some kind of unpleasant horizon must be sketched to the employees. The other approach is to go for the horizon of major possibilities. Possible actions that can be taken lie along the lines of:

- Informing the employees and operators on the market position of VDL ES.
- Make it tangible what the effect will be if the labyrinth process keeps functioning the way it currently does.
- Make it tangible what the revenue of changing the labyrinth process will be.

6.1.2.2 Create a core coalition

The next step that needs to be made is to create a coalition of people throughout the company, so not only presidents or managers, that come together and develop a shared commitment to excellent performance through renewal. For big companies, this coalition should be in the range of 20-50 people, of which the core is formed with senior managers. Companies that fail in phase two usually underestimate the difficulties of producing change and thus the importance of a powerful guiding coalition.

The task for VDL ES is to create such a coalition. Since the number of people involved with labyrinths is not very big, a group of five to ten persons is a good size coalition. It is important to find the people who feel the need for change and to make sure that they operate in different areas and levels in the process. This coalition will work on the task of guiding the change process. To do this in a successful manner, it is important that the members have such a background that the coalition has enough 'power' to be able to move the project forward.

6.1.2.3 Develop and form a strategic vision

In successful transformations, the guiding coalition develops a picture of the future that is relatively easy to communicate and appeals to customers, stockholders, and employees. Such a vision goes beyond the numbers of a five-year plan but is something that helps clarify the direction in which an organisation needs to move. After some time working out the vision, a strategy for achieving that vision is also developed. For this strategy and vision, it is important that it not becomes too big and

detailed. As a rule of thumb: if you can't communicate the vision to someone in five minutes or less and get a reaction that signifies both understanding and interest, you are not yet done with this phase of the transformation process.

For the management and guiding coalition at VDL ES, it will be very important to think of and work out the direction in which the company must go (at least for labyrinths). In the process, it is extremely important to keep in mind that this vision must be understandable and can be explained in under five minutes.

6.1.2.4 Communicate and share vision plans

Change is only possible if many people are willing to help, even at the cost of short-term sacrifices. Employees will not make sacrifices, even if they are unhappy with the status quo unless they believe that useful change is possible. Without credible communication, and a lot of it, the hearts and minds of the troops are never captured. This phase is particularly challenging if the short-term sacrifices include job losses. Therefore, successful visions usually include new growth possibilities and the commitment to treat fairly anyone who is laid off. Executives who communicate well incorporate messages into their hour-by-hour activities. In everything they do they take the bigger picture into account, or address what influence behaviour or actions have on the vision. Additionally, executives should use every possible communication channel, especially those that are being wasted on nonessential information. Communication comes in both words and deeds, and the latter are often the most powerful form. Nothing undermines change more than the behaviour of individuals that is inconsistent with their words.

For VDL ES, this means that once the vision is determined it is of great importance that the management and the guiding coalition propagate the desired behaviour in everything they do and make sure that every possible channel of communication is used to share the vision with the employees.

6.1.2.5 Empowering employees to act on the vision

Renewal requires the removal of obstacles. Too often, employees understand the new vision and want to make it happen, but an obstacle is blocking the path (e.g. job categories, other persons, non-existent blocks that exist in their head). In the first half of a transformation, no organisation has the momentum, power, or time to get rid of all obstacles. However, the big ones must be confronted and removed. If the blocker is a person, it is important that he or she be treated fairly and in a way that is consistent with the new vision. Nonetheless, action is essential, both to empower others and to maintain the credibility of the change efforts as a whole.

When VDL ES arrives at the fifth phase, we advise to do a lot of monitoring of the employees to find out all the obstacles that employees encounter/experience. If these obstacles have been found and there turn out to be many, an impact-effort matrix can be used to prioritise as the biggest obstacles need to be removed first.

6.1.2.6 Generate short-term wins

Transformation takes time, and a renewal effort risks losing momentum if there are no short-term goals to meet and celebrate. However, there is a difference in hoping for short-term wins and creating short-term wins. In successful transformations, managers actively look for ways to obtain clear performance improvements, establish goals in the yearly planning system, achieve the objectives,

and reward the people involved with recognition, promotions, and even money. When it becomes clear to people that major change will take a long time, urgency levels drop. Commitments to product short-term wins help keep the urgency level up and force detailed analytical thinking that can clarify or revise visions.

For the management and guiding coalition at VDL ES, it is important to draw a progress path of the change process. In this path, they should clearly define milestones which are likely to be achieved in time so that progress is made tangible and can be celebrated. This way urgency and morale can be kept high.

6.1.2.7 Consolidate gains and produce more change

After a few years of hard work, managers may be tempted to declare victory with the first clear performance improvement. Although celebrating is fine, declaring the war won can be catastrophic. It takes five to ten years for a changes sink deeply into a company's culture, new approaches are thus fragile and subject to regression. Instead of declaring victory, leaders of successful efforts use the credibility afforded by short-term wins to tackle even bigger problems. They go after systems and structures that are not consistent with the transformation vision and have not been confronted before.

For the labyrinth process, this means that every participant or entity that plays some kind of role in the process must be aligned with the vision for the labyrinth process. It may be the case that the vision must be applied to other processes outside of labyrinths because they interact in some way with the labyrinth process.

6.1.2.8 Initiate and set new changes

Change sticks when it becomes "the way we do things around here" when it is anchored deep in the company's culture. There are two factors particularly important in institutionalising change in the corporate culture. The first is a conscious attempt to show people how the new approaches, behaviours, and attitudes have helped improve performance. Otherwise, there is a risk that employees make their own (false) causal relations to the improvements. The second factor is taking sufficient time to make sure that the next generation of top management really does personify the new approach.

The recommendation for VDL ES is to keep these two factors in mind when getting to the end of the change project. Something that can help is by keeping detailed logs of the actions and the results throughout the project. This can serve as a source to show which actions lead to improved performance. Next to that, it might be a good thing to promote new managers from the own ranks, in which the new status quo is anchored, so that the change effort is maintained.

6.2 THE ERP SYSTEM

The first precondition that should be fulfilled for successful implementation is the adjustments to the ERP system.

6.2.1 Connections & compatibility

The solutions that are described require a lot of connections in the ERP system that do not exist at this moment. The first connections that need to be created are connections that can link a certain

operation to documents. For example, the sawing line connects a material certificate to an order, a glowing operation can connect a glowing report to an order, drawings in a production order are automatically added to a calculation in that order.

Next to that, there is the compatibility with scanner devices which can be used to sign orders on and off. In combination, a pop-up functionality must be created.

Lastly, there is the compatibility of the ERP system with the planning software. This software is capable of making very detailed production schedules which should be an important input in the ERP system. At the moment it is not possible to connect this planning to specific orders. To be able to steer and control the process from the ERP system this must be possible.

6.2.2 Right tariffs

The goal of this research is to decrease the number of working hours so that ultimately this reduction of hours translates to reduced costs. These costs are determined based on the hour tariffs that are in the ERP system. However, for all the process steps the tariffs lie in a small range. This is weird since one would expect that the expensive machines have way bigger hour tariffs than process steps that only require an operator (such as inspection), whereas the opposite is sometimes the case. If the costs must be reduced, then the tariffs should be accurate. Therefore, a check if all tariffs are accurate is recommended.

6.2.3 The glowing process step

As with the tariffs, the data regarding the glowing process step is also not very realistic in the ERP system. Because the glowing operation is one that runs (semi) automatically, but for a long time, it is hard to approach it the same way as other production steps. The working hours that are needed are not that many but the total operation takes a long time (a lot of hours or even days). Therefore, the routing consists of a glowing line, but not of an accurate time indication. The glower knows what he has to glow, but not exactly how much time he gets for glowing. The implication is that it is hard to analyse data with regard to glowing and when there is no good data available it becomes hard to plan the process. Therefore, the hours that the glowing process is expected to take and the number of working hours per product should be determined or estimated such that it becomes possible to use it as input for the planning and to be able to do useful analysis.

6.2.4 Sign off times

The last thing that must be changed in the ERP system is not essential to one of the solutions, but nevertheless it is very useful in improving the ability to analyse the process. At the moment, when an operator signs off his process step the exact date and time are registered in the ERP system, up to the second. This data is very useful for, e.g., measuring lead and waiting times which can be used in further improving the process. However, at the moment, orders are signed off completely when no action is left to be done (this is when they are delivered and paid without complications), and when that happens the sign off times of the operators are updated to the sign off moment for the whole order. This is a pity since a lot of useful data is thrown overboard. With some adjustments, this data can be saved, gathered and analysed in the future.

6.3 STANDARDISED PROCEDURES

When the margins are small, as is the case with labyrinths, it is important to do procedures as efficient as possible. The Japanese/Lean philosophy is that for improving a process one must institute a standard procedure. These procedures are not dictated top-down but reached by consensus among the employees. A standard operating procedure describes which objects and tools are needed, in which order the activities are done and which quality checks must be performed (Theisens, 2018).

For VDL ES this means that all the procedures in the process must be standardised as much as possible. For each process step, it should be clearly defined what the order of actions is, which tools are used for which action or characteristic, how and where to book their hours, and which actions to perform in the ERP system. Every operator must then perform the same procedure, when a better way of doing the procedure is found, the procedure can be updated.

With the procedure, and thus its inputs, clearly defined, VDL ES can also be clearer to customers how and what type of information they want to be supplied. This shall then reduce the time that is needed to process this input data and will reduce the probability of errors due to, for example, unclear technical drawings.

6.4 EMPLOYEE(S) RESPONSIBLE FOR IMPROVEMENT

To make the improvements to the labyrinth process a success, there must be one person, or a group/coalition, who is responsible for the progress of all the improvement projects. This person/group can keep an overview and also makes sure that periodic improvement meetings are held and that the feedback that is given from the operators is processed. This person/group must not have too many tasks so that he or she can focus on improving the labyrinth process specifically. This way the improvements can be implemented in a structured way.

7 CONCLUSION

In this last chapter, we will summarise the answers to the research questions that we found. Next to that, we will give a short overview of our recommendations. The last part will be the answer to our main research question.

7.1 ANSWERS TO THE RESEARCH QUESTIONS

Below, we will quickly answer the five sub research questions that we defined in Section 1.6.

7.1.1 What does the current process look like?

The first step of this research was to create a full overview of how the current process runs, which process steps it contains, which actions fall under each step and how much time each step and action take.

We did this mapping by combining three pieces of information. The first was a complete overview of all the actions per process step to create a full process map. Because it was not possible to do enough measurements to create valid data, we used the historical ERP data to determine an average per process step. The third and last piece of information was measuring the duration of actions and use its relative contribution to the total measured time and the ERP average as a means to deduce an average duration per action.

We found that the process to produce a labyrinth takes on average 4.42 working hours of which 1.14 are support working hours and 3.29 are production working hours. Next to that, we did some other relevant observations:

- Deviations in planned and needed hours.
- Quality Issues.
- Manual Checks.
- Inaccurate registration of hours in the ERP system.

The process steps and their actions, as well as process flows, can be found in Appendix A.

7.1.2 Which methods are there to map waste in a process?

In Chapter 3, we researched different methods to map 'waste' in a process. We found three possible methods: Value Stream Mapping, Manufacturing Critical-Path Time and a Time Value Map. Although everyone has its advantages and disadvantages, the choice was made to use a Time Value Map. The advantages of the Time Value Map over the other two are that it is focussed on time only, making it very suitable for our action problem. The other is the distinction between value added, necessary and non-value added activities in contrast to only touch time and non-touch time distinction of the Manufacturing Critical-Path Time method.

7.1.3 Which steps in the process are value-adding, which are not and which are necessary?

With a complete overview of the process and a method to map waste, we could do an analysis of the current process. All the actions that were identified in Chapter 2 were categorised as either value added (VA), necessary (N) or non-value added (NVA) activities. With this categorisation, a Time Value Map for the whole process was made. Next to that, it became clear that the total of 4.42 working hours that the process takes consists of 1.66 value-added hours (38%), 1.47 necessary (33%), and 1.30 non-value added time (29%).

	VA (hr.)	%	N (hr.)	%	NVA (hr.)	%	Pot. (hr.)	%
Support	0.11		0.53		0.49		0.65	
		10%		47%		43%		-43%
Production	1.55		0.93		0.81		2.48	
		47%		28%		25%		-25%
Total	1.66		1.47		1.30		3.13	
		38%		33%		29%		-29.29%

Table 9 Division of value added, non-value added and necessary working hours in the process and the potential improvements

With the actions categorised it is also possible to formulate potential for improvement. When all the non-value added activities are eliminated the process would take 0.65 support working hours (-0.49) and 2.48 production working hours (-0.81) which brings the potential total to 3.13 working hours which is a 29.29% reduction compared to the current 4.42 hours.

7.1.4 What are possible solutions to reduce the number of working hours?

With the analysis of the process in Chapter 4 solutions could be drafted. The solutions are divided into three categories: solutions for a specific process step, solutions for the whole process and long term solutions. Next to that, the impact-effort matrix is used to determine the solutions that do not take too much effort and resources (solutions per process step and for the whole process), so-called 'Quick Wins' and 'Fill ins'. The long term solutions take more effort and fall in the category of 'Major Projects' in the impact-effort matrix.

With these three groups of solutions and their classification in the impact-effort matrix, it is possible to say which solutions can be implemented on short term and which take longer. Each solution helps to make the process take less working hours, being more predictable and more standardised. However, it is not possible to make a good estimation of the reward of each solution. Therefore, we used only the reward of solutions that we could determine to create an indication of the decrease in working hours as a result of the solutions.

With these solutions implemented we determined that the new process would take 0.69 working hours for support and 2.94 for production. Bringing the total number of working hours the process to produce a labyrinth will take to 3.63, which is a reduction of 17.97%. This is not the 29.29% reduction potential that was identified in Chapter 4, but this reduction does not include all solutions that have been proposed and there still remains some unquantifiable reduction from the these (extra) solutions.

By actively doing improvement projects on the long term areas of improvement, an even greater reduction can be attained. But it is hard to say how much that will be exactly at this moment.

7.1.5 How to implement the solutions?

In the last chapter, we described the preconditions that must be arranged in order to bring the solutions to a success. These four preconditions are:

- Enough cooperation and involvement of employees and operators are created so that the improvement process works bottom-up. Kotter's 8-step change management model can serve as a framework to manage the change of the labyrinth process.

- For the ERP system: Making sure the ERP system makes the right connections and is compatible with scanners and planning software; That the tariffs in the ERP system are up-to-date; The ERP system accommodates enough possibility for the glowing operation to be realistically managed; And lastly, that the sign off times are not overwritten when an order is completely processed.
- All procedures in the process are standardised so that good analysis and improvement can be done.
- There is an employee responsible for all improvement projects within the labyrinth process so that there is someone with an overview and the projects are performed in a structured manner.

7.2 RECOMMENDATIONS

With the five research questions answered, we can do our final recommendations. First of all, we recommend VDL ES to implement all the solutions. Starting with implementing the solutions that are classified as Quick Win as fast as possible, these solutions are the low-hanging fruits. After that choose the improvement projects wisely so that they can build on each other, e.g. there is no point in making VC versus NC analyses if there are no scanners implemented that provide accurate data. The short term solutions for the whole process are ordered in such a way that they build on each other. This order might help in the choice of improvement projects.

What is important for VDL ES to keep in mind is that the goal of the solutions all together is not only to eliminate waste from the process. During the research, it became clear that there is great room for improvement in predicting, registering and analysing the process. Multiple problems came to the surface that showed that the process is not predictable and not dependable enough.

Therefore, it is important that VDL ES keeps in mind that every improvement project they do with regard to the labyrinth process should make sure that the process becomes:

- More **standardised**, always the same procedures and no room for deviations.
- More **dependable**, meaning the quality of the products improves.
- Better **'analysable'**, so that more and better data can be measured.
- More **controllable**, making sure all information that is needed is available and that the hours that are being sold are accurate.

7.3 HOW CAN LEAN BE USED TO REDUCE THE NUMBER OF NEEDED WORKING HOURS BY 30%?

At the end of this research, it is time to answer the main research question *'How can the process of labyrinth production be redesigned, using lean management theory, such that 'waste' is reduced so that the number of needed working hours is reduced by 30%?'.* We have mapped and analysed the process and based on this drafted several solutions.

The answer to the question is that from lean manufacturing the definition of waste is successfully used to identify waste in the process. But also the principles of value, flow and pull were useful in determining what the process needs to reduce the number of working hours.

The identifying and mapping of waste enabled us to reduce the number of needed working hours with 17.97%, however, there is more potential. The theory of lean helps to standardise the process

so that a pull process can be created and great steps towards 'First Time Right' can be taken to further improve the process and enable VDL Energy Systems to get in control of the labyrinth process.

7.4 DISCUSSION

Now that we have found the answer to the main research question, we have to address the accuracy of the answer. In Chapter 2, we found and mentioned multiple issues that forced us to make assumptions or simplifications. In this last section, we will address the extent to which the conclusions we have drawn are valid given these issues.

7.4.1 Inaccurate registration of hours

The first issue is the inaccurate registration of working hours. At this moment it is done manually and although there are rules on when to book hours, it has been said by multiple employees and found in the ERP system that the registered times are not the actual times.

The data that is used in this research is the ERP data, of which we know it is not completely realistic. Therefore, we cannot say that the process times that we have presented are the actual average times. Most probably the true time lies lower than the 4.42 hours that was found in Chapter 2. As a result, it is likely that the presented decrease in working hours is not as big as we presented because it is based on times that cannot be assumed to be realistic.

However, the process steps and underlying actions that were used to map the process are accurate. And from those steps and the definition of waste, we did identify the actions that do not add value and thus should be eliminated. And because of the relative size of actions based on measurements, we can say that the relative decrease in the number of working hours will still be the same. Thus the solutions that are presented are not less valid because of the inaccurate times in the data (only the result may differ from the presented result).

7.4.2 Variation in the process versus averages

As is explained, the labyrinth is not just one type of product which is produced over and over again. Each labyrinth is a unique one and is produced according to customer specification. As a result, the routing and processing times per process step differ a lot between labyrinth orders.

In the available data set it was not possible to categorise the orders so that a more detailed analysis could be done. Therefore, all the data was put together to create overall averages. The durations presented in this research are thus averages of all different types of labyrinths.

Does this create a problem with regard to our conclusions? It does in the sense that the data does not enable VDL ES to say something about a specific labyrinth. However, VDL ES will be able to redo the procedures we did and create a similar analysis over the whole (average) process to see whether or not the process has improved over time by comparing the outcome with earlier analyses. Next to that, the solutions that are drafted will enable VDL ES to make much more detailed analyses in the (near) future, which will automatically solve this problem.

7.4.3 ERP database build versus support hours

The way that the employees, that work at support process steps, have to book their hours is organised awkwardly in the ERP system. In short, all the support hours are registered in the same type of entity

as a regular order, which are combined in one big project (which can consist of multiple products). This means that the support hours are divided over all the products in the project. Making it impossible to directly calculate an average per labyrinth.

Therefore, we have constructed a way to process the support data such that we get a reasonable average outcome per labyrinth. To get there, the actual data is averaged twice, meaning that we lose a lot of insights and also cannot claim the amount to be realistic. This sounds very bad, but we have checked the data and found that the assumption that every product has an equal share in the number of support hours of that project is very reasonable, as the squared deviations from the average per project are less than 1%. This means that the second time we average is realistic and thus makes the values more closer to the truth than we might have thought at first.

With the current way of registering support hours, it will remain very difficult to connect realistic support data to single labyrinths for analysis. However, the method remains useful. The times that we found might not be completely realistic, but the method can be used very well to measure the effectiveness of the solutions. If the solutions are implemented, it must result in less work needed in all steps of the support part of the process, and therefore there should be a decreasing trend in the number of working hours spent on support over the longer term.

BIBLIOGRAPHY

- CIToolkit. (2020). *Time Value Map*. From citoolkit.com: <https://citoolkit.com/articles/time-value-map/>
- Galli, B. (2018, September). Change Management Models: A Comparative Analysis and Concerns. *IEEE Engineering Management*, pp. 124-132.
- Galli, B. (2019, September). An Engineering Manager's Guide for Commonly Used Change Management Approaches - From One Practitioner's Experience. *IEEE Engineering Management*, pp. 118-126.
- GroupMap Technology Pty Ltd. (2019). *Impact Effort Matrix*. From GroupMap.com: <https://www.groupmap.com/map-templates/impact-effort-matrix/#1495520565504-1eea2e40-1ef6>
- Gustavsson, H., & Axelsson, J. (2010). *Improving the System Architecting Process through the Use of Lean Tools*. Portland International Center for Management of Engineering and Technology.
- Hardwick, L. (2014, September 18). *How To Cure Priority Paralysis: Using An Action Priority Matrix*. From SiteSpect: <https://www.sitespect.com/blog-how-cure-priority-paralysis-using-action-priority-matrix/>
- Kotter, J. (1995, March-April). Leading Change: Why Transformation Efforts Fail. *Harvard Business Review*, pp. 59-67.
- Lucid Software inc. (2020). *Value Stream Mapping Symbols and Icons*. From Lucidchart.com: <https://www.lucidchart.com/pages/value-stream-mapping/value-stream-mapping-symbols>
- Luna, L., Klökner, P., & Ferreira, J. (2013). Applying Value Stream Mapping to Identify and Evaluate Waste in a Company of the Ceramic Sector. *International Conference Flexible Automation and Intelligent Manufacturing* (pp. 1515-1525). Porto: FAIM.
- Noort, P. (2019, March 9). Lecture Slides SLR - IEM Module 11.
- Rother, M., & Shook, J. (1999). *Learning to see: value stream mapping to add value and eliminate muda*. Cambridge: The Lean Enterprise Institute.
- Slack, N., Brandon-Jones, A., & Johnston, R. (2016). *Operations Management*. Harlow: Pearson Education Limited.
- Stewart, M. (2018). 8.2.6.1.1. Labyrinth Seal. In M. Stewart, *Surface Production Operations*. Gulf Professional Publishing. From [sciencedirect.com: https://www.sciencedirect.com/topics/materials-science/labyrinth-seal](https://www.sciencedirect.com/topics/materials-science/labyrinth-seal)
- Suri, R. (2011). *Beyond Lean: It's About Time!* From www.qrmcenter.org.
- Suri, R. (2015, October). A Timely Metric. *Industrial Engineer*, pp. 36-41.
- Theisens, H. (2018). *Lean Six Sigma Greenbelt Mindset, Skill set & Tool set*. Amersfoort: Lean Six Sigma Academy.
- VDL Group. (2018, November 16). *VDL Groep neemt activiteiten Siemens Hengelo over*. From [www.vdlgroep.com: https://www.vdlgroep.com/nl/nieuws/vdl-groep-neemt-activiteiten-siemens-hengelo-over](https://www.vdlgroep.com/nl/nieuws/vdl-groep-neemt-activiteiten-siemens-hengelo-over)
- Wikipedia. (2018, December 29). *Siemens Nederland*. From [wikipedia.org: https://nl.wikipedia.org/wiki/Siemens_Nederland](https://nl.wikipedia.org/wiki/Siemens_Nederland)
- Womack, J., & Jones, D. (1996). *Lean Thinking: Banish waste and create wealth in your corporation*. London: Simon and Schuster.

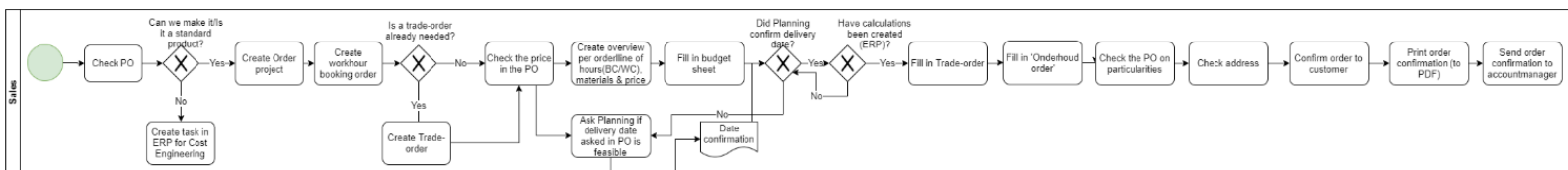
APPENDICES

A. THE CURRENT PROCESS STEPS

In this appendix, the actions per process step are given. Each activity is categorised as either VA, N or NVA. The potential is determined by counting the minutes of VA and N time and applying the reduction on the ERP average (which can be found under 'Total Avg.'). For the production steps, a yellow arrow indicates transport of the product of 15 metres or less, a red arrow indicates transport of more than 15 metres.

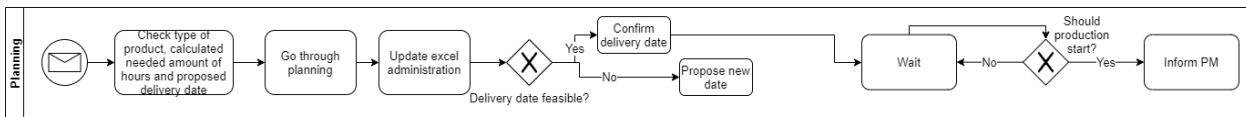
a. Sales

Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check PO	N	This part has been shielded for this public version			
Create Order Project	VA				
Create workhour booking order	VA				
Check the price in the PO	NVA				Over-processing
Ask Planning if the delivery date in the PO is possible	NVA				Over-processing (two people doing the same task)
Create overview per orderline of hours (BC/WC), materials & price	N				N, because the customer wants them to happen, the action itself is waste
Fill in the budget sheet	N				
Fill in Trade-order	VA				
Fill in 'Onderhoud Order'	VA				
Check the PO on particularities	NVA				Over-processing
Check address	NVA				Over-processing
Confirm order to the customer	VA				
Print order confirmation to PDF	N				
Send order confirmation to account manager	VA				
Total					
Pot.					



b. Planning

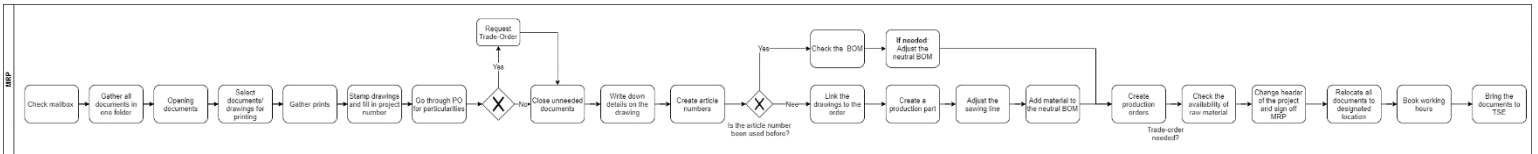
Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check type of product, calculated needed amount of hours and proposed delivery date	N	This part has been shielded for this public version			
Go through Planning	N				
Confirm delivery date	N				
Total					
Pot.					



c. MRP

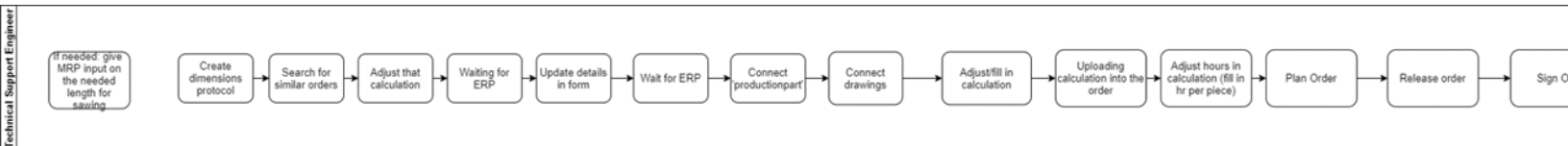
Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check Mailbox	N	This part has been shielded for this public version			
Gather all documents in one folder	NVA				Transport
Opening documents	N				
select documents for printing	N				
Gather prints	N				
Stamp drawings and fill in project number	N				
Go through PO for particularities	N				
Close unneeded documents	N				
Write down details on the drawing	N				
Create article numbers	VA				
Link drawings to the order	N				
Create a production part	VA				
adjust the sawing line	NVA				Over-processing
add material to the neutral BOM	VA				
Create production orders	VA				
Check availability of raw material	NVA				NVA because the system and purchasing should check this.
Change header of project and sign of MRP	N				
Relocate all documents to the designated location	NVA			Transport	

book working hours	N	This part has been shielded for this public version
Bring documents to TSE	N	
Total		
Potential		



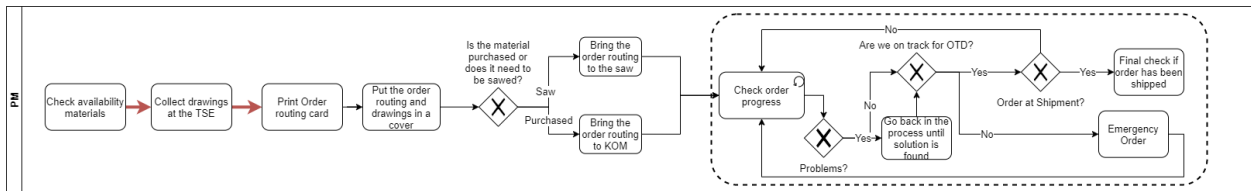
d. Technical Support Engineer

Action	Type	Time per action (min)	Total Avg.:		XXX Remarks
			%	Average per action (hr.)	
Create dimensions protocol	N	This part has been shielded for this public version			
Use Laby Generator	VA				
Search for similar orders	NVA				Over-processing
Adjust that calculation	NVA				Over-processing
Waiting for ERP	NVA				Waiting
Update details in the form	NVA				Over-processing
wait for ERP	NVA				Waiting
Connect production part	VA				
connect drawings	NVA				NVA because MRP connects drawings to production order, why would TSE then do the same?
adjust/fill in calculation	NVA				Over-processing
uploading calculation into the order	VA				
adjust hour in calculation (fill in hr per piece)	NVA				Over-processing
Plan order	VA				
Release order	VA				
Sign off TSE	N				
Total					
Potential					



e. Project Management

Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check availability materials	NVA	This part has been shielded for this public version			Over-processing
Collect drawings at the TSE	NVA				Movement
Print Order routing card	N				
Put the order routing and drawings in a cover	N				
Bring the order routing to the appropriate place	N				
Continuously checking of progress	NVA				A lot of checking, over-processing.
Total					
Potential					



f. Quality MDB

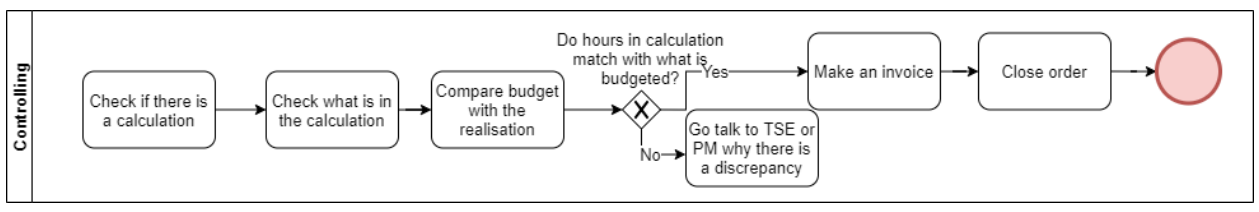
Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check the order to see what is needed	NVA	This part has been shielded for this public version			Over-processing
Make an overview in the excel list per item which documents should be delivered	NVA				Over-processing
Sign off 'PO checked' in excel list	NVA				Over-processing
Check routing if needed quality demands are processed	NVA				Over-processing
Sign off 'routing check' in excel list	NVA				Over-processing
Check if all documents are digitalized and complete	N				
Release order	N				
Gather all documents in a PDF	N				Only N because the customer specifically wants it. It is waste.
Upload PDF in system	N				
Sign of order in excel list	NVA				
Total					
Potential					



No signal that routing is ready for Q MDB. So no incentive to start these actions

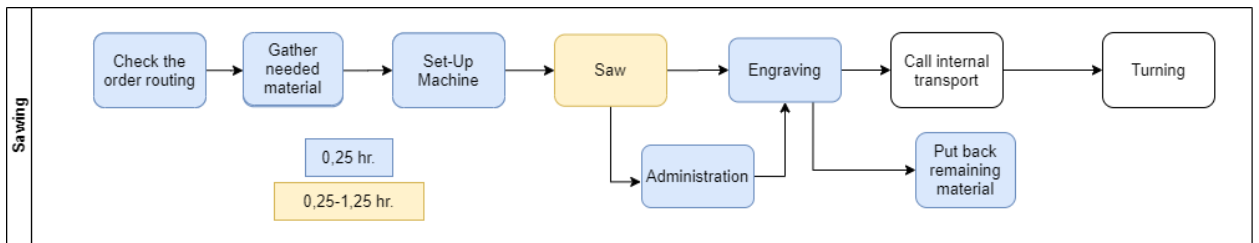
g. Controlling

Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check if there is a calculation	N				
Check what is in the calculation	VA				
Compare budget with the realisation	VA				
Make an invoice	VA				
Close order	N				



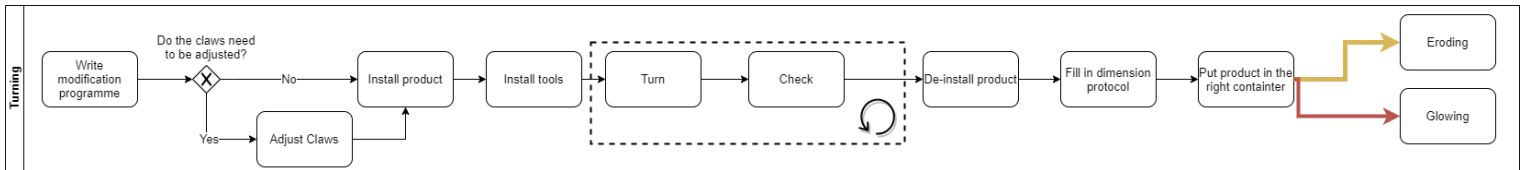
h. Sawing

Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Check the order routing	NVA	This part has been shielded for this public version			Over-processing
Gather needed material	NVA				Transport
Set-Up Machine	N				
Saw	VA				
Administration	NVA				Over-processing
Engraving	N				
Call internal transport	N				
Put back remaining material	N				
Total					
Potential					



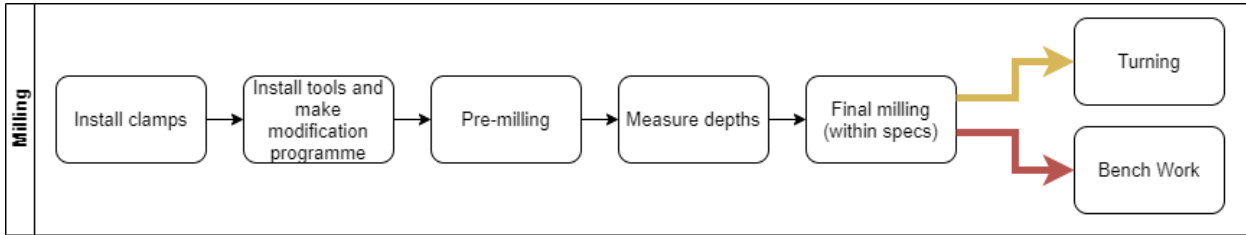
i. Turning

Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Write modification programme	N	This part has been shielded for this public version			XXX
Adjust Claws	N				
Install product	N				
Install tools	N				
Turn	VA				
Check	NVA				Over-processing
Turn	VA				
Check	NVA				Over-processing
Turn	VA				
Check	NVA				Over-processing
De-install product	N				
Fill in dimension protocol	NVA				Over-processing
Put the product in the right container	N				
Total					
Potential					



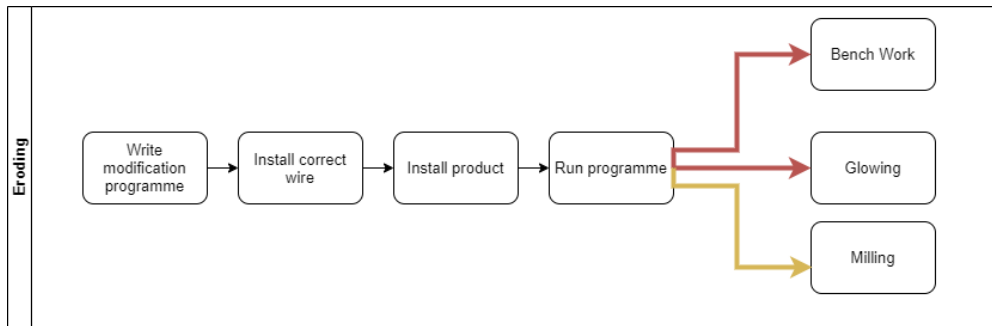
j. Milling

Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
Install clamps	N	This part has been shielded for this public version			XXX
Install tools and make modification programme	N				
Pre-milling	VA				
Measure depths	NVA				Over-processing
Final milling (within specs)	VA				
Filling in the dimensional protocol	NVA				Over-processing
Total					
Potential					



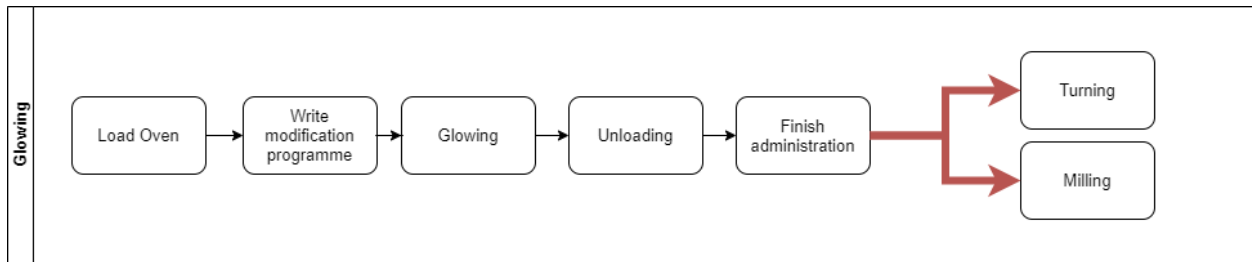
k. Eroding

Action	Type	Time per action (min)	Total Avg.:		XXX
			%	Average per action (hr.)	Remarks
Write modification programme	N	This part has been shielded for this public version			
Install correct wire	N				
Install product	N				
Run programme	VA				
Useless time	NVA				Over-processing
Total					
Potential					



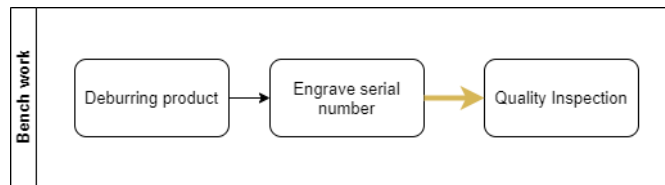
l. Glowing

Action	Type	Time per action (min)	Total Avg.:		XXX
			%	Average per action (hr.)	Remarks
Load Oven	N	This part has been shielded of this public version			
Write modification programme	N				
Glowing	VA				The glowing itself can take up to 4 days
Unloading	N				
Finish administration	N				
Total					
Potential					



m. Benchwork

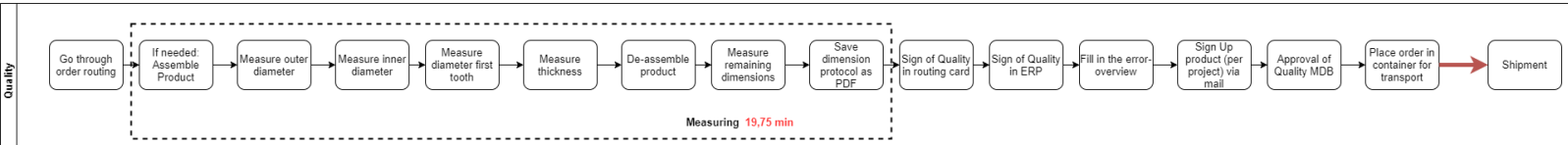
Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
					XXX
Deburring product	VA	This part has been shielded for this public version			Both actions are simple and could be done in another step. saves transport time and risk
Engrave serial number	VA				
Total					
Potential					



n. Quality Inspection

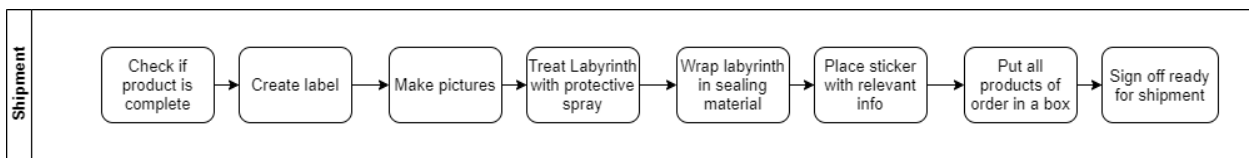
Action	Type	Time per action (min)	Total Avg.:		Remarks
			%	Average per action (hr.)	
					XXX
Go through order routing	NVA	This part has been shielded for this public version			Over-processing This is all NVA. because these are checks. If the process was reliable enough. checking could be done in samples. which would save a lot of time.
If needed: Assemble Product	N				
Measure outer diameter	N				
Measure inner diameter	N				
Measure diameter first tooth	N				
Measure thickness	N				
De-assemble product	N				
Measure remaining dimensions	N				
Save dimension protocol as PDF	N				
Sign of Quality in routing card	N				
Sign of Quality in ERP	N				

Fill in the error-overview	NVA	This part has been shielded for this public version	Over-processing
Sign Up product (per project) via mail	NVA		Over-processing
Total			
Potential			



o. Shipment

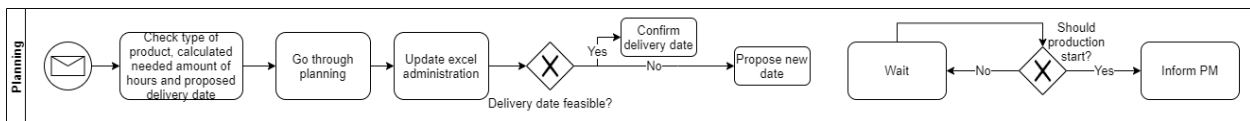
Action	Type	Time per action (min)	Total Avg.:		XXX
			%	Average per action (hr.)	Remarks
Check if the product is complete	NVA	This part has been shielded for this public version			Over-processing
Create label	N				
Make pictures	NVA				Over-processing
Treat labyrinth with a protective spray	VA				
Wrap labyrinth in sealing material	VA				
Place sticker with relevant info	VA				
Put all products in a box	VA				
Sign off ready for shipment	N				
Shipment	N				The shipment itself has not been researched
Total					
Potential					



B. THE FUTURE PROCESS STEPS

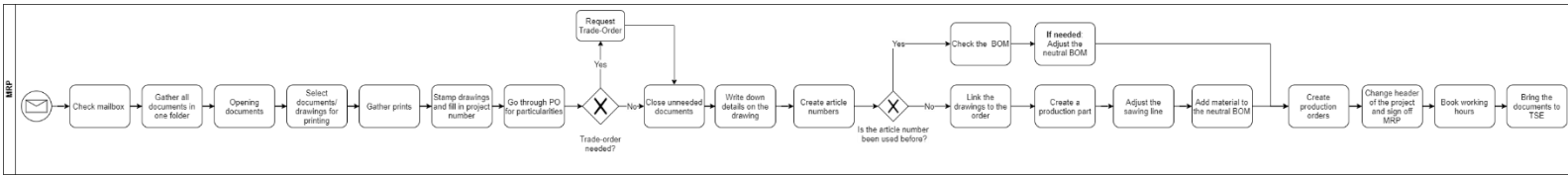
a. Planning

Action	Type	Expected duration (hr.)	Remarks
Check type of product, calculated needed amount of hours and proposed delivery date	N	This part has been shielded for this public version	
Go through Planning	N		
Confirm delivery date	N		
Total			



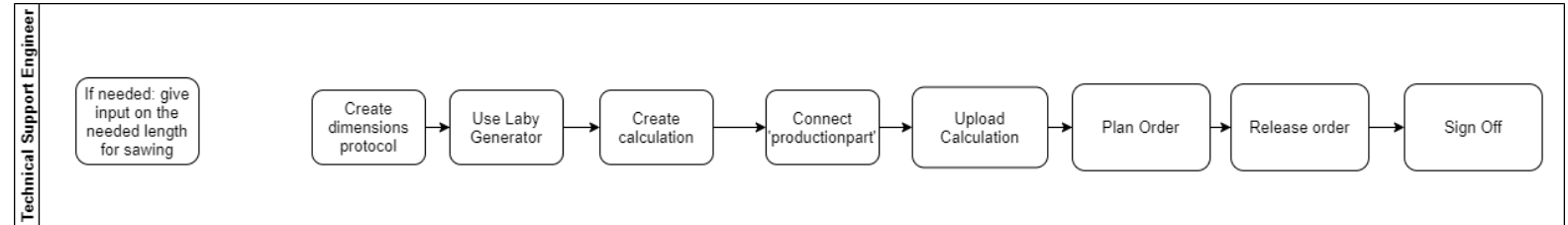
b. MRP

Action	Type	Expected duration (hr.)	Remarks
Check Mailbox	N	This part has been shielded for this public version	
Gather all documents in one folder	NVA		
Opening documents	N		
select documents for printing	N		
Gather prints	N		
Stamp drawings and fill in project number	N		
Go through PO for particularities	N		
Close unneeded documents	N		
Write down details on the drawing	N		
Create article numbers	VA		
Link drawings to the order	N		
Create a production part	VA		
add material to the neutral BOM	VA		
Create production orders	VA		
Change header of project and sign of MRP	N		
book working hours	N		
Bring documents to TSE	N		
Total			



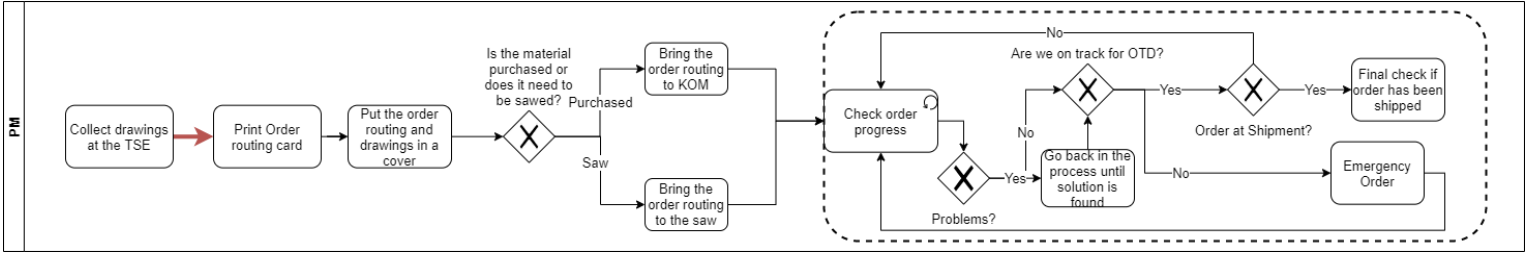
c. Technical Support Engineer

Action	Type	Expected duration (hr.)	Remarks
Create dimensions protocol	N	This part has been shielded for this public version	
Use Laby Generator	VA		
Create Calculation	VA		
Connect Production Part	VA		
Upload Calculation	VA		
Plan order	VA		
Release order	VA		
Sign off TSE	N		
Total			



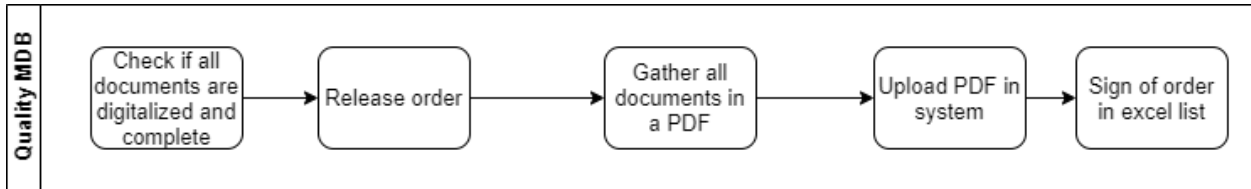
d. Project Management

Action	Type	Expected duration (hr.)	Remarks
Check availability materials	NVA	This part has been shielded for this public version	
Collect drawings at the TSE	NVA		
Print Order routing card	N		
Put the order routing and drawings in a cover	N		
Bring the order routing to the appropriate place	N		
Continuously checking of progress	NVA		
Total			



e. Quality MDB

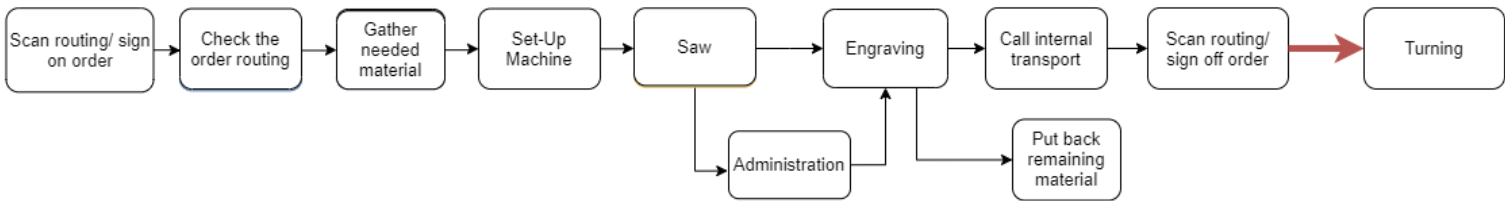
Action	Type	Expected duration (hr.)	Remarks
Check if all documents are digitalized and complete	N	This part has been shielded for this public version	
Release order	N		
Gather all documents in a PDF	N		
Upload PDF in system	N		
Total			



f. Sawing

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
Check the order routing	NVA		
Gather needed material	N		
Set-Up Machine	N		
Saw	VA		
Administration	NVA		
Engraving	N		
Call internal transport	N		
Put back remaining material	N		
Scan/Sign off order	N		
Total			

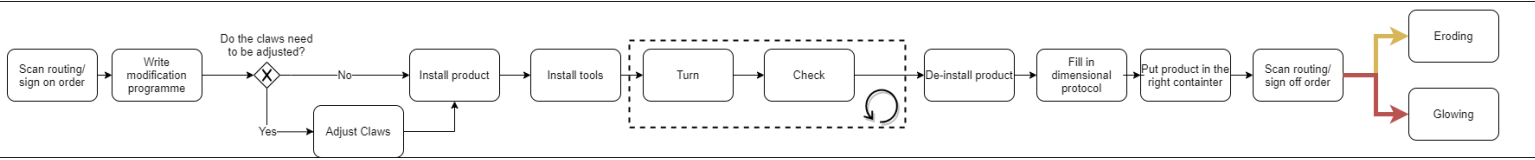
Sawing



g. Turning

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
Write modification programme	N		
Adjust Claws	N		
Install product	N		
Install tools	N		
Turn	VA		
Check	NVA		
Turn	N		
Check	NVA		
Turn	VA		
Check	NVA		
De-install product	N		
Fill in dimension protocol	NVA		
Put the product in the right container	N		
Scan/Sign off order	N		
Total			

Turning

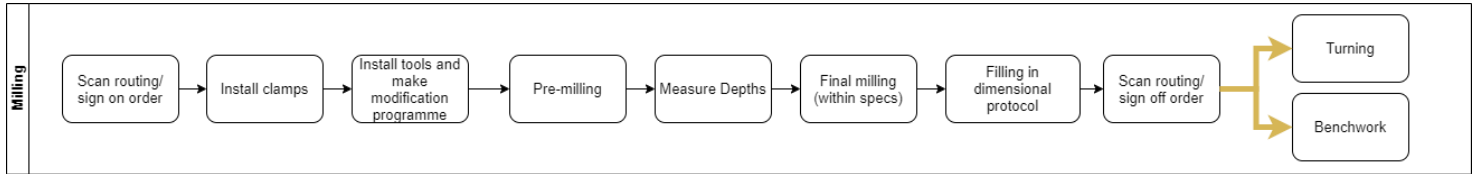


h. Milling

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
Install clamps	N		
Install tools and make modification programme	N		
Pre-milling	VA		
Measure depths	NVA		

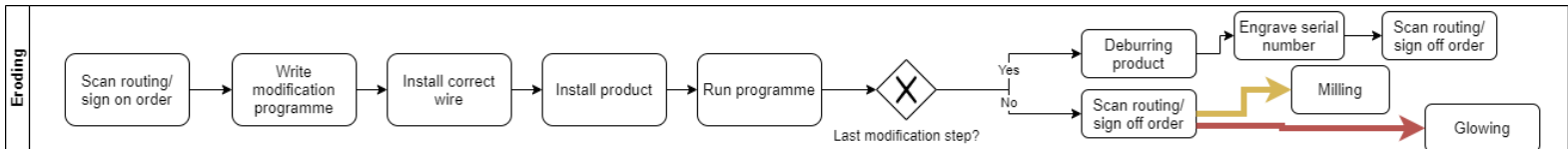


Final milling (within specs)	VA	This part has been shielded for this public version	
Filling in the dimensional protocol	NVA		
Scan/Sign off order	N		
Total			



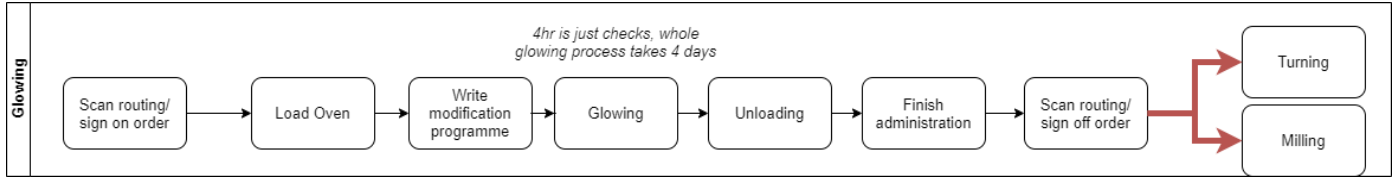
i. Eroding

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
Write modification programme	N		
Install correct wire	N		
Install product	N		
Run programme	VA		
Scan/Sign off order	N		
Total			



j. Glowing

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
Load Oven	N		
Write modification programme	N		
Glowing	VA		
Unloading	N		
Finish administration	N		
Scan/Sign off order	N		
Total			

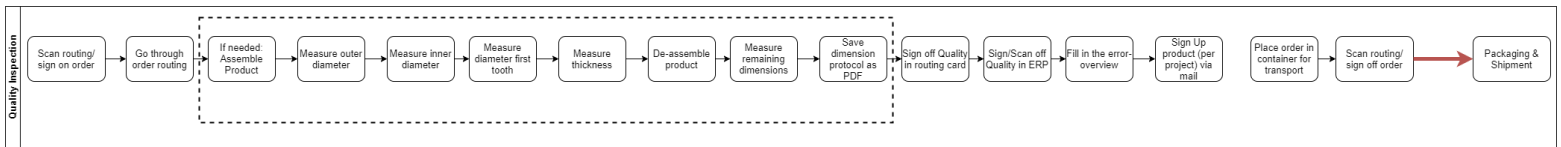


k. Benchwork

Action	Type	Expected duration (hr.)	Remarks
Deburring product	VA	This part has been shielded	
Engrave serial number	VA		
Total			

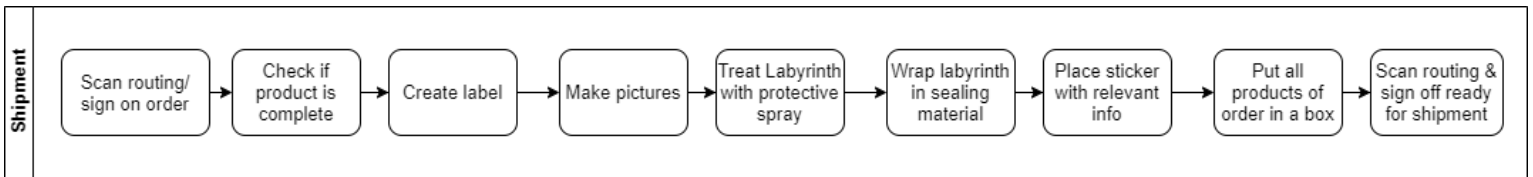
l. Quality Inspection

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
If needed: Assemble Product	N		
Measure outer diameter	N		
Measure inner diameter	N		
Measure diameter first tooth	N		
Measure thickness	N		
De-assemble product	N		
Measure remaining dimensions	N		
Save dimension protocol as PDF	N		
Sign of Quality in routing card	N		
Sign of Quality in ERP	N		
Fill in the error-overview	NVA		
Sign Up product (per project) via mail	NVA		
Place order in a container for transport	N		
Scan/Sign off order	N		
Total			



m. Packaging & Shipment

Action	Type	Expected duration (hr.)	Remarks
Scan/Sign on order	N	This part has been shielded for this public version	
Check if the product is complete	NVA		
Create label from ERP system	N		
Make pictures	NVA		
Treat labyrinth with a protective spray	VA		
Wrap labyrinth in sealing material	VA		
Place sticker with relevant info	VA		
Put all products in a box	VA		
Sign off ready for shipment	N		
Scan/Sign off order	N		
Shipment	N		
Total			



C. CALCULATIONS

In this appendix, we will give some explanation on how we have come to the values we have presented in this research.

a. Determining the performance of production process steps

A big part of this report is the analysis of the performance of the process steps. The first thing we will explain is the performance of the production process steps. The ERP system gives output that contains a lot of information with regard to these process steps. In this section, we will explain step by step how we processed different pieces of data of this output so that it will be possible to reconstruct this process in a later stage.

1. The first things that we need are two sets of data. The first is a full export of the 'Orderbewerkingen Kubus' and the second an export of the 'Calculaties' sheet, both from the ERP system.
2. Secondly, we have to determine out of all the orders in de 'Orderbewerkingen sheet' which orders are for labyrinths and which are not. To do this there are two complementary approaches. The first is manually sorting the data on all descriptions that contain the word 'labyrinth'. This does not contain all labyrinth orders. So the second thing we have done is making a connection between the 'Calculaties' sheet and the 'Orderbewerkingen' sheet. This connection can be made on the variable 'Codenr', which is in both sheets. In the 'Calculaties' sheet, we have deleted all lines that do not contain a labyrinth code in the 'Maak Methode' column. Then we have created a new column named 'Laby' which contained a formula which gave a '1' as output if that order line had a code that corresponded with a code in the 'Calculaties' sheet (which only contained labyrinths). Based on this 0 or 1 value we could sort out all labyrinth orders that did not contain the word 'labyrinth' in its description.
3. To be able to do an analysis of the planned and realised hours (VC and NC resp.) per single labyrinth we created a new column next to the following already existing columns: 'VC Uren', 'NC Uren', 'Verschil stel uren', 'Verschil Totaal'. And in these new columns, we divided the value of the column left to it with the number of labyrinths in that order.
4. For the analysis, we made a list of all the (unique) machine numbers to be able to analyse each machine/process step individually.
5. To get average values for these process steps we took the averages over the columns that we made at step 3. Important to note is that we only took the average for that specific machine number, and most importantly we left out all the values where the 'NC Uren' value was 0. We did this because orders are planned long in advance and thus not every order in the data set had been in production, secondly because also orders are in the dataset that needed to be reworked, causing some '0-rows'. These zero values make the average lower than it is in reality, therefore it needs to be left out.
6. With these five steps, we have been able to create the average values for planned and realised values. We can also calculate the sample standard deviation to get an idea of how the spread is in the realised hours and more importantly the difference. With this data, we can also count the times a machine produces in less hours than planned, exactly the number or more than the planned number.
7. It is also possible to analyse per order instead of per labyrinth, then one should do exactly the same but not take averages over the 'new' columns but over the ones that were already in the data set.

b. Determining the support hours

With the above-described procedure, we can analyse the production process steps. The next step is to explain how we did the analysis on the support process steps. A great deal of the approach has already been described in Section 2.1.2.1 and we will not repeat that here. What we will do is describe the exports we used and what we did to modify that data to get to the result. Again, step by step:

1. In addition to the exports that are used for the production process steps, we need an extra export that gives data on hours specifically. For determining the support hours we have used an export of the 'Uren Kubus' from the ERP system. This overview contains all the hours booked on an order. As explained, the support hours are only booked on one order.
2. Since we have a list of labyrinth orders from what we did in Section a, determining which orders and projects contain labyrinths is easier. If an order number appears in the list of labyrinth orders we can make sure (with something like the IF formula in Excel) that a 0 or 1 is placed in the rows of projects that contain at least one labyrinth order.
3. The next thing we wanted to know was how many production orders are in a project. This could be determined by copying the columns with project and order numbers to a different sheet and remove all duplicate order numbers (so not project numbers!). This way we could count for each project number how many production orders were in that project by counting the order with a number higher than 9000000. Lastly, we had to subtract one from this number because the hour booking order also has a number greater than 9000000.
4. To be able to use the formula as described in the report we need more data. The next thing we wanted to know was the number of labyrinth production orders in a project. To determine this we used VBA code. However, first, we made a new column in which counts the times an order number appeared in the long list of labyrinth orders we determined earlier. So this column contained either 0 or some value between 7 and 20. The basic idea of this code was to loop through this new column and count every time the value changed to something bigger than 0 or if an order number changed with the value in the new column being greater than 0, all of this while the project number remained the same.
5. The last thing we needed was the number of labyrinths in a project. To determine this, we retrieved the number of labyrinths of an order from the list of labyrinth orders. Then we made a new list like with step 3, but now with the extra column that contained the number of pieces in that order. Again, we removed duplicate values, sorting on order numbers. Then it was possible to add up the number of labyrinths per project.
6. To get to our final values, we added up all the hours a certain department/process step booked on that project. To get the support hours per process step per order, we simply had to divide by the number of orders. For the support hours per process step per labyrinth, it is a bit trickier. In principle, one can use the formula, but if one first determines the average time per order and goes on calculating with that value, a problem arises when there are only labyrinths in the project. If this is the case, one should directly divide the hours in the project with the number of labyrinths. With the IF formula in Excel, one can easily fix this.

c. Determining waiting time for production process steps

An interesting piece of information that was not of use in this research but could be used to analyse the production process in the future is the waiting time between production steps. The ERP system outputs a sign off time, which shows up to the second when a process step is signed off as ready. By calculating the difference between two sequential process steps and subtracting the production hours one has the waiting time between two process steps for a single product.

In a likewise manner one could calculate, and thus compare lead times of orders and use that as a key performance indicator in the future.

Important is that the ERP system gets changed a bit. At the moment the sign off date gets overwritten as soon as the order is signed off as a whole (so when the invoice has been paid and the order can be archived).

d. Determining the VC costs from the price list

In contrast to the hours for the production process steps, there is not a planned number of working hours (VC) that a support process step has as a guideline. Therefore, to still be able to compare the realised hours to those that are ‘planned’ we took a look at the price list from where customers can place orders. There we found a list of actions and the time they are expected to take. These hours are sold to the customer and can thus be considered the number of hours that a support step can take.

The actions in the price list are not directly connected to a process step, so we had to do that ourselves. Based on this overview and the actions we connected to each process step we were able to determine a VC value for support process steps in [Table 11](#).

Action	Assigned process step	Sold Hrs.	Remark
MDB			This part has been shielded of for this public version
Creating Dimensional Protocol			
Checking the protocol			
Release production order and print/release routing card			
Prepare production order			
MRP connecting to drawings			
Prepare MRP production order			
Prepare routing card			
Prepare MRP delivery			
Internal transport of material from building 21 to shop			
Internal transport to the expedition			
Notify and supporting external transport			
Sold Support hrs. Per piece			
For Whole order base costs			
Sold Support hrs. (approx.)			

Table 10 Sold support hours per process step

**Internal Transport hours are not registered in the ERP system and thus not analysed in this research*

e. Determining the costs of rework

As has been stated in the report, the costs of rework are high. In this section, we will explain how we came to the number of hours that the rework of a single labyrinth costs on average.

The first thing that we have done is to go through all NCC forms and create an overview in excel. An NCC (non-conformity) is a form that is filled in when a mistake/damage is reported and it contains information about the damage, cause, location, and solution.

For the orders of which it was possible to indicate them as labyrinth we followed the following steps to make a good estimate of the extra working hours that were made because of the rework:

1. Go to the production order of the broken product and add up all the hours that have been registered on the product up until the process step where it was damaged.
2. Add up all the hours that have been registered on the new production order that has been made for the reworked product.
3. Based on the support hours as described in [Table 10](#) and the number of labyrinths in the order create an estimate of the support hours that have been spent on the initial product.
4. For the support hours that have been spent on the rework, look for hours booked by steps that are typically at the beginning of the process (MPR, Planning, TSE) at or just after the date that the damage was reported.
5. For a reworked product, the time until delivery is shorter than planned, therefore the project manager is spending more time making sure the product gets through the process on time. Thus for a reworked product, there are more project manager hours booked later in time, how much of that is specifically caused by the rework is hard to say exactly. However, by comparing to similar orders one can make a guess and also take some of those later PM hours into account.

If all hours from the above five steps are added up we have a total number of hours that is spent on a reworked product. The extra hours can be determined by subtracting the sum of hours found at step 1 and 3 (these are the hours that would have been spent under normal conditions) from the total.

f. Overview of the performance data of the process steps per labyrinth

In [Table 11](#) an overview of the results of the performance, or VC and NC, analysis is given. This data is the result of the above-described procedures. We will give an explanation of all the columns:

- ‘#’ shows the frequency of the process step in the data set.
- ‘**Avg. Waiting time**’ shows the average time between the signing off of the prior process step and the signing off time of that step minus its realised duration (NC).
- ‘**Avg. Diff. SU**’ shows the average difference between the number of hours that was planned for setup and the number of hours that were registered on setup.
- ‘**Avg. VC**’ shows the average time that was planned for that process step. For support steps, this VC is determined by the price list in Section d of this Appendix.
- ‘**Avg. NC**’ shows the average number of hours that are registered for this process step.
- ‘**Std. NC**’ shows the sample standard deviation of all the NC values for that process step.
- ‘**Avg. Tot. Diff.**’ shows the average difference between the total time (incl. set up) that was planned for that process step and the actual time registered on that process step.
- ‘**Std. Diff**’ shows the sample standard deviation of all the total differences of that process step.

Process step	#	Avg. Waiting Time (days)	Avg. Diff. SU (hr.)	Avg. VC (hr.)	Avg. NC (hr.)	Std. NC (hr.)	Avg. Tot. Diff. (hr.)	Std. Diff (hr.)
Planning								
MRP								
Technical Support Engineering								
Project Management								
Q MDB								
Sawing								
Turning 3-Claw								
Turning 4-Claw								
Milling								
Eroding								
Glowing								
Benchwork								
Quality Inspection								
Packaging								
Shipment								

This part has been shielded of for this public version

Table 11 Performance data of the process steps per labyrinth

D. MANUAL FOR THE ANALYSIS OF PRODUCTION HOURS

Since the manual is meant for VDL Energy Systems, the manual will be in Dutch.

Deze handleiding is bedoeld om uit te leggen hoe, met behulp van twee exports vanuit het ERP systeem, het mogelijk is om de prestaties van de productiestappen voor labyrinten te analyseren. In de handleiding wordt er van uitgegaan dat de gebruiker in het bezit is van het Excel workbook 'VC-NC Analysis Tool V1.xlsx'.

1. Export de Calculaties en Orderbewerkingen kubus naar Excel.
2. Laad de data van deze twee workbooks naar de sheets 'Calculaties' en 'Orderbewerkingen kubus' respectievelijk.
 - a. *Data tab > Get Data > From File > From Workbook*
 - b. Klik het juiste workbook aan uit de juiste folder.
 - c. Druk op de pijl naast *Load* en klik op *Load To*.
 - d. Zorg dat je de cel A1 van de goede sheet geselecteerd hebt.
 - e. Klik op *load to existing worksheet*
 - f. Klik *Load*

In de sheet 'Orderbewerkingen Kubus':

3. Creëer links naast kolom E of 'Wz' een nieuwe kolom E.
4. Noem deze kolom in de tabel 'Labyrinth'.
5. Vul in de cel E2 de volgende formule
in: =IF(COUNTIF(Calculaties[#All];[Codenr]);[@Codenr]);1;0)
Deze formule zal automatisch voor de gehele tabel gelden.
6. Voeg nog 7 kolommen in links van de kolom 'Wz'.
7. In kolom F, rechts naast 'Labyrinth' voeg je deze formule in:
=VLOOKUP([@Codenr];Calculaties[#All];[Codenr]:[Maak methode]];5;FALSE)
8. Vervolgens selecteer je de gehele kolom F door op de bovenste cel te gaan staan en de volgende toetsen in te drukken: CTRL + SHIFT + 'Pijl naar beneden'. En kopieer deze data.
9. Klik vervolgens met de rechtermuisknop op de bovenste cel, gelijk aan de bovenste cel van de eerder gemaakt selectie. En onder 'paste special' klik op 'paste values'.
10. Daarna selecteert U de gehele kolom G op dezelfde manier als onder 8.
11. Druk onder de data tab *Data>Tekst to Columns*.
12. Kies 'Fixed Width', en scrol in het menu daaronder totdat u een LABY-XXXXXX nummer gevonden heeft.
13. Plaats de lijnen door te klikken op de plekken zoals aangegeven in **Figure 17**.
14. Klik op *Next* en dan op *Finish*.
15. Geef de kolommen de volgende namen:
 - a. H: *Type Laby*
 - b. I: *Materiaal*

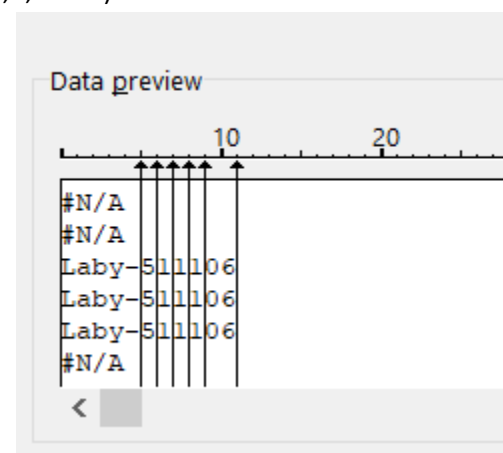


Figure 17 Lijnen in 'Text to Columns'

- c. J: *Split*
- d. K: *Diameter*
- e. L: *Aantal Tandem*

Hierna kunt U kolom G eventueel verwijderen.

16. Selecteer alle data in de sheet 'Orderbewerkingen Kubus' door CTRL + A te drukken.
17. Ga naar de data tab *Data > Pivot Table* en plaats de pivot table in de sheet 'Dashboard'.
18. Zorg dan dat de volgende setup is ingesteld (Figure 19).
19. Boven de pivot table krijgt U dan het beeld in Figure 18. Dit is het menu van de tool waarin U kunt sorteren op bepaalde karakteristieken die ook in de code beschreven zijn. Rechts van de selectievakken ziet U een tabel die uitlegt wat ieder nummer in iedere categorie betekent.
20. Om meerdere selectie criteria te maken moet U bij ieder criterium de selectie vakje 'Select Multiple Items' aanvinken.
21. Belangrijk is dat U bij NC uren alle waardes selecteert behalve de waarde 0, proces stappen met waarde NC = 0 hebben nog niet plaatsgevonden en zullen de gemiddelden alleen maar 'vertroebelen'.

U heeft nu de data voor zich om alle productie stappen in het labyrint proces te analyseren, succes!

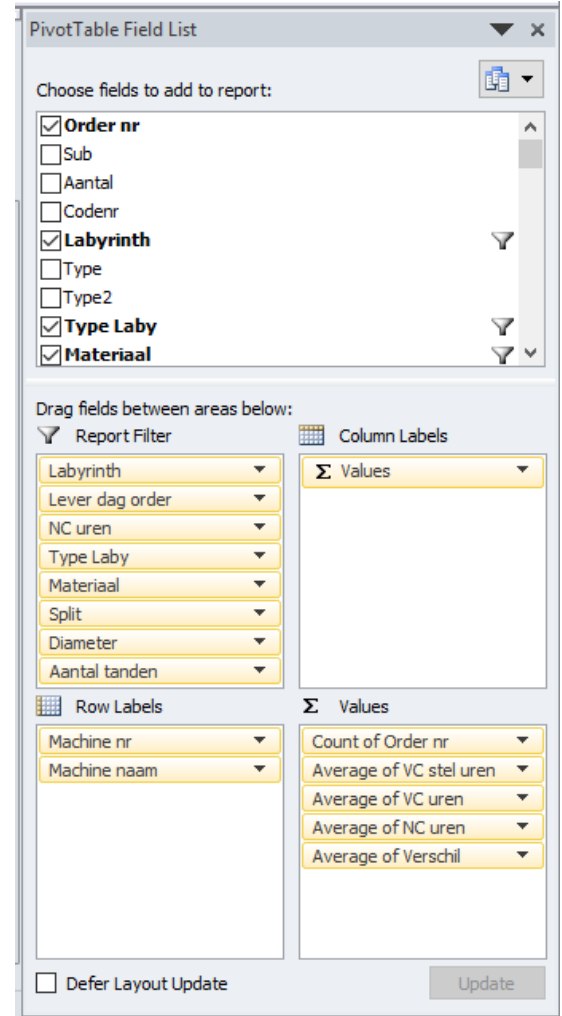


Figure 19 Setup van de pivot table

Labyrinth	1		Type Laby	Materiaal	Split	Diameter
Lever dag order	(All)		1	1	L8731 G / AlMg 4,5	= 0 <=330
NC uren	(Multiple Items)		2	2	L8302-3B / X20Cr13	>0 >330
Type Laby	5		3	3	X6CrNiTi 18-10 / Monel	Geen
Materiaal	2		4	4	ALCu2Mg 1.5Ni	
Split	(All)		5	5		
Diameter	(All)		6	6		
Aantal tanden	(All)					

Figure 18 Menu van de Tool/Pivot Table

E. SYSTEMATIC LITERATURE REVIEW

In order to answer the research questions as stated in Section 1.6, a systematic literature review is conducted. The literature review consists of the following steps:

1. **Define:** Knowledge problem and research question.
Define the key theoretical concepts.
2. **Scope:** Requirements and plan.
Determine inclusion and exclusion criteria. Choose a database, type of source.
3. **Conduct the search.**
Build a structured search query. Evaluate and improve on initial searches.
4. **Review the literature.**
Apply criteria, appraise sources. Use a conceptual matrix
5. **Composes the review**
Document; method used, sources found. Draw conclusions and discuss.
(Noort, 2019)

a. Systematic literature review about the method Value Stream Mapping.

Research Question: *“How can Value Stream Mapping be applied?”*

The goal is to find a step-by-step approach on how to build a value stream map.

Date of Search	Search terms	Scope	Date Range	Number of articles
Scopus				
14-5-2020	“Value Stream Mapping” AND “How to”	Title, abstract, keywords	1998-2020	64
14-5-2020	“Value Stream Mapping” AND “Identify” AND “Waste”	Article Title	-	1
Business Source Elite				
14-5-2020	“Value Stream Mapping” AND “How to”	Title, Abstract	2001-2020	16
14-5-2020	“Value Stream Mapping” AND “Identify” AND “Waste”	Broad	1998-2020	37
Total				118
Exclusion Criteria				-39
Paid articles				0
Selection after scanning & reading abstract				-73
After reading the article				0
Added afterwards				2
End Total				10

Table 12 Search terms Value Stream Mapping

Although “How to” is not a key concept, the goal was to find a step-by-step approach, how to apply value stream mapping. Therefore I found it useful to add that part to the search string.

The date ranges that can be seen above are the ranges of all the articles the search string yielded. I found that the creation of VSM was in 1998, so the date range is set from then until the present. For one search string, this meant that the range was from 2001 as it didn’t find articles before 2001 based on that search string.

The two articles added afterwards are ‘Gustavsson, H., & Axelsson, J. (2010). *Improving the System Architecting Process through the Use of Lean Tools.*’ and ‘Rother, M., & Shook, J. (1999). *Learning to see: value stream mapping to add value and eliminate muda.*’. These articles were found in another IEM bachelor thesis and via google scholar (respectively). Rother and Shook were mentioned by other articles, but I could not find them via Scopus or BSE. Therefore, I tried google scholar, where I found a slideshow that explained the approach of Rother and Shook.

I was searching for articles that explained how to use VSM in a step by step approach. Most of the articles I found made use of VSM, to some extent, but very little showed an approach on how to apply VSM. This became clear from reading the titles and abstracts, therefore 73 articles were excluded.

Number	Criteria	explanation
1	Academic Journals	There is a lot of material about VSM. So to make sure that the sources had a good build-up and referencing, I choose only academic Journals
2	Computer Science	This field of science is not relevant to the research.
3	Decision Sciences	This field of science is not relevant to the research.
4	Mathematics	This field of science is not relevant to the research.
5	Chemical Engineering	This field of science is not relevant to the research.
6	Environmental Sciences	This field of science is not relevant to the research.
7	Biochemistry, Genetics and Molecular Biology	This field of science is not relevant to the research.
8	Energy	This field of science is not relevant to the research.
9	Physics & Astronomy	This field of science is not relevant to the research.
10	Social Sciences	This field of science is not relevant to the research.
11	Earth & Planetary Sciences	This field of science is not relevant to the research.

Table 13 Exclusion criteria Value Stream Mapping

These fields of science have been excluded because I was looking for an explanation of how to construct a value stream map. This falls under the field of industrial engineering as it is about mapping and analysing a (production) process. That does not fall under the fields of science that have been excluded, although the method itself could be used in an analysis of, for example, a chemical plant.

The final ten articles have been summarised below in Table 14. Per article relevant content with regard to the two sub-questions *How can the method be applied?* and *What are (dis)advantages of the method?* is summarised.

Source	Application of method	(Dis)advantages	Conclusion
Gustavsson, H., & Axelsson, J. (2010). <i>Improving the System Architecting Process through the Use of Lean Tools.</i>	There are four stages in the mapping process. Value stream scope (Determine which process needs to be improved), current state (how things currently operate), future state (design a lean flow) & work plan and implementation (ensure improvements are implemented).	Focus on value creation.	Four stages, VSM scope, current & future state and work plan. VSM puts focus on value creation.
Rother, M., & Shook, J. (1999). <i>Learning to see: value stream mapping to add value and eliminate muda.</i>	Start with product family, current-state, future-state & work plan & implementation. They also include eight questions to answer when drawing a future-state.	Helps to visualize more than the single-process level. It helps you to see waste. Provides common language for talking about processes. VSM forms basis for implementation plan. Shows link between information and material flow. More useful than quantitative tools.	Four stages. Visualises, more than single process and waste. Provides common language and forms basis for implementation. Link between information and material flow.
Carvalho et al. (2017). <i>Value stream mapping as a lean manufacturing tool: A new account approach for cost saving in a textile company.</i>	After production flow observation construct a current state map. After main wastes have been detected, create a future state map.	-	Current stage map and future state map.
Jasti et al. (2018). <i>An application of value stream mapping in auto-ancillary industry: a case study.</i>	In addition to the five steps of Rother and Shook two more steps are added: 1) Identify and select product family. 2) Form a cross functional team to address the problem. 3) Map the processes in the production line. 4) develop current state VSM. 5) analyse the wastes and propose kaizen events. 6) propose future state VS. 7) make a work plan and achieve it	VSM is helpful in identifying waste activities. It helps improve productivity and quality in the organisation. It looks simple to develop a current state map, but when the process lacks standardisation it is difficult to capture the reality. It is also difficult to apply VSM to complex processes such as automobile manufacturing.	7 steps to make a VSM. VSM helps identify waste, improve productivity and quality. However, making a current state map is not always easy.
Seth, D., Seth N., Dhariwal, P. (2017) <i>Application of value stream mapping (VSM) for lean and cycle time reduction in complex</i>	Briefly address choosing product family, current state, future state. Almost all researchers that looked into VSM applications in complex environments conclude that micro-concepts: takt time, supermarket to	Graphical resources of VSM is a good basis to identify VA and NVA activities. VSM did not cover challenges for engineer to order (ETO) and high-mix-lo-volume	For complex environments, lean tools do not work. Graphical resources of VSM are good basis. But VSM does not

Source	Application of method	(Dis)advantages	Conclusion
<i>production environments: a case study</i>	facilitate pull, releasing per pacemaker do not work.'	(HMLV) production environments.	cover challenges for ETO and HMLV.
Cahyo et al. (2019) <i>Improving the performance of an assembly line to increase production capacity using value stream mapping: A study case</i>	Purpose is to identify value adding, non-value adding or necessary non-value adding (VA, NVA, NNVA) activities.	VSM is quick and easy to learn. It's inexpensive and can be critiqued early by the workforce.	Purpose of VSM is to identify VA, NNVA & NVA. VSM is easy to learn and inexpensive.
Kosasih et al. (2018). <i>Applying value stream mapping tools and Kanban system for waste identification and reduction(case study: a basic chemical company)</i>	-	-	This article turned out to be not useful.
Luna, L., Klökner, P., & Ferreira, J. (2013). <i>Applying Value Stream Mapping to Identify and Evaluate Waste in a Company of the Ceramic Sector.</i>	Also mention the four steps: product family, current state, future state & plan of improvements.	-	Four stages for creating a VSM, same as mentioned earlier.
Lovelle, J. (2001) <i>Mapping the value stream.</i>	Four steps: Current-state (including choosing product group), internal mapping (go observe production floor and write times down working backwards through the process), identify waste (identify the types of waste) & future-state (calculate takt time, compare with cycle time and use lean tools (e.g. Kaizen, 5s) to eliminate waste). There are four types of Icons material flow, information and general icons. Mapping the value stream starts with customer demand.	Powerful but simple. No tool can outline and distinguish the true value of a product as a VSM. VSM allows the user to see the waste throughout the stream and imagine a future state that more closely resembles lean.	Four stages, but different than articles above. A powerful and simple tool. Allows the user to see waste throughout the stream.
Lasa et al. (2008) <i>An evaluation of the value stream mapping tool.</i>	Five phases: Selection of Product family, current state mapping, future state mapping, defining a working plan & achieving the working plan.	Clearly showing of waste and the use of a standardized language.	Five stages, same as earlier articles, but

Source	Application of method	(Dis)advantages	Conclusion
	<p>For making a future state map:</p> <p>1) Production rate must be imposed by production rate (takt time). 2) Establish continuous flow where possible. 3) When a continuous flow is not possible, employ pull systems. 4) One pacemaker process commands the production of other parts. 5) Downstream, flow if FIFO, upstream is triggered by pull signals. 6) Pacemaker process scheduling will deal with maximization of production mix and volume. 7) Improve overall process efficiency.</p>	<p>Establishing the pacemaker as a point of scheduling is not taken into account by criteria in theory.</p>	<p>adds achieving work plan. 7 step list for making future state map.</p> <p>Clearly shows waste and is standardised language. The pacemaker as the point of scheduling is not taken into account by theory.</p>

Table 14 Concept Matrix for Value Stream Mapping