Modelling the total cost of ownership of stock materials

at VDL Energy Systems

UNIVERSITY OF TWENTE.

Graduation Thesis

Bachelor Industrial Engineering and Managment

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February 2021

Bachelor thesis Industrial Engineering and Management

Modelling the total cost of ownership of stock materials at VDL Energy Systems

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Preface

Dear reader,

You are about to read the bachelor thesis "Modelling the total cost of ownership of stock materials at VDL Energy Systems". This research has been executed at VDL Energy Systems in Hengelo as final assignment for my bachelor Industrial Engineering and Management at the university of Twente. This thesis aims at modelling the total cost of ownership of stock materials.

At VDL Energy systems, I have gained so much new insights and I am grateful for this opportunity. Especially because the research has been performed in extraordinary circumstances, the COVID-19 pandemic. I want to thanks VDL Energy Systems that I was allowed to work in the factory during this difficult time.

A special thanks to my supervisor Robbert ten Velde, who guided me during the research. I want to thank him for all his extensive feedback and patient. During all the meetings we had, he was willing to help me. His insights helped me to finish this research. I also want to thanks Jeroen Karssies, for the evaluation meetings and feedback provided on the thesis. During the research I worked a lot in the warehouse and production facility. I want to thank all the employees who were always willing to help me and giving answers to any question I had.

Without a doubt, I would like to thank my UT supervisor Eduardo Lalla. I really enjoyed our meetings and he was always willing to provide me feedback. Without his extensive feedback and insights, I was not able to write this thesis. I learned so much about writing a thesis thanks to him. I would also like to thanks Ipek Seyran Topan for her support during the preparation phase of the thesis. In difficult times, she always asked how things were going and if she could provide some help. Besides that, I want to thanks her for being my second supervisor as well.

Finally, I would like to thank my family and friends for their support during the execution time of this research. They always supported and helped me to finish this thesis. I especially want to thank Chiel Nijhuis. He helped me to keep motivated and provided me with extensive feedback and opinions about the research. Due to this, I was able to improve my thesis.

Laurens Kok

February 2021

Management summary

This research has been performed at VDL Energy Systems (VES) in Hengelo. In today's logistics environment, there is a tremendous need for accurate cost accounting and information. It is indicated that VES did not have a clear procedure on how to deal with the material flow of their stock materials. To solve this problem, this research focused on identifying the total cost of ownership (TCO) of stock materials and optimizing the logistics processes. In the relationship between departments, cost knowledge is essential. In this research, the total cost of ownership has been defined as all the related costs the moment a material is purchased, until the moment it is used by the mechanics in the factory. This involved departments such as procurement, production control, logistics and production. So, we were interested in identifying the costs and optimizing the processes. We focussed on the logistics flows, which represents the actions that need to be done to get a material from one place to another. Therefore, the main research question addressed in this thesis is formulated as follows:

What is the optimal logistics flow for stock materials at VDL Energy Systems?

To understand the situation at the company in a better way, we executed context analysis. By performing observation study at VES' office, warehouse and production facility as well as by conducting interviews, we were able to create better insights in the processes. Three logistics flows are determined: General stock and two types of bulk stock, bulk stock supplied by VDL warehouse and bulk stock supplied by an external supplier. This last flow is called vendor managed inventory (VMI). To provide an overview of the flows, for each of them a business process model is created. In these models the activities that need to be performed can be seen. To map the major activities of the flows, a value stream map is created. By analyzing these mappings, we were able to state focus points of the research.

After mapping the processes, the the total cost of ownership could be calculated. But first, a literature study was executed to find an appropriate method for cost accounting. We needed to know which methods were available in order to allocate costs as best as possible for the situation at VES. Three concepts were evaluated: Activity-based costing, time-driven activity-based costing, and lean accounting. The activity-based costing method was selected as cost accounting method to be applied in this research. The stock materials were then analyzed to create better insights about the type of materials. Keeping overview of key, therefore we categorized the materials in groups, based on common properties. Four material groups were defined: 'quality', 'goods of length', 'exact quantity' and 'bulk stock'. For each of the material groups, we made a decision which of the three logistics flows fit the best.

To make this decision, we executed the activity-based costing method by observation study in the factory and warehouse. Involved departments were selected and at these departments interviews were conducted. By observing, for each of the departments the defined processes are distinguished into activities. For each of the activities, in cooperation with employees, we measured involved times. Out of these measurements, we defined formulas to calculate the TCOs of the logistics flows. These costs function are analyzed. Out of these analyses, we concluded that for material groups 'quality' and 'goods of length' the optimal flow was the general flow. For the 'bulk stock' and 'exact quantity', we needed to design a model that could be used as a decision supporting tool.

Therefore, we programmed a model. Using the model, the proportions of influences of the departments at the TCO can be calculated. Moreover, for mass data it is possible to calculate whether to outsource bulk stock materials or not. This is done by making a comparison between the TCOs of bulk stock supplied by VDL warehouse and VMI. The model was analyzed. It is concluded that for the material group exact quantity, the general stock flow fits the best.

Besides that, we searched for improvements to optimize the logistics processes. After observation study we concluded that the process of picking materials in the warehouse was time consuming. To reduce this, we compared the processes of counting and weighing in the warehouse. Out of multiple measurements, we stated that the moment more than 50 materials need to be picked, weighing would improve the picking process.

Zooming in at the bulk stock, using the model, a decision can be made whether to outsource the inventory (VMI) or not (Bulk stock supplied by VDL warehouse). Through applying the model and analyzing the logistics flows, the following main conclusions are made.

- For the material groups exact quantity and bulk stock, the model can be used as a decision supporting tool.
- At the general stock, we concluded that the logistics flow can be optimized by using weighing instead of counting in case more than 50 materials need to be picked.

- Comparing the three flows, when executing the bulk stock supplied by VDL warehouse, most activities need to be performed. Therefore, under same circumstances, using the bulk stock supplied by VDL warehouse will cause the highest total cost of ownership out of the three flows.
- 59 materials that follow the bulk stock supplied by VDL warehouse are analyzed using the model. It is concluded the moment the purchase price of the VMI supplier will be between 0% and 10% higher the company's own supplier, savings can be made the moment these 59 materials will be outsources. In that case, each time the moment these 59 materials will be purchased again, savings between €2408,38 and €3071 can be made.

Based on the performed research and stated conclusions, recommendations are made to VDL Energy Systems. The main recommendations are as follow.

- To calculate the TCOs of the different flows, we recommend making use of the model.
- We suggest to minimize the use of the bulk stock supplied by VDL warehouse flow.
- When bulk stock is considered, we advise to outsource the inventory management, so add them to VMI.
- We recommend to make use of a wireless, logistics weighing scale to optimize the picking process in the warehouse.

Lastly, it is advised to focus on information sharing between the departments procurement, production control, logistics and production to keep optimizing the processes and performing like VDL's slogan: *'Strength through cooperation'*.

Contents

Reader's guide

Along the eight chapters, we described how the research at VDL Energy Systems is performed. We shortly introduce the chapters.

Chapter 1: Introduction
An introduction to the research is given in the first chapter. Shortly, the main activities of VDL Energy Systems are described. Moreover, the research methodology is explained and the core problem within this thesis is defined.

Chapter 2: Context analysis
This chapter provides a better insight in the research, a context analysis at VDL Energy Systems is given. Business process models are presented and the value stream map is discussed to create better understandings in the logistics processes at the company.

Chapter 3: Literature study
Literature study is described in the third chapter. The total cost of ownership should be calculated, therefore better insights in which theories and methods are available when it comes to cost accounting are provided in this chapter. Different theories are outlined and the relevancy for the assignment is given.

Chapter 4: Categorizing materials
The stock materials are analyzed in chapter four. Materials are categorized in material groups, based on indicators. The different materials groups are explained and showed in an overview.

Chapter 5: Activity-based costing
The execution of the activity-based costing method at VDL Energy Systems is described in this chapter. A step-by-step approach is given on how the method is applied within this research. The cost calculations of the different logistics flows are outlined.

Chapter 6: Solution method
To make a decisions which flow a material group should follow, a model has been designed. In chapter six, this model is explained. A decision supporting tool is designed to calculate the different costs of the logistics flows. Moreover, an analysis of the method is provided and explained in this chapter.

Chapter 7: Implementation and evaluation
How the solution can be implemented at the company is described in chapter seven. The need for implementation is outlined and technical details about the implementation are provided. Moreover, how the solution can be used at the new location is explained. Besides that, results are presented to the most important stakeholders. Based on this, a survey is filled in by the stakeholders and described in this chapter.

Chapter 8: Conclusions, recommendations and future research
Conclusions and recommendations about the performed research are given in this last chapter. Besides that, potential future research is explained.

List of acronyms

Acronyms

ABC Activity-based costing.

BOM Bill of Materials.

CT Cycle time.

ERP Enterprise Resource Planning.

FPQ Full package quantity.

HoL Head of Logistics.

KPI Key Performance Indicator.

LA Lean Accounting.

LM Lean Management.

LWC Logistics warehouse coordinator.

MPSM Managerial Problem-Solving Method.

NPR Non Product-related.

NVA Non-value added.

PC Production controller.

PQ Picking quantity.

PR Product-related.

SAP Systems, Applications, Products.

TCO Total Cost of Ownership.

TDABC Time-driven activity-based costing.

TLP Team Leader Production.

VA Value added.

VBS Van der Leegte Besturings Systeem.

VES VDL Energy Systems B.V..

VMI Vendor Managed Inventory.

VSM Value Stream Method.

1 Introduction

This bachelor thesis is conducted at VDL Energy Systems (VES). Focus points of the research are mapping logistics activities and optimizing processes of stock materials at VES. This to calculate the total cost of ownership (TCO) of the stock materials. Section 1.1 introduces the reader to the company. In Section 1.2 the problem identification is given. Section 1.3 provides an overview how the research is designed.

1.1 Company description

VDL groep

VDL Energy Systems is located in Hengelo, the Netherlands. The company is part of the larger 'VDL groep', an international industrial and manufacturing company. It has been founded in 1953, by *Wim van der Leegte*. In almost 70 years, the company has grown into a large family cooperation, consist out of more than 100 companies all over the world. VDL groep can be divided into four divisions: Subcontracting, Car Assembly, Buses and Coaches and Finished Products. In total, the company is active in a lot of different markets, such as the automotive, medical, mechanical engineering and energy market. VDL groep has a turnover of approximately 6 billion euros (VDL, 2019).

VDL Groep: "Strength through cooperation"

VDL Energy Systems

VDL Energy Systems is part of the VDL Groep. To be more specific, the company is part of the 'subcontracting companies'. At the moment, the company's main activities are:

- Assembly and testing of compressor and gas turbine packages
- Service activities for rotating equipment market
- Balancing and full load testing of gasturbines/ compressors/ generators
- VES new business product development: Fuel cells

The factory is located in Hengelo. VDL took over this factory from *Siemens* in 2018. The Siemens' employees had to make a transition to the philosophy of VDL. When executing the research, Siemens is still one of the main clients for VDL Energy systems. Besides these activities, VES is also focussing on the Energy transition portfolio, this is called the 'VES new business product development'. In 2021, the company will move to a new built factory in Almelo, in order to work more efficient and focus on the future. The focus in this bachelor thesis lies on the stock materials used to build the gas turbine machines. An example of a gas turbine in Ves' factory can be seen in Figure 1.

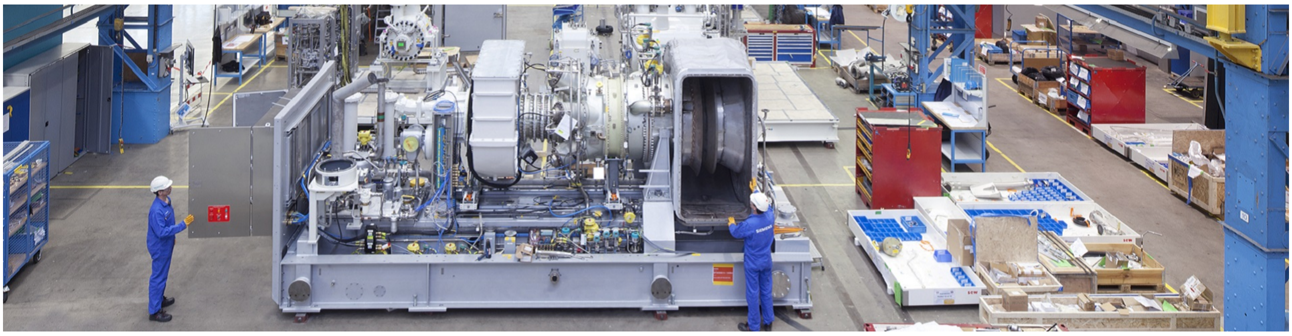


Figure 1: Example of gas turbine at VDL Energy Systems

1.2 The problem

This section outlines the problem identification presented at the company. Section 1.2.1 states the action problem of this thesis. The problems occurred at VDL Energy Systems are outlined in Section 1.2.2. Section 1.2.3 provides the core problem and the motivation behind the choose.

1.2.1 Action problem

Product-related materials

The company distinguished two types of products that have to be purchased for the machine: Product-related (PR) and non product-related (NPR) materials. PR materials will directly be used at the machine. NPR materials will not directly be used at the machine. Examples are for instance tools and safety gloves. The focus in this bachelor thesis lies on PR materials.

Types of stock
Each of the machines, which will be assembled in the factory, is unique. Due to the fact that the machines will be placed all over the world and each country might has his own regulations and restrictions. Therefore, each machine will be an unique project. This means VES can be seen as a project-based company. This results in the fact that the company will purchase most of the components separately, based on project. Besides that, some components will be purchased as stock. These are materials which will be used on almost each machine. Examples of this are bolts, nuts and rings.

The process this assignment analysed was the moment when the company is purchasing PR materials which have been purchased as stock. The company distinguishes three types of stock: general stock, bulk stock supplied by VDL warehouse and bulk stock supplied by external vendor. The last one is also called vendor managed inventory (VMI). The concept of VMI is explained in more detail in Section 2.1.3. Each type of stock has its own logistics flow, which is described in Chapter 2.

VDL Energy Systems wants to manage their costs as best as possible. When dealing with stock products, several costs have to be indicated. Take for instance handling costs at the logistics department. The company wanted to identify the total cost of ownership (TCO) of the stock materials in order to optimize the logistics processes. By identifying the costs, a decision can be made what the optimal logistics flow for a certain material group will be. The concept of material groups is described in Chapter 4. This leads to the main research question of this thesis:

What is the optimal logistics flow for stock materials at VDL Energy Systems?

Stating this research question, the action problem is determined as follows:

At VDL Energy Systems, the total cost of ownership of stock materials, need to go from unidentified to identified and the logistics process should be optimized.

Total cost of ownership
According to Chopra and Meindl (2016), the TCO is defined as the acquisition costs plus ownership costs. In this research the focus lied on identifying the TCO. At VES, we defined the TCO as purchase price plus costs of operation for the material. To be more specific, the acquisition costs are calculated by adding up the purchase price and any additional costs made by the procurement department. Ownership costs included all costs of the material the moment it will arrive at the logistics department untill the material will be used by the mechanic to build the machine. The costs calculations are made in Chapter 5. According to Twin (2020), the TCO is a good method when analyzing considerations and making the right decisions.

Norm and reality
An action problem is where the reality deviates from the norm (Heerkens and Winden, 2017). In this specific action problem, the norm is the identification of the TCO and an optimization of the logistics processes. This deviated from the reality, unidentified TCO and not optimized logistics processes.

1.2.2 Problem identification

To identify the root of the action problem, a problem cluster to map all the related problems with their connections is made to identify the core problem (Heerkens and Winden, 2017). The problem cluster, which is used to map all problems along with their connections, can be seen in Figure 2. The stated action problem has marked red in the figure.

At the warehouse, the logistics employee will count and collect the materials which have to be used in production. This is called "Order picking" (Murray, 2019). Due to the fact that most of the components will be collected in exact collected quantities, (e.g., 15 bolts) this is a time consuming process. This results in the problem that handling times in the warehouse are high. Therefore, for some products it will be more beneficial to be placed as VMI and follow that logistics process, due to the fact that in the VMI process, picking is not involved. This is described in detail in Chapter 2.1.3. Unfortunately, the company indicated that they do not have sufficient insights the moment it will be more beneficial to place materials to the VMI.

The problem cluster shows that the high handling costs have two causes. The logistics indicates that the administration of products is hard and difficult. Administration means the registration of the products in the ERP-system, called VBS. Therefore, the administration process is time consuming.

A reason for the fact that the logistics process is not optimized is that it occurs that some stock products are placed for a long time in the warehouse. Sometimes, it even occurs that some product has been put in the warehouse for years, without being used, which costs money. A reason for this is the fact that some products will come back out of production. This is called the "return". The problem at VES is that they do not exactly know what to do with the return materials. Products can be used again or placed as stock, but the administration of these products in the ERP-system is hard and time consuming at that moment. Besides that, the risk of not using the products again is reasonable.

The fact that products come return has mainly two reasons. First of all, it is hard to determine what the optimal logistics flow will be when it comes to the amount of material which have to be given to the production. If for example the logistics will exactly give 8 cable glands to the production (because that is indicated at the bill of material) there is chance that it will be too less. It is possible that the mechanic indicates that more should be needed to build the machine, because of practical reasons. Secondly, small materials can be lost in the production facility, because of their tiny size. In order to solve this problem, the production control can determine to choose for another logistics flow, namely bulk stock. The different flows are described in more detail in Chapter 2. It was hard to determine which logistics flow would fit the best to solve the problem, because there were insufficient insights in the costs.

Sometimes it also occurs that products return, but not as safety stock as described before. In that case, materials are not even used by the production department. In other words, too many products have been prepared at the logistics for the production. The procurement department can decide, because of financial reasons to purchase more materials than needed. Another reason can be that the mechanics work differently then indicated at the technical drawings because of practical issues when building the machine.

Unknown insights in which materials should be added to the VMI and the fact that the type of stock is hard to identify, were caused by an other problem. VES indicated that they do not have a clear procedure on how to deal with stock materials. They did not exactly know for each of the materials if they should place it in the factory as VMI, or in the warehouse as bulk stock for the logistics. Besides that, they did not know what the best method would be when it comes to picking of the materials. To summarize, there was insufficient insight on the procedure on how to deal with the logistics flow of the product-related, in stock materials.

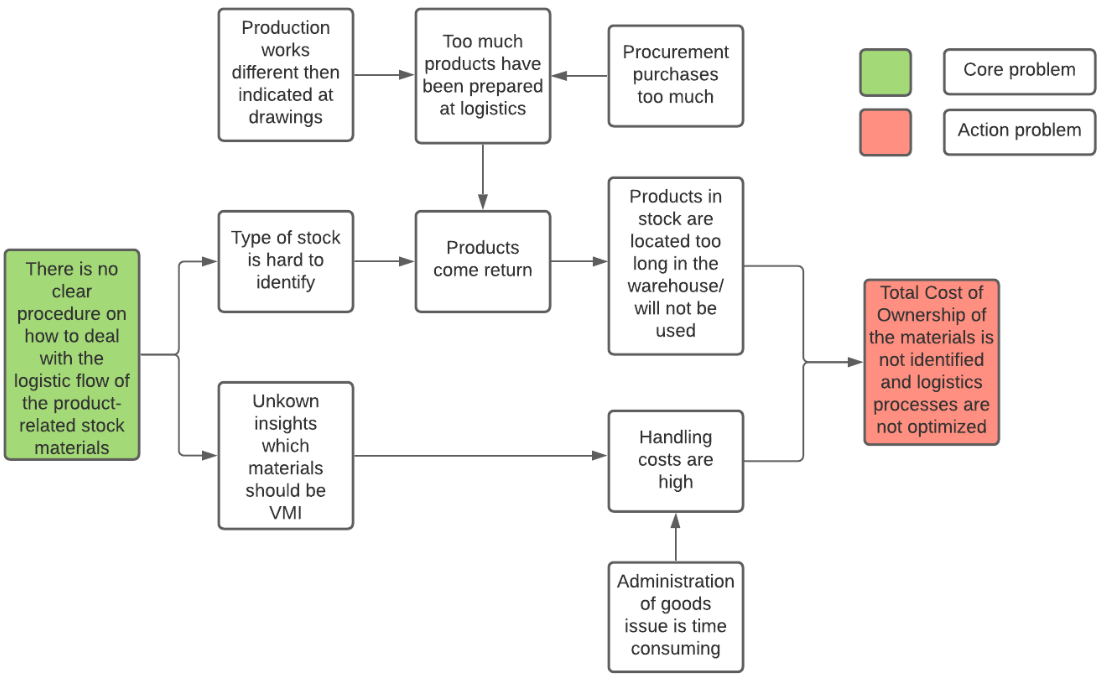


Figure 2: Overview of the problem cluster at VDL Energy Systems

1.2.3 Core problem and motivation

All the problems of the problem cluster have been indicated by executing interviews with different stakeholders. A closer look is made on the problems which do not have a cause by themselves. These can be seen as possible core problems. Out of these problems, the core problem is selected the moment it can be influenced. If more problems can be selected as a core problem, the most important one will be selected as the core problem (Heerkens and Winden, 2017).

The moment of executing this research, a student was working on the problems which can occur at the procurement department. The student was analysing the moment the strategic decisions should be made whether to purchase a material as stock or not. Therefore, that problem is not included in this bachelor assignment. Considering the fact that the mechanics sometimes deviate from the technical drawings, was out of the scope of this project.

The administration of goods issue in the ERP-system is time consuming. This problem can be treated as a core problem, but the company indicated that they do not want to put priority on this. Besides that, the company indicated that learning the ERP-system of the company will take a lot of time, because of the complexity. The problem that VES has not a clear procedure on how to deal with the logistics flow of the stock materials can be seen as a core problem, according to the definition of Heerkens and Winden (2017). The company indicated that they want a clear method/theory which can be used for solving this problem. By having this, the overall chain can be improved. Therefore this can be treated as a core problem.

In this regard, we indicated that VES wanted to have a solution, where the optimal logistics flow of a material group, from the moment of purchasing untill the production department, can be determined. This to reduce waste in the process. The problem that the administration of goods issue in the ERP-system is time consuming should be taken into account, but in cooperation with the company, this was not selected as the core problem.

To conclude, the following problem has been selected as core problem of this thesis:

There is no clear procedure on how to deal with the logistics flow of the product-related stock materials

The core problem and the action problem are marked respectively green and red in Figure 2.

1.3 Research design

In order to answer the stated main research question and to solve the action and core problem, research is conducted. This is done by answering knowledge questions. Per knowledge question, the main steps and its purpose are given. The knowledge questions have been formulated by following the seven steps of the managerial problem-solving method (MPSM), according to Heerkens and Winden (2017). Section 1.3.1 outlines the research questions. An step-by-step overview of the performed research is presented in Figure 3. In Section 1.3.2 describes the restrictions stated as guidelines for this thesis. The deliverables are defined in Section 1.3.3.

1.3.1 Research questions

1. *How can the logistics flows of the materials be determined and which problems occur at VDL Energy Systems?*

   To solve the action problem, a better insight in the current situation is obtained. A context analysis has been conducted, a descriptive study is performed. The logistics flows and problems are identified. Observation study is executed in VES' warehouse. Moreover, interviews are conducted to get a better insight in the processes. A value stream has been created to map the current process. The three different types of logistics flows are described to create a better understanding in the decisions that should be taken. In Chapter 2, the context analysis is described in detail.

2. *What are the relevant methods and theories for identifying the costs of the logistics flows at VDL Energy Systems?*

   A literature study is conducted to find appropriate methods for allocating the costs of logistics processes, such as for VDL Energy Systems. The methods are analysed and the best suitable cost allocation method for this assignment is used to identify the main processes and the involved costs. In Chapter 3, the literature study is described in detail.

3. *Considering the logistics flows, how can the materials be categorised in material groups?*

   The production control department of VES has indicated that they want to determine the optimal logistics flows for specific material groups. To do this, stock materials had to be categorized in different material groups. By answering the third research question, materials are categorized in four different groups, based on common properties. The materials have extensively been analyzed, explanatory study is performed to identify possible relations between the materials. A decision tree is made, to quickly categorize a material in one of the groups. The groups are described in detail in Chapter 4.

4. *Taking into account the current logistics flows and new insights, which procedure can be defined for the different material groups?*

   The current way of working had to be defined. This is done using the insights out of the first research question. By using the current situation, new insights out of scientific literature and common sense are defined. Explanatory study is executed to define different logistics flows for the material groups. The activity-based costing method is used to identify and calculate the related costs of the processes. The detailed explanation of the executed activity-based costing analysis is described in Chapter 5.

5. *How should the solution approach for determining the most optimized logistics flow for the material groups look like, considering the related costs?*

   By mapping the logistics flows, executing literature study and analysing the total costs, we designed a solution method for determining the most optimized logistics flow for the material groups. Explanatory research is performed to come up with a design for the solution. This is done in cooperation with VES' production control department, the most important stakeholders in the process of the solution design. The TCO is the main output variable that is used for modelling the model. A model is programmed, using *Microsoft Excel*, where the TCO of the different material groups can be calculated. A detailed explanation of the solution method is given in Chapter 6.

6. *How can the solution be implemented and evaluated at VDL Energy Systems, taking the restrictions into consideration?*

   In order to implement the solution in an optimal way, explanatory research is performed. In cooperation with the involved stakeholders, an implementation plan is made. This is done based on the stated restrictions of the company. An advise on the current situation and for the new location is given. Besides that, an explanation how the solution can be evaluated in the future, to make sure that the solution will be updated, is given. The implementation plan is described in detail in Chapter 7. Moreover, a survey has been filled in by stakeholders to evaluation the solution approach and to conclude if conclusions and recommendations were useful for the company.

7. *What recommendations and conclusions can be made from conducting the thesis at VDL Energy Systems?*

   The final step was to write down the main recommendations and conclusions after conducting the assignment at VES. The recommendations, conclusions and future research explanation are described in Chapter 8.

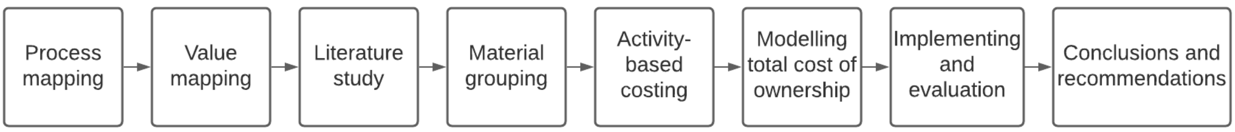


Figure 3: Step-by-step overview of performed research

1.3.2 Restrictions

To solve the action and core problem, we stated some restrictions for the research to perform as guidelines when executing the study. The following four restrictions have been taken into account.

- **Key Performance Indicators:** The solution method had to be designed using key performance indicators (KPI). Examples of these are the total cost of ownership and the purchase price.

- **Clarity:** The solution had to create clarity for the involved stakeholders. Explanation about the solution had to be provided to all stakeholders involved in the processes. By doing this, possible misfits and misunderstandings could be covered and the solution could be implemented in the right way.
- **Administration:** When designing the solution, it had to be taken into account what possible changes need to be done in VBS. If things had to be changed, we had to explain that.
- **New factory:** VDL Energy Systems will move to a new build factory in 2021. The solution should also be applicable at the new location. An advise had to be written how to implement the solution at the new location.

1.3.3 Deliverables

This section provides an overview of the main deliverables that resulted from the bachelor thesis performed at VDL Energy Systems. The deliverables are linked to the sub-questions explained in Section 1.3.1.

1. Business process models of the logistics flows
2. Value stream map of the main process
3. Theoretical framework; literature study and review for relevant costs allocation methods
4. Overview of materials categorized in different material groups
5. Solution approach for determining the most optimized logistics flow for the material groups
6. Implementation and evaluation plan
7. Recommendations, limitations and conclusions from research

2 Context analysis: Mapping the process

This chapter contains the context analysis of the bachelor thesis performed at VDL Energy Systems. This is done by answering the first stated research question.

How can the logistics flows of the materials be determined and which problems occur at VDL Energy Systems?

A logistics flow is defined as the material flow the moment of purchasing until the materials is used in the production facility by the mechanics. The question is answered by first making business process models of the different logistics flows of the materials, which are described in Section 2.1. By executing observation study, times have been measured of the performed processes and are described in Section 2.2. Section 2.3 outlines the created value stream map. A discussion with regard to the time measurements is made in Section 2.4. Section 2.5 outlines the problems and challenges indicated after the time measurements. Lastly, a conclusion is made in Section 2.6.

The main input for this chapter was provided by observation study and conducting interviews. The production control, logistics and production departments have been analysed in this chapter.

2.1 Business process models

This section outlines the business process models which have been created after the observation study. Section 2.1.1 provides the model for the general stock. The bulk stock supplied by VDL warehouse is described in Section 2.1.2. Section 2.1.3 outlines the VMI process.

At VDL Energy Systems, three types of stock can be distinguished: general stock, bulk stock supplied by an external vendor (VMI) and bulk stock supplied by an internal vendor, the VDL warehouse. This last flow is termed 'bulk stock supplied by VDL warehouse'. At the moment of executing this research, the general stock is stored in the warehouse, the VMI is stored in the production hall and the bulk stock supplied by VDL warehouse is also stored in the production hall, but the safety stock is placed in the warehouse. In Figure 4, a short overview can be seen with the general process of the materials flows. In general, this is the process for all materials which have not been outsourced to an external supplier. When materials have been outsourced, other processes are followed. This is described in this chapter. In Figure 5, a simplified floor plan, where the locations of the different stocks can be seen. This floor plan was provided by the company. It can be seen that the factory consists out of multiple buildings. Therefore, at the current factory, walking times are high because of large distances. This will change when moving to the new factory. For each of the three different types of stock, the logistics flows can be determined. By conducting interviews and observation study, the flows have been determined. These are explained in detail in this section.

Figure 4: General process of material flows at VES

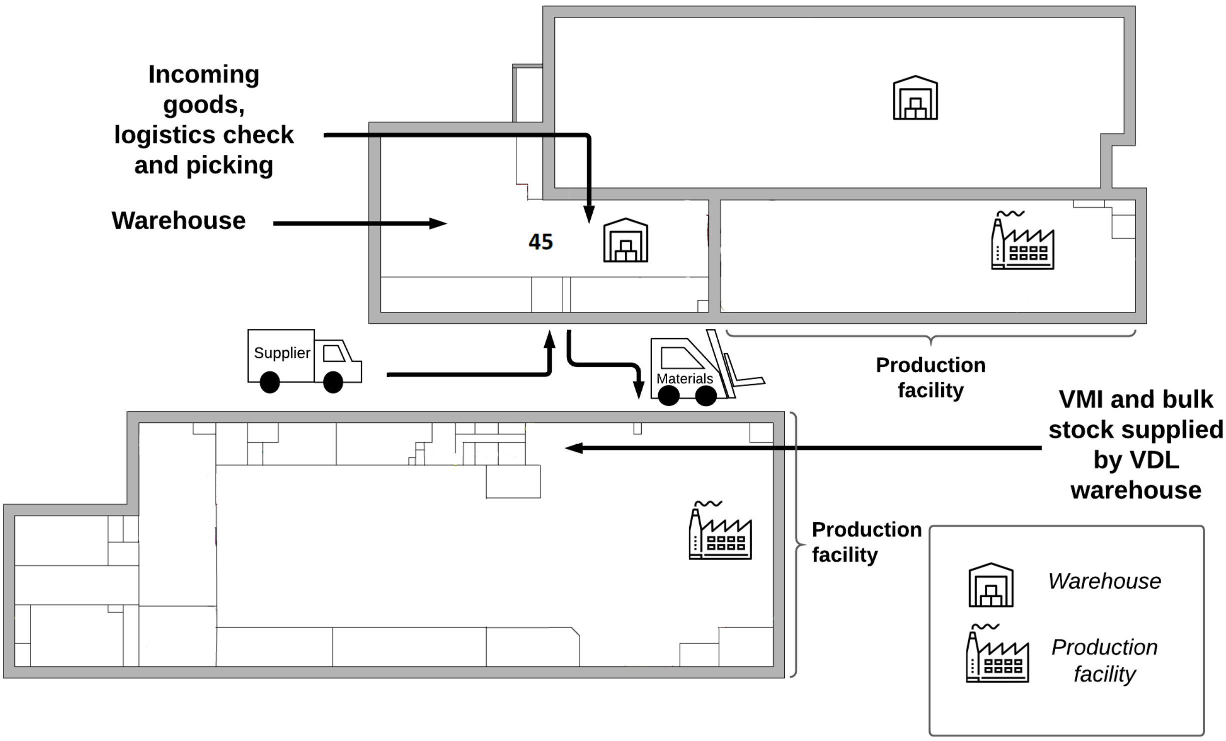


Figure 5: Simplified floor plan of the warehouse and production hall at VDL Energy Systems

2.1.1 General stock related flow

Incoming goods

The general stock is the first type of stock that is discussed. The general stock is located in the warehouse. The logistics flow is explained step-by-step. The starting point is the fact that the materials have been purchased by the procurement department. The supplier of the materials delivers the product to the warehouse. The location where the materials are delivered in the warehouse is called "Incoming goods". A truck will stop at the warehouse. The way of unloading the truck depends on how big the material is. If the supplier will deliver only boxes, the material will be placed at a roller bench by the truck driver. If the materials have been placed on a pallet, a forklift of VES is needed to unload the truck.

An employee will unpack the package. The time it takes to execute this operation depends on how big the material is. Besides that, how the material has been packaged has also significant influence. The more difficult the material is packaged, the more time it takes to unpack it. The next step in the process is the administration of the incoming goods. At VES, this is called "Collie administration". An logistics employee will administrate the incoming goods in the computer, by filling in information such as, the supplier, distributor, quantity and purchase order number. After that, the computer will process stickers, with the involved information, which have to be placed on the package. The next step at the incoming goods department is to allocate the material in the quality rack. This is an intermediate allocation location, where the material can be placed to first administrate all the incoming goods. If a product has to be inspected by the quality department, the quality inspector can take the material out of the rack. If not, the logistics check will be the next step. The final step of incoming goods, is to scan the packing list in the computer and book the material in VBS, the ERP-system of the company. After booking, the computer will process a label which have to be placed on the package. This is another label than the one from the first administration. The label is used to allocate a material on a location in VBS. The time it takes to execute this operation depends on the amount of items the box consist of. Each item has to be booked in VBS separately.

Logistics check

The objective of the logistics check is to check if the quantity of the material matches the purchase order and to allocate the material in the warehouse. The employee will take the material out of the quality rack and unpack it. After checking if the quantity of the materials corresponds with quantity indicated at the packing list, the materials will be prepared to be allocated in the warehouse. If for example the bolts have to put together, the employee can count the bolts and put them in a bag. After preparing the requested material, it will be allocated in the warehouse. If the material has been placed on a pallet, the material will be located on a pallet location in the warehouse. For materials which are small, and therefore not placed on a pallet, the most suitable location will be searched by the employee to locate the material. In doing so, the employee takes the scanner and walks to a as small as possible location to allocate the material in the storage rack. By scanning the material and the location, the material has been administrated in VBS. Here ends the tasks of the logistics check, the material has been placed on location.

Picking process
When the production department asks to provide them with materials, so the mechanics can start working, the picking process will start. A logistics employee will generate a picking list, where all the materials which have to be delivered, are placed. The specific employee will briefly check if the materials that cannot be picked are held up in the receiving process. After the checking, the picking list will be printed and the picking process can be started.

The picker receives the picking list and takes the scanner to pick the materials. A so-called pick trolley is needed, where stuff like tape and stickers are placed. After collecting these necessities, the picker will walk to the pick location, the location in the warehouse where the material has been placed. The material will be scanned, the exact demand will be picked and confirmed on the scanner. For instance, if 56 bolts are asked by production, the picker will count 56 bolts exactly and put them in a storage bin. If all the materials are collected, the bins can be placed in a container. After that, a bill of lading can be made to let the intern transportation department know that the container with materials can be delivered to the production facility.

Intern transportation
The intern transportation departments receives a trigger to start with transporting the materials to the production facility. The employee will take the forklift and lift the container. As can be seen in Figure 5, the warehouse and production facility are placed in two different buildings. So, the employee has to transport the materials to the other building.

Assumptions
A business process model has been made to show an overview of the material handling at the general stock, with all the detailed steps. The model can be seen in Figure 6. Due to the fact that a lot of exceptions can be made when it comes to general stock, a couple of assumptions were considered in the business process model and performing the observation study.

- The incoming goods are small and have not been placed on a pallet. The material will be delivered on the roller bench.
- The incoming goods will be registered in the current ERP-system: VBS. The old ERP-system, SAP, will not be considered in this model.
- The materials do not require quality inspection
- The material can be placed in a storage bin and the bins can be placed in the container.

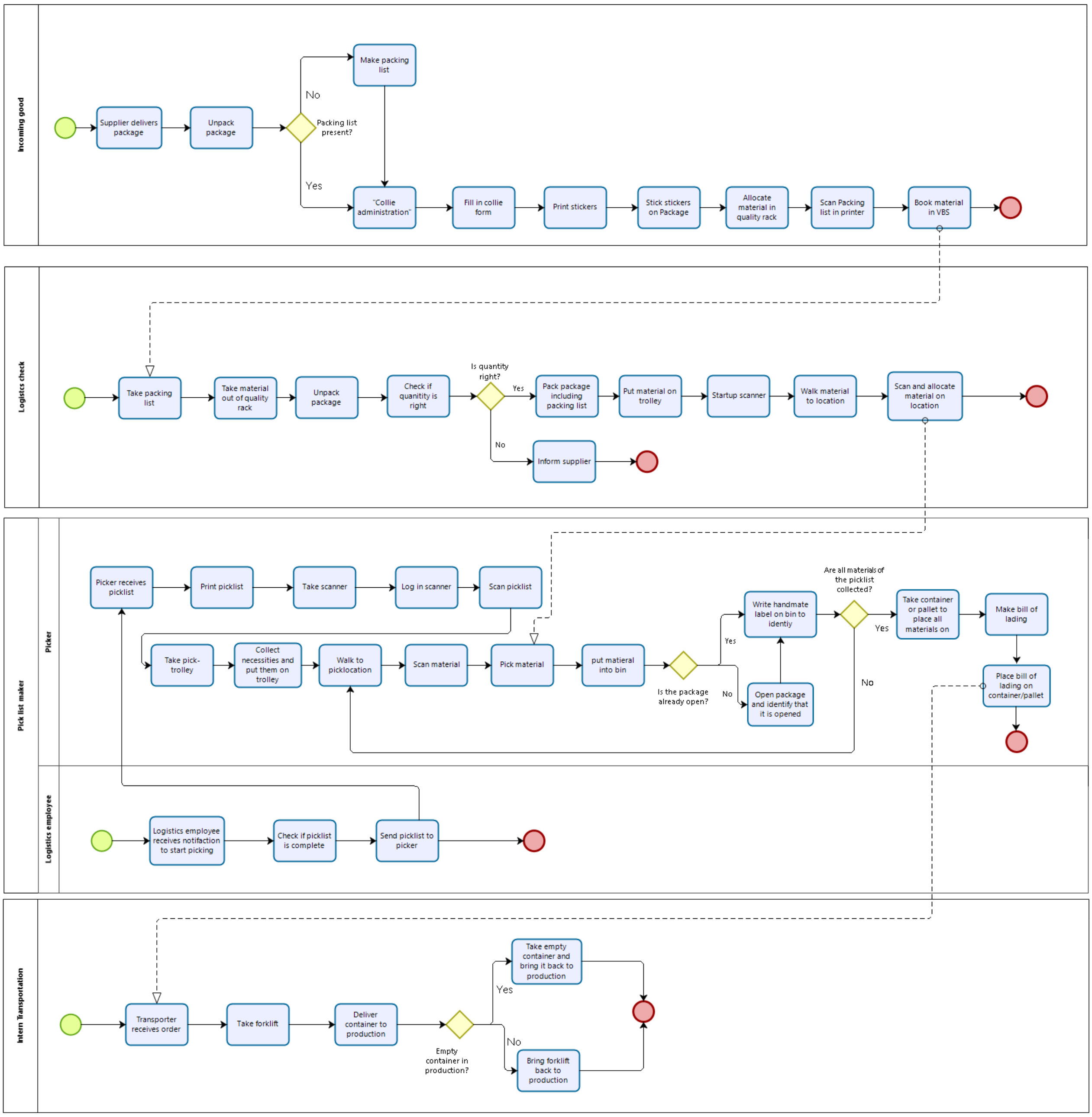


Figure 6: Business process model of the general stock

2.1.2 Bulk stock supplied by VDL warehouse related flow

The bulk stock supplied by VDL warehouse is the second type of stock which is investigated. The logistics flow looks similar to the one from the general stock, but the distinction can be made when it comes to picking the material. As described, the bulk stock is located in production hall, as can be seen in Figure 5. For building the machine, a bill of materials (BOM) is created. By knowing which materials are needed for the machine, a picklist can be made. On the picklist, all the materials which are stored in the warehouse can be seen. In other words, the bulk stock will not be indicated on the picklist, because it is not placed in the warehouse but in the production facility. Only the safety stock is placed in the warehouse.

Why bulk stock?

To be able to build the machine, hundreds of components are needed. The machine has been engineered and the required materials, with corresponding quantities, are indicated. But, for the components which are required a lot, it can be hard to determine the exact type of component and the quantity of it. For instance, the amount of ty-raps that are needed to cluster the cables is hard to identify beforehand. To tackle the problem that the mechanic will walk back to the warehouse and ask for the more components, stock has been located in the production hall, this is called bulk stock. In this case, the mechanic can walk to the bulk stock location and take some ty-raps in order to build further on the machine. Besides that, most of these materials are small and tiny and are needed a lot on the machine. This will bring difficulties when these materials are provided to the production in exact quantities. If for example, the mechanic needs 56 tiny washers, the possibility that the mechanic will drop a washer when building is the machine is high. If exactly 56 washer are needed and there will be none stock available in the production hall, once again the mechanic needs to walk back to the warehouse and ask for a couple of washers. These walking times are waste, because it is valuable time where the mechanic cannot work on the machine, the activity where in the end the company will earn revenue. To conclude, bulk stock has been created to tackle these problems.

Two-bin system

Back to the material handling of the bulk stock supplied by VDL warehouse. The different materials are placed in bins in a storage bin rack. A so called two-bin system is used. This means that two bins with materials are placed behind each other in the storage rack. The moment it will be indicated that the first bin is empty, one can replace the empty bin with the second bin, which is full with components. This second bin is used to have enough items to last until the order for the first bin will be refilled (Liberto, 2019).

Refill

The logistics flow will be continued the moment the first bin is empty and replaced by the second one. The empty bin will be placed next to the storage rack. By doing this, it can be seen that the bin is empty and needs to be refilled. An employee of the logistics department takes all the empty bins and walks to the warehouse where the safety stock have been placed. This employee is called "the runner". When arriving at the warehouse, the needed material have to be booked in VBS, where the production control department will connect the costs of the material to the specific machine. After this, the bins can be refilled and the runner will place the refilled bins in the storage rack. In Figure 7, the business process model can be seen with the logistics flows of the bulk stock supplied by VDL warehouse.

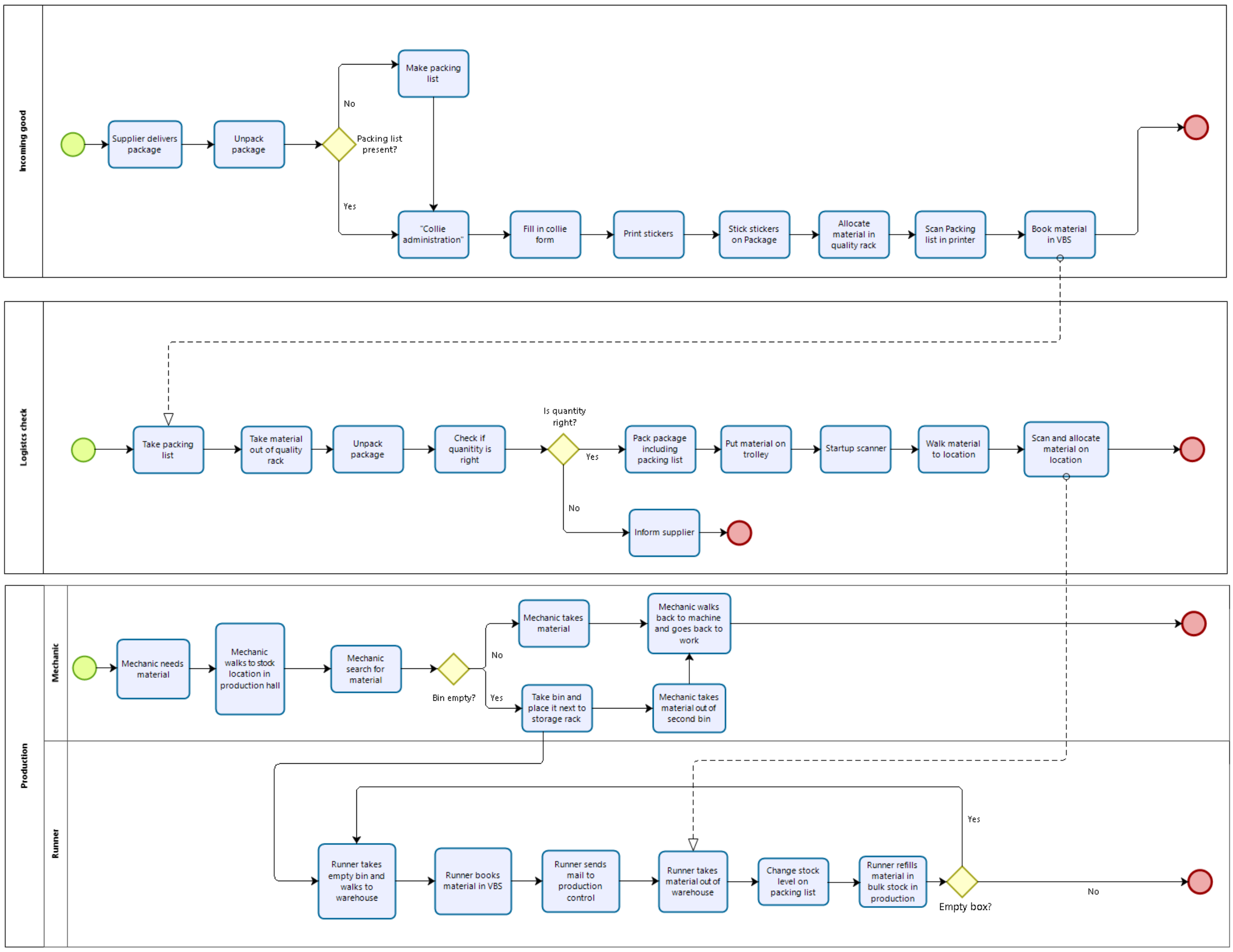


Figure 7: Business process model of the bulk stock supplied by VDL warehouse

2.1.3 Vendor managed inventory related flow

Definition

The third logistics flow which is described is the one from the vendor managed inventory (VMI). An other name for the bulk stock supplied by an external vendor is VMI. VMI is a system where the vendor of the product will take full responsibility for maintaining an agreed inventory of the materials. The buyer of the product will provide the vendor of information about the products (Murray, 2018). Vendor managed inventory has become a competitive supply chain management tool that has been used by retailers, manufacturers and suppliers in order to reduce inventory management cost over the last few decades (Beheshti et al., 2020). In other words, the suppliers, which are the vendors, are accountable for a customer's inventory restocking the moment supply is low. To be practical, at VES, materials which are placed as VMI, will be refilled by the VMI supplier by using a two-bin system. This works the same as for the bulk stock supplied by VDL warehouse. The moment the first bin is empty, the supplier will refill it. In the meantime, the second bin is supposed to have enough items to last until the order for the first bin arrives (Liberto, 2019).

Logistics flow

The storage racks with VMI materials have been placed next to the storage rack of the other bulk stock. For the view of the mechanics there will be no difference between the VMI materials and the bulk stock supplied by VDL warehouse, on both storage racks the materials should be available for them in any case. When looking at the logistics flow of the VMI, there is certainly a difference. As described, the VMI materials have been outsourced. The external supplier will take fill responsibility to refill the bins, by also using a two-bin system. Therefore, the moment the first bin is empty, the only thing the mechanic has to do is placing the bin next to the storage rack. By doing this, the supplier will be able to see which bins have to refilled. In Figure 8, a business process model has been made where the logistics flow of the VMI process can be seen.

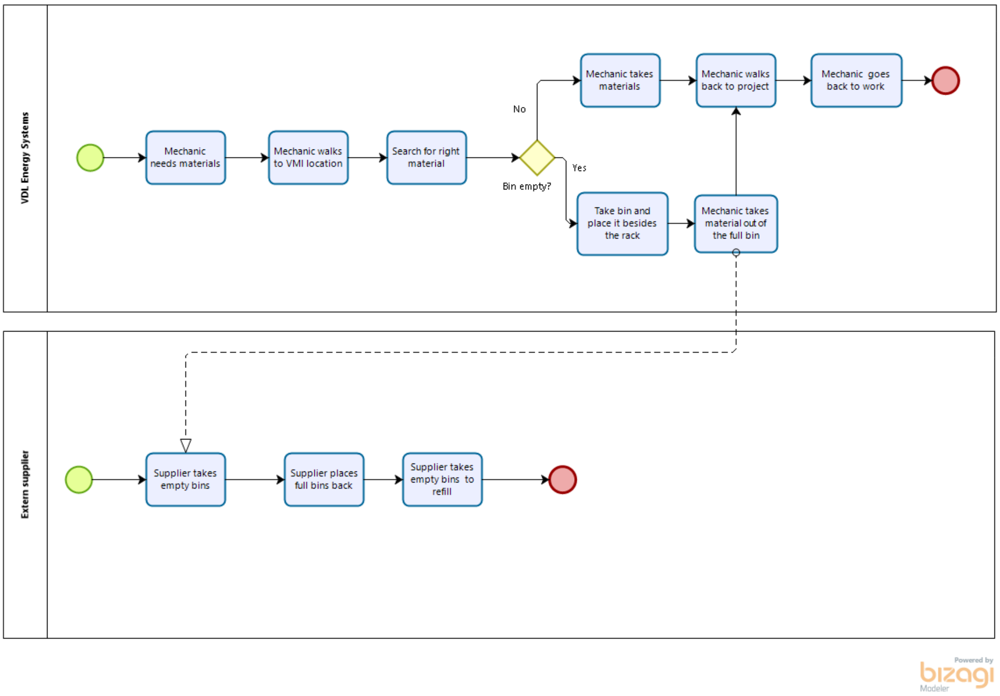


Figure 8: Business process model of the VMI process

Overview
The three logistics flows have been discussed. A simplified overview is presented in Table 1 to keep an overview of the flows. In the table, the three different flows are mentioned. For each flow how the materials are processed is described. Moreover, the location of the activities can be seen in the table as well.

Table 1: Simplified overview of the logistics flows

Logistics flow	Materials	Location of activities
General stock	Processed by VDL	Warehouse
Bulk stock supplied by VDL Warehouse	Processed by VDL	Warehouse, production facility
Vendor managed inventory	Outsourced to an external supplier	Production facility

2.2 Time indication

In order to calculate the TCO of the stock materials, the handling times had to be indicated. This to transform time into costs. Using the logistics flows described in the previous section, the main activities were observed. By using observation study, the cycle times were determined. Research was executed at VES' warehouse and factory. With the help of the employees in the factory, we were able to observe all the processes and measure the time it takes to execute an activity. Times are measured, simply making use of a stopwatch. Multiple measurements are done to calculate the average times.

The cycle time (CT) can be defined as the the time it takes an operator to go through all of their work elements before repeating them (Rother and Shook, 2003). First of all, in Table 2, the time measurement of the VMI process can be seen. Secondly, in Table 3, the time measurement of the general stock are reported. Thirdly, in Table 4, the time measurement of the bulk stock supplied by VDL warehouse can be seen. In the tables, the main activity and description of it are reported. For each activity, time measurements were executed. The minimum, maximum and average time can be seen. Some of the times are dependent of variables. If that is the case, the variable is mentioned. On top of that, the related key performance indicators (KPI) are defined. The times are based on the same assumption as stated in Section 2.1.1.

Table 2: Time measurement of the activities performed when vendor managed inventory is applied

Activity	Description	Min Time (s)	Max Time (s)	Average Time (s)	Variable	KPI
Walking	Mechanic walks to VMI materials	10	60	30	Distance	Time to walk
Searching	Mechanic search for right material	10	120	60	Location of material	Time to find material
Collect materials	Collect the materials	5	20	15	Size of material	Amount of materials needed
Walking	Mechanic walks back to machine	10	60	30	Distance to machine	Time to walk

Table 3: Time measurement of the activities performed when general stock is applied

Activity	Description	Min Time (s)	Max Time (s)	Average Time (s)	Variable	KPI
Unpackaging	Unpack the incoming goods	10/box	180/box	20/box	Amount of boxes	Time to unpack a box
Administration	Administrate in Colli	15	40	30	-	Time to administrate order
Collie stickers	Put stickers and label on package	10	40	10	-	Time to sticker
Booking incoming materials	Book material in VBS	10/item	74/ item	28/ item	Amount of item on order	Time to book an item
Scanning	Scan and archiving	10/packing list	10/ packing list	10/ packing list	Amount of packing lists	Time to scan a packing list
Put away	Put away package in quality rack	10/box	60/box	20/box	Amount of boxes, distance to quality rack	Time to allocate package
Collecting	Take material out of quality rack	10/box	60/box	20/box	Amount of boxes, distance to quality rack	Time to collect the material
Unpackaging and checking	Check if quantity is right	60/box	180/box	60/box	Amount of boxes	Time to check a box
Packaging	Package material in desired package	10/order	60/order	15/order	Amount of orders	Time to package an order
Allocation in warehouse	Put material on trolley and transport it to location + allocate	74	120	80	-	Time to transport and allocate
Preparation	Walk to pick location and take staff	60	80	60	-	Time to walk to location with staff
Scanning	Scan the location and material	8/order	10/order	9/order	Amount of orders	Time to scan an order
Picking	Pick the material	1.148/piece	1.27/piece	1.20/piece	Amount of pieces to pick	Time to pick one piece
Identification	Change stock level and write label to put on bin	27/pick order	30/ pick order	30/ pick order	Amount of pick orders	Time to change stock level
Allocation in container	Allocate material in container	15	15	15	-	Time to allocate material

Table 4: Time measurement of the activities performed when bulk stock supplied by VDL warehouse is applied

Activity	Description	Min Time (s)	Max Time (s)	Average Time (s)	Variable	KPI
Unpackaging	Unpack the incoming goods	10/box	180/box	20/box	Amount of boxes	Time to unpack a box
Administration	Administrate in Colli	15	40	30	-	Time to administrate order
Stick stickers	Put stickers and label on package	10	40	10	-	Time to sticker
Booking incoming materials	Book material in VBS	10/item	74/ item	28/ item	Amount of item on order	Time to book an item
Scanning	Scan packing list	10/packing list	10/ packing list	10/ packing list	Amount of packing lists	Time to scan a packing list
Put away	Put away package in quality rack	10/box	60/box	20/box	Amount of boxes, distance to quality rack	Time to allocate package
Collecting	Take material out of quality rack	10/box	60/box	20/box	Amount of boxes, distance to quality rack	Time to collect the material
Unpackaging and checking	Check if quantity is right	60/box	180/box	60/box	Amount of boxes	Time to check a box
Packaging	Package material in desired package	10/order	60/order	15/order	Amount of orders	Time to package an order
Allocation in warehouse	Put material on trolley and transport it to location + allocate	74	120	80	-	Time to transport and allocate
Indication	Runner indicates empty bins	10	10	10	Location of bin	Time to search bin
Walking	Runner takes empty bins and walk to warehouse	60	60	60	Distance	Time to walk to warehouse from production hall
Booking used materials	Employee books material	60	120	80	Amount of materials	Time to book material
Mail sending	Employee sends mail to production control	60	60	60	Length of mail	Time to send a mail
Walking	Runner walk to pick location and takes pickcar	30	40	35	Distance	Time to walk to location
Picking	Pick material	1.148/piece	1.27/piece	1.20/piece	Amount of pieces to pick	Time to pick one piece
Walking	Walking back to production hall	80	90	85	Distance	Time to walk

2.3 Value stream map

The first step to determine the logistics flow is explained. The second step was to create an overview where the flows can be seen. This to identify main problems and challenges. To get more insight in mapping a process and identifying challenges, literature study is conducted. This is described in Section 2.3.1. Section 2.3.2 explains the values stream map.

2.3.1 Literature

Lean management (LM) is a well-known theory when it comes to identifying and eliminating waste in a process. LM is a concept that was developed based on the Toyota Production System and integrates different set of tools and techniques to eliminate the wastes from the operations and helps the manufacturer to meet customer's requirements and expectations of the product (Shingo, 1981). Lean management is derived from the need to increase product flow velocity through the elimination of all non value-added activities. This is the main reason for the fact that LM has been chosen to use in this research over the concept of Six Sigma, an other optimization approach. Six Sigma is developed from the need to ensure final product quality (Arnheiter and Maleyeff, 2005). The focus laid not on this point of view in the assignment.

Further research into the concept of LM brought us to the a tool of mapping a process, called value stream mapping VSM. To implement lean management in a manufacturing organization, critical tools are needed (Alaya, 2016)(Jasti et al., 2019). Value stream mapping is one of the critical tools. It is the tool for identification of the value-adding activities (VA) to eliminate the waste as impacted from the non-value adding activities (NVA (Purba et al., 2018). According to Andreadis et al. (2017), no organization is even able to implement lean principles without using VSM. The main advantages of VSM over other mapping techniques is the fact that it displays product flow, information flow and the flow of the product within a shop floor (Braglia et al., 2006)(Jasti et al., 2019). After literature review and based on these reasons, VSM has been selected as critical tool to implement lean management in the logistics environment at VDL Energy Systems.

In the past, value stream mapping has developed as most effective methodology to implement LM principles within the internal activities of the organizations. (Jasti et al., 2019). A value stream map consists of all the materials and information required in the manufacturing of a particular product and how they flow through the manufacturing system (Chen et al., 2010). On top of that, according to Jasti and Sharma (2015), VSM can be implemented in any industry, to any activity and expanded downstream or upstream.

The aim of VSM is to follow a product's production path from customer to supplier, and carefully draw a visual representation of every process in the material and information flow (Rother and Shook, 2003). Because VES did not have clear insight on how to treat the materials, first a mapping had to be made. By using VSM, the material logistics path the moment it will be received at the logistics department, until the material can be used in production hall, can be draw. VSM has been selected to answer the first knowledge question because of the following reasons: (Rother and Shook, 2003)

- It helps visualizing more than just a single-process level. The flows can be seen.
- It helps seeing more than waste. Mapping helps seeing the sources of waste in the value stream.
- It makes decisions about the flow apparent, so it can be discussed. Otherwise, many details and decisions on the floor just happen by default.
- It ties together the lean concepts and techniques.
- It shows the linkage between the information flow and the material flow.

VSM will show both the material and the information flow in one overview. By using VSM the related costs cannot be seen immediately. Therefore, an addition method should be used. Additional literature study is executed to select an appropriate cost allocation method. This is described in Chapter 3.

2.3.2 Mapping the process

In case of the assignment, a value stream map (VSM) has been created to identify the main stream of the in stock materials. Based on the business process models, the key activities of handling the material were mapped. The aim of this VSM was to follow the materials logistics path from supplier, to the end customer. Besides that, a visual representation of every process in the material and information flow has been created (Rother and Shook, 2003). The value stream map applied in the logistics environment at VDL Energy Systems, can be seen in Figure 9. The VSM consists out of the most important activities of the general stock and bulk stock supplied by VDL warehouse flows. This due to the fact that the logistics flow of the VMI materials do not consists out of significant activities within the organization.

The value stream map is made to identify the main handling activities when it comes to the general stock. The assumptions made in Section 2.1.1 have been applied. In order to make the VSM not too complex or extensive, only key activities have been mapped in the stream. Key activities are the activities where most handling times are included. By conducting interviews in the warehouse, the key activities are stated. The stream starts with the fact that the production control department made a decision that the product will be treated as general stock. The procurement department will purchase the materials, for example three boxes of 100 bolts. After the lead time, the supplier supplies the material at the warehouse. From the moment VES receives the material, the key activities will be started. The following activities are mapped in the value stream:

- **Unpacking**
  The incoming goods will be received by a logistics employee. The package will be unpacked. The time it takes to unpack is dependent on the amount of received boxes and the size of a box. On average, it takes 20 seconds to open a box. Therefore the cycle time of unpacking is stated as 20 seconds per box.

- **Collie administration**
  The incoming goods have to registered. The logistics employee has to fill in a form with information about the supplier, distributor, quantity of the material and purchase-number. On average this takes 30 seconds.

- **Booking ERP**
  The materials have to be registered in VBS. The logistics employee has to fill in the information about the stock material. Within a purchase order, there can be multiple items. Each item has to be booked in VBS. The cycle time is 28 seconds per item.

- **Logistics check**
  At the logistics check the actual quantity within the box will be compared with the purchase quantity. If the quantities corresponds and the material is not damaged, the materials have been proved. The cycle time of the logistics control is on average 60 seconds per box.

- **Allocating**
  The stock products have to be allocated in the warehouse. Each material will be placed on a so-called location. Each location is registered in VBS. By scanning both the bar-code at the location and the one from the material, the location of the material will be registered in VBS. The allocation process consists out of walking with the material to the location, scanning the product and the location and allocate the material in a bin. The cycle time of this process is on average 74 seconds.

- **Order picking**
  If the material will be needed for the production department, the material should be picked. At the moment, the material will be provided in exact quantities, for instance 56 bolts. These bolts will be counted. After measurements it turned out that on average it will take 0.96 seconds per components to be picked. So if 56 bolt are needed, this will take 0.96 times 56 equals 54 seconds. The picked materials will be placed in a bin. In Chapter 5, the time measurements are described in more detail.

- **Identification and allocation**
  After picking the material, the stock level should be changed. This will be done by changing manually the level on the packing list. Besides that, the amount of components in the bin should be written on a label and the label will be placed at the bin. This to identify the material and the quantity. Besides that, the bin should be allocated in the container where all the rest of the materials will be placed. This process will take on average 45 seconds.

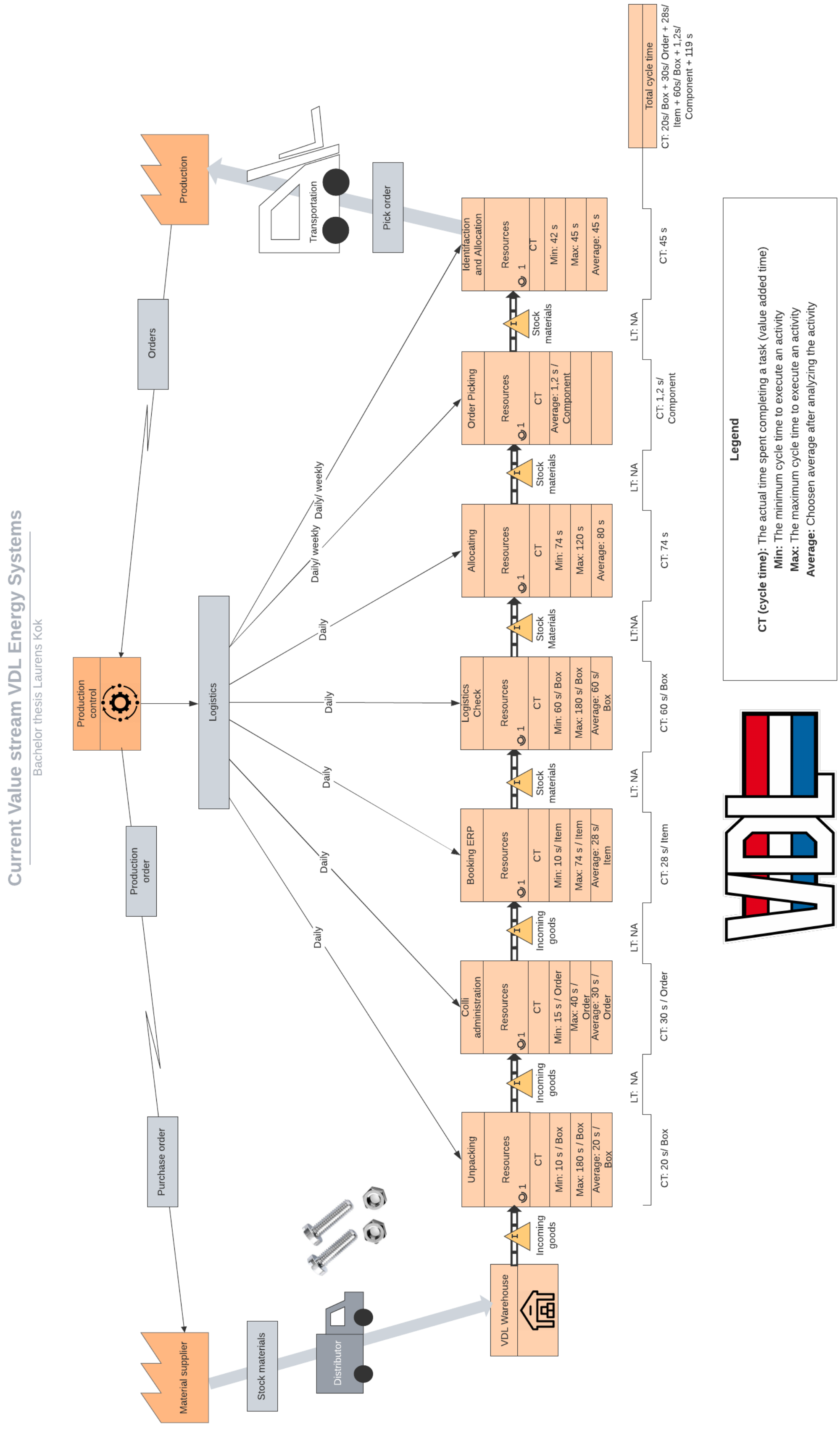


Figure 9: Value stream map of the general stock at VDL Energy Systems

2.4 Limitations with regard to the measurements

There are a couple of points to keep in mind after reading this chapter.

We performed this research in the winter semester of 2020-2021. The COVID-19 pandemic caused some threats to the validity. First of all, the workload in the warehouse and factory decreased. Suppliers lead time increased due to the BREXIT and COVID-19 pandemic. Therefore, measurements were not executed during normal circumstances. In the observation study, we tried to measure the times as under normal conditions.

Speaking of time observation, we come to our second validation issue. As described, times have been measured using stopwatch and observation. Multiple measurements are done and the minimum, maximum and average time it takes to execute an activity are measured. In practical situations, there is a lot of variety in the time it takes to execute an certain operation. This was taken into account when making decisions which are close to break-even.

2.5 Problems and challenges

In the process of indicating the logistics flows, a better insight in the current situation is created. By executing the observation study and making the value stream map several problems and challenges are identified related to the core problem, *"There is no clear procedure on how to deal with the logistics flows of the product-related stock materials"*. The main problems and challenges are itemized, based on the processes in the models and value stream map.

- **Agreements**
  In the entire process from the start that the material will be purchased until the moment it can be used by the mechanic, different departments are involved. Procurement has to purchase the material, production control has to decide what the optimal logistics flow will be, the logistics need to handle the material and last but not least the production department will use the material when building the machine. Between the departments, agreements have been made which department is responsible for each process. In the research is is taken into account that communication between the different departments is key.
- **Picking Process**
  When it comes to picking of materials, the moment it will be delivered in exact quantities, the handling process of counting the materials will take a lot of time. Further calculation are done in Chapter 6 in order to make a decisions at which moment it will be more beneficial to count the material in exact quantities or performing alternative approaches.
- **ERP-System**
  As described in the introduction, the VDL groep took the facility of Siemens in Hengelo over in 2018 and changed it into VDL Energy Systems. In the Siemens period, the company made use of the ERP-system of SAP. At the moment, the company is using VBS The development and optimization of VBS is a continuous process. Therefore it is possible that sometimes changes cannot be made in VBS, because it is not programmed yet in the right way. The company is working hard to implementing changes.
- **Mechanic**
  One of the main targets is the fact that the mechanics should work on building the machine. This sounds logical, but it has been kept in mind during the research. When materials are not delivered correctly to the production, the mechanics have to search or ask for the right materials. The involved time is waste and should be reduced. Also when making decisions about the stock materials, the position and potential movements (and therefore the involved time it will take) of the mechanics are taken into account. The challenges laid in making the right decisions about the action a mechanic need to take.

2.6 Conclusion

At VES, the total cost of ownership of stock materials is unidentified and should be identified. Moreover the logistics process should be optimized. By executing a context analysis, we were able to get a better understanding in the logistics flows at the company, which is the first step of solving the core problem. We determined the logistics flows by executing observation studies in VES' warehouse and factory. Three business process models have been created for the three different logistics flows. To identify the main problems which occur in the processes, a value stream map is made. We analysed the VSM, and formulated the main problems and challenges. After this analysis, the challenges were taken into account in the remaining research.

3 Cost accounting: Literature study

After mapping the process, it was time to get more insights on what to do with the information gained out of the business process models and the value stream map. Literature study has been executed to find more insights on how to translate the information into cost measurements, in order to calculate the TCO of the different materials. In this chapter, the following research question is answered:

"What are the relevant methods and theories for identifying the costs of the logistics flows at VDL Energy Systems.

Section 3.1 describes the concepts of logistics costs. In Section 3.2, the different cost management methods are introduced. The discussion with regard to the literature review is described in Section 3.3. Finally, the conclusion of this chapter is stated in Section 3.4.

3.1 Logistics costs

Better management of the logistics costs offers the potential for large savings for business at the manufacturing level. According to Lambert et al. (1998), logistics costs may exceed 25 percent of the total costs. Therefore it can be stated that indicating the logistics costs plays an important role when it comes to cost accounting. In many firms, logistics costs are not managed in a proper way. An important reason for this is that the cost data required for successful cost accounting are not available (Lambert et al., 1998). When analyzing the costs, according to Lambert et al. (1998), the main logistics activities which drive the total logistics costs can be stated as follow:

- Inventory carrying costs
- Transportation costs
- Warehousing costs
- Lot quantity costs
- Order processing and information costs

For the assignment, order processing, warehousing, transportation and lot quantity costs were important in order to calculate the total cost of ownership of the different materials. When focusing on warehouse management, according to Kusrini et al. (2018), the main logistics activities which drive the total cost can be stated as follow:

- Receiving materials
- Put away of materials
- Storage
- Picking
- Shipping

3.2 Cost management methods

Logistics is becoming more and more recognized as the critical step in the process of meeting the demand of the customer. Moreover, with regard to the importance of customer service in a company's strategy, companies have a growing need to concentrate on the logistics costs (Krajnc et al., 2012). A result of this is that transparent reporting of logistics costs and the related accounting of their cost drivers can present a significant factor for the successful management of material flows and the related logistics activities in production companies (Krajnc et al., 2012). To manage all the costs, cost accounting systems can be used. Traditional cost accounting methods in manufacturing companies have been used to account these costs in the past. Unfortunately, these traditional methods have disadvantages. Out of literature review it became clear that in the methods, the arbitrary allocation of indirect costs to products using volume-related allocation rates does not enable such a system to adequately show these costs when it comes to individual products, customers, or other cost objects (Krajnc et al., 2012). To assign costs to individual activities, activity-based management of logistics costs can be used. An example of this is activity-based costing, also called ABC (Krajnc et al., 2012). Besides this, compared to the traditional cost analysis approaches, ABC offers better information for the supply chain management as its cost information is more accurate which allows the supply chain strategies to be monitored (Fang and Ng, 2011). From the literature, we found that besides ABC, time-driven activity based costing (TDABC) and lean accounting (LA) were also modern cost accounting methods (Monroy et al., 2014)(Siguenza-Guzman et al., 2014). These three methods are analysed and described in detail in the next sections.

3.2.1 Activity-based costing

Activity-based costing (ABC) is a cost management method which could be helpful by calculating the costs of individual activities and assigning those costs to cost objects such as products and services on the basis of the activities undertaken to produce each service or product (Fang and Ng, 2011). ABC is also an advanced costing calculation that seeks to remedy the limitations of traditional methods (Siguenza-Guzman et al., 2014). Besides that, the analysis of cost and profitability of individual products, services, and customers represents a critical issue that companies were concerned with and one where ABC tries to help (Gríful-Miquela, 2001). On top of this, in essence, the ABC uncovers the true cost of business (Lin et al., 2001).

Steps of activity-based costing
From the literature review, it turned out that several authors mentioned different amount of steps that should be taken in order to implement ABC. Gríful-Miquela (2001) defined nine steps when it comes to implementing the ABC. The main sources mention the seven steps described by (Lin et al., 2001).

1. Selecting the team
2. Analyzing the supply chain functions
3. Breaking processes down into activities
4. Identifying the resources consumed in performing the activities
5. Determining the costs of the activities
6. Tracing the costs to the costs of the activities
7. Analyzing the final cost information from a total cost perspective

According to Fang and Ng (2011), the ABC approach contains basically out of four steps. This approach is based on the underlying assumption that activities drive the cost which is in turn driven by the product or customer. The following four steps have been defined by Fang and Ng (2011).

1. Assigning and analysing activities
2. Gathering cost data and tracing costs to activities
3. Establishing outputs
4. Identifying the activity drivers and analysing the costs

Advantages and disadvantages of the ABC approach
Although a relatively extensive stream of literature concludes that ABC systems provide advantages for decision making, ABC has also its limitations (Siguenza-Guzman et al., 2014). The main advantages and disadvantages of the ABC approach can be described. First of all the advantages and benefits (Gríful-Miquela, 2001).

- The activity-based costing approach provides more accurate product and service costing, particularly where non-volume-related overhead are significant.
- ABC provides a better understanding of cost behaviour as well as identifying the costs of complexity.
- ABC can reduce uncertainty and provides a more solid basis for strategic decisions.
- ABC focuses on value added activities. On the other had, by using ABC also the non-value added activities can be determined. The company should try to eliminate them.

After implementing it turned out that ABC has also some disadvantages and causes problems. The main difficulties have been summarized (Gríful-Miquela, 2001).

- Implementation of ABC is very time consuming, requiring not only gathering and processing of data, but also interpreting the results.
- When using ABC, it can be difficult to collect accurate data.
- Cost management is difficult because several activities are performed cross different department and department boundaries.

3.2.2 Time-driven activity-based costing

The second method which is described is time-driven activity-based costing (TDABC). TDABC is a useful cost accounting technique developed by *Kaplan* and *Anderson* in 2004 to overcome the difficulties presented by previous systems (Siguenza-Guzman et al., 2014)(Kaplan and Anderson, 2007). A key concept of activity-based costing is the fact that it uses a single driver rate for each activity (Everaert et al., 2008). Therefore, it can be difficult to model multi-driver activities. An example given by Everaert et al. (2008) is that order processing costs not only depend upon the number of order processed, but also on the type of communication medium used by the customer. In order to tackle these difficulties, a new approach have been designed, time-driven activity-based costing. This approach identifies the different departments, their costs and their amount of time that employees can work, without overtime (Everaert et al., 2008). TDABC focuses on time estimation and the time of performing an activity is estimated for each specific case of the activity. According to Everaert et al. (2008), TDABC can include multiple drivers for each activity, in complex environments wherein the time needed to perform an activity is driven by many drivers. The different steps that should be taken, compared to the ABC method, can be seen in Figure 10. To implement TDABC, mainly two input parameters are needed. According to Monroy et al. (2014), the unit cost of used resources and time required to perform an activity are the two parameters for this method.

Panel A: ABC	
Step 1	Identify the different overhead activities
Step 2	Assign the overhead costs to the different activities using a resource driver
Step 3	Identify the activity driver for each activity
Step 4	Determine the activity driver rate by dividing the total activity costs by the practical volume of the activity driver
Step 5	Multiply the activity driver rate by the activity driver consumption to trace costs to orders, products or customers
Panel B: TDABC	
Step 1	Identify the various resource groups (departments)
Step 2	Estimate the total cost of each resource group
Step 3	Estimate the practical capacity of each resource group (e.g. available working hours, excluding vacation, meeting and training hours)
Step 4	Calculate the unit cost of each resource group by dividing the total cost of the resource group by the practical capacity
Step 5	Determine the time estimation for each event, based upon the time equation for the activity and the characteristics of the event
Step 6	Multiply the unit cost of each resource group by the time estimate for the event

Figure 10: Steps that should be taken when using activity-based costing versus time-driven activity-based costing (Everaert et al., 2008)

3.2.3 Lean accounting

As described in Section 2.3.1, the lean management concept is philosophy that non-value-adding activities are being recognized and eliminated in lean manufacturing environments (Monroy et al., 2014). To apply lean principles in the area of cost accounting, the method lean accounting (LA) has been developed. LA method supports three key aspects of a lean organization, namely visual management, value stream management, and continuous improvement. Five principles are important when using lean accounting (Monroy et al., 2014).

1. "Lean and simple business accounting." This principle is applying lean management tools such as value stream maps, kaizen and problem-solving approaches.

2. "Accounting processes that support the lean transformation." At this principle, control of production processes is doing by visual performance measurements and trying to transform the organization.

3. "Clear and timely communication of information." The visual management will be transformed to visual performance boards, to communicate the information properly.

4. "Planning from a lean perspective."

5. "Internal accounting control." The transaction elimination matrix tool is needed to execute this final step.

3.3 Discussion

We analyzed different costs accounting methods. The ABC method is a suitable cost management method which could be helpful by calculating the costs of individual activities and assigning those costs to cost objects. The TDABC is a useful cost accounting technique which identifies the different departments, their costs and their amount of time that employees can work. It focuses on time estimation and the time of performing an activity. The LA method supports the three key aspects of a lean organization: visual management, value stream management and continuous improvement. In order to solve the action problem of this bachelor thesis, we had to select an appropriate method. First of all, the activity-based costing method. According to Krajnc et al. (2012), the application of ABC for logistics costs accounting in a manufacturing company can disclose far more indirect logistics costs at the level of group of products than the traditional (volume-based) costing approach. As described in Section 3.2.1, the ABC method has also some disadvantages, such as collecting accurate data.

Secondly, the TDABC seemed like a perfect method for this assignment, because of the focus on time driven activities and measurements. The main advantages of TDABC compared to traditional ABC, is the fact that ABC uses a single driver rate for each activity, where TDABC is able to model multi-driver activities. The main challenges lied in the complexity of the method. As said, implementing ABC has been faced as difficult, therefore modeling multi-driver activities when using TDABC might cause even more difficulties.

Thirdly, the lean accounting method. LA seemed appropriate when it comes to optimizing processes and implementing the lean management philosophy. The main advantages is that the value stream map, described in Chapter 2, can be used as one of the tools needed to implement LA. The different tools cause also a disadvantage. When implementing LA several lean management tools are needed.

We analyzed the three methods, and selected the activity-based costing method as cost accounting model for this bachelor thesis. Due to the fact that implementing TDABC might cause difficulties because of the multi-driver calculations. The LA method is a suitable method when it comes to implementing lean management, but the focus lied on identifying the cost of the logistics activities. Therefore, the activity-based costing method has been selected as cost accounting mode. Multiple articles described that the ABC can be implemented in a logistics environment (Fang and Ng, 2011) (Krajnc et al., 2012) (Xiao et al., 2009).

3.4 Conclusion

In this chapter, we executed literature review to find a relevant method for identifying the costs of the logistics flows at VDL Energy Systems. From the literature reviewed, we found that the traditional cost accounting methods in manufacturing companies were not suitable. Therefore, modern accounting methods have been searched. We found three methods: activity-based costing, time-driven activity-based costing and lean accounting. After analyzing, we selected the activity-based costing method as relevant method for identifying the costs of the logistics flows. Multiple articles emphasized that the ABC method can be applied in logistics environment. In Chapter 5, the method has been executed and described.

4 Categorizing materials

For building the machine hundreds of different materials are needed. VES indicated that they do not want to make a decision for each of the single materials. For practical reasons, it has been chosen to categorize the materials in different groups to make a decisions about what the optimal logistics flow for the material group should be. Based on several indicators, a material is classified. In this chapter, the different types of materials are concerned and described. The following research question is answered.

Considering the logistics flows, how can the materials be categorised into material groups?

To get better insights on the properties of the materials, observation study has been executed in VES' warehouse. The materials have been analysed by conducting interviews with employees in the warehouse and the mechanics in the factory. Section 4.1 outlines the different types of stock materials. Indicators in order to categorize the materials are described in Section 4.2. The material groups are stated in Section 4.3. Finally, the discussion and conclusion are respectively described in Section 4.4.

4.1 Stock materials

For this research, we were provided by the company with a list consisting out of approximately 1500 stock materials. After conducting interviews, it turned out that roughly speaking, three types of materials are placed in the warehouse.

- **Quality inspection required materials**
  Some of the stock materials need a quality inspection before placing them in the warehouse. The quality inspectors check the materials on stated requirements. At VES, these are only a couple of materials. Most of the materials which require quality inspection are not stock materials, but components which have been purchased for a specific project.

- **Goods of length**
  Materials which can be expressed in (milli)meters. When using these materials on the machine, most of the times they have to be cut. These materials are purchased as stock. Most of the times, a couple of meters have been placed as stock in the warehouse. An example of the tubes at VES can be seen in Figure 11. Examples of these materials are: Cables, pipes, wires, hollow profiles and tubes.

Figure 11: Example of tube storage in VES' warehouse

- **Materials expressed in pieces**
  The last type of materials are the ones that cannot be expressed in (milli)meters, but in pieces. This can be bolts, nuts, cable glands, washers, sleeves and a lot of more different materials. Most of the stock materials which have been analyzed during this thesis, are materials expressed in pieces.

4.2 Indicators

To categorize the materials in different groups, indicators are stated. The following indicators are stated to classify the materials in groups.

- **Quality inspection**
  The company wants to make sure that supplied materials satisfy the requirements of the final customer. If quality inspection is involved, this requires addition handling times by the quality inspectors. The quality inspection is done before allocating the material on location in the warehouse. Because of this addition required time, quality inspection has been stated as the first indicator.
- **Unit**
  The second indicator is the type of unit where the material will be expressed. This can be either in pieces or in (milli)meters.
- **Good indication of the required quantity**
  The third indicator is the fact if for a material a good indication of the required quantity can be made. As described in Section 2.1.2, because of practical reasons, the quantity of a material needed to build to machine cannot always be determined beforehand. Take the example of ty-raps. For this material it is difficult to determine beforehand how many are needed. To distinguish these materials, we asked ourselves the question if a good indication of the required quantity can be made.

4.3 Material groups

The analyzed materials are categorized using the stated indicators. Four different material groups can be defined and are explained. An overview of the grouping procedure can be seen in Figure 12. In the figure, the indicator are applied. When new stock materials are defined, they can be classified using the procedure.

1. **Bulk stock**
   The first material group is the *bulk stock* group. As can be seen in Figure 12, these materials do not require quality inspection, can be expressed in pieces and it is not possible not make a good indication of the required quantity. When analyzing the materials, it turned out most of the times these materials do have a low value purchasing price. The following materials are examples which have been placed in this material group.
   - Screws
   - Bolts
   - Nuts
   - Pins
   - Washers
   - Cable lugs
   - Ty-raps
   - Wire End Ferrule
   - Head shrink sleeves
2. **Exact quantity**
   Materials which do not require quality inspection, can be expressed in pieces and where a good indication of the required quantity can be made, are placed in the second group, the *exact quantity* group. The materials can be delivered in exact quantities to the production department by the logistics employees. In this case, the mechanics do not have to collect the materials by themselves. Examples of these materials are spiral wound gaskets.
3. **Goods of length**
   The third group consists of materials which can be expressed in terms of (milli)meters. The materials are collected together in one group, because of the storage requirement. The materials can be delivered in long lengths, for example 100 meter of cable reel and will be placed in the cable storage rack. When using a material out of this group on the machine, most of the time it should be cut or sawed.
4. **Quality**
   The last material group consists of all the materials that require quality inspection. This can be both materials expressed in (milli)meters or pieces. Examples of these materials are adaptors, plugs and bars. These materials are grouped together, because additional handling times are required in order to deliver them to the production department.

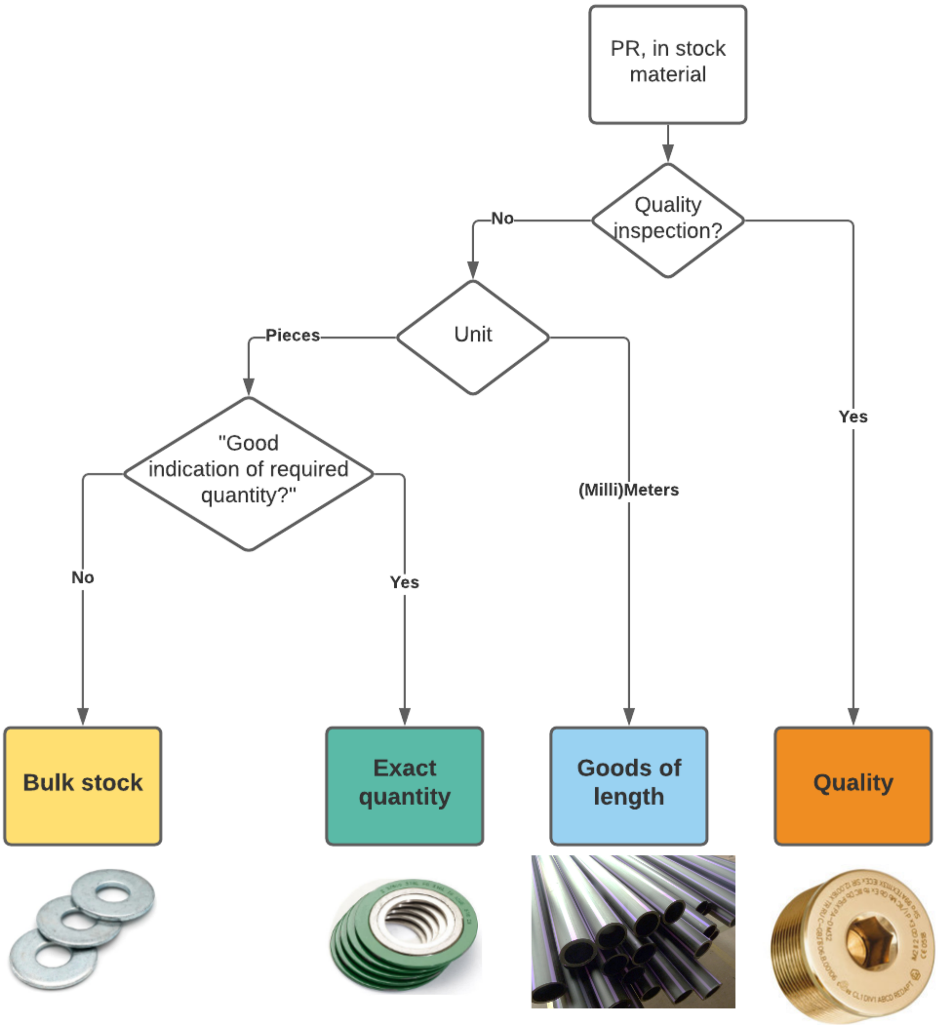


Figure 12: Decision tree of the grouping procedure for the stock materials

4.4 Discussion and conclusion

We decided to classify the materials in four different groups. A discussion can be made whether more groups are needed. Due to the fact that over more than 1500 materials are analysed, material groups will consist out of a lot of materials. Therefore, several other groups could be made. Indicators could be added. Take for instance the bulk stock group. Within this group, an indicator such as price per unit could be added. Also within the goods of length a distinction could be made on the kind of material. Examples are cables or heat shrink tubing. We decided not to do that, because of the simplicity when making as few as possible material groups. Also the fact that price groupings were difficult to make, made it more attractive to keep this out of the research. Under the statement, *"less is more"*, we decided to classify the materials in four different groups.

Considering the logistics flows, the materials can be categorised into material groups using indicators. The indicators are defined as "quality inspection", "unit" and "good indication of the required quantity". Using these indicators, four material groups are made: Bulk stock, exact quantity, the goods of length and the quality materials.

5 Activity based costing

For each of the defined material groups, the logistics flows are determined. In this chapter the following research question is answered.

Taking into account the current logistics flows and new insights, which procedure can be defined for the different material groups?

Retrieved from literature review described in Chapter 3, the activity-based costing method has been selected in order to allocate the costs related to the stock materials at the company. Based on the logistics flows and processes described in Chapter 2, key activities are explained and cost drivers are selected. By conducting observation study, the involved times to process an activity is determined. We conducted interviews and studied the processes in detail in VES' warehouse and production facility. Times are measured using a stopwatch and in cooperation with the stakeholders.

Using the activities and times, the total cost of ownership of a stock material is calculated. The execution of the activity-based costing method at VDL Energy systems is described in this chapter using the steps defined by Lin et al. (2001).

1. Selecting the team
2. Analyzing the supply chain function
3. Breaking processes down into activities
4. Determining the cost of the activities
5. Tracing the costs to the cost object
6. Analyzing the final cost information from a total cost perspective

Section 5.1 provides the step-by-step approach of the execution of ABC. The effects on the material groups are described in Section 5.2. In Section 5.3, respectively the discussion and conclusions about the approach are described.

5.1 Implementation of ABC

This section provides the implementation of the activity based costing method, based on the stated steps of Lin et al. (2001).

5.1.1 Selecting the team

Before the cost allocation, it is important to define which stakeholders and departments plays a role when executing the activity-based costing method. By calculating the TCO of the stock materials the following departments have been measured.

- **Production control**
  The production control department is responsible for strategic decisions when it comes to the materials. First of all, the question have to be answered whether to purchase a material as stock or as a specific order. Secondly, which type of logistics flow the material has to follow is also part of the decisions which have to made by the production control department. Besides that, the administration of the materials in VBS are taken into account.
- **Procurement**
  The procurement is responsible for the purchasing of the materials. The involved purchasing activities for a standard, not quality inspection required, stock material are analyzed.
- **Logistics**
  The third department is the logistics department, which is responsible for material handling and warehousing activities.
- **Production**
  The production department is the last department involved in the ABC. Activities performed by the mechanics in order to use the materials on the machine are monitored.

5.1.2 Analyzing the supply chain function

This step involves scrutinizing the logistics function and identifying and classifying the major processes per department (Lin et al., 2001). The major processes are defined by using the key logistics activities which drive the total logistics costs stated by Lambert et al. (1998). The major processes for each department are shown in Table 5.

Table 5: Major processes of each involved department

Department	Major process	Description
Procurement	Order processing	Purchasing process of the stock materials
Production control	Inventory carrying and management	Administration of the materials in VBS and strategic decision on logistics flow
Production	Engineering	Assemble of the machines
Logistics	Warehousing and material handling	Receiving incoming goods, allocation and picking of materials

5.1.3 Breaking processes down into activities

This step of the ABC method distinguishes specific, resource consuming business activities within the logistics process of the materials. By breaking down the processes defined in the previous state into as many as possible well-defined activities allows a better analysis of the cost of the process. Each of the major processes defined in Table 5 are analysed. All the task in to execute the involved process are indicated by observation study. Interviews and observations are executed to collect all relevant information about the involved tasks.

Order processing
When ordering a standard, stock material which does not require quality inspection, tasks have to be executed at the procurement department. The tasks can be seen in Table 6.

Table 6: Order processing: tasks that need to be performed by procurement department

Activity	Task
Create purchase order	Making purchase order
	Check data of sending
	Send purchase order to supplier
	Save purchase order in VBS
Check order confirmation	Check for order confirmation
	Accept order
	Save order in VBS

Inventory carrying and management
The second department which plays a role in the process of the stock material, is the production control department. At this department, strategic decisions are made how to treat the materials when it comes to the logistics flow. "Can the material be considered as bulk stock"? Or "does the material be added to the VMI assortment"? are relevant questions at the department. Besides this, if a material will be treated as bulk stock supplied by the VDL warehouse, the production control department has to administrate the material in VBS. With administrate it is meant that the materials will be booked to a specific project, so that the finance department can calculate the costs to the customer.

Engineering
The production department is responsible for the assembling of the machine. The materials which are needed for building the machine will be delivered by the logistics department. As described not all the materials will be delivered, the mechanics need to collect the bulk stock by themselves. So both the VMI materials as the bulk stock supplied by VDL warehouse. The steps which are involved in collecting this materials are described in Table 7.

Table 7: Tasks that the mechanic has to execute in order to collect the desired bulk stock material

Activity	Task
Walking	Mechanic walks from machine to bulk stock location
Searching	Mechanic search for right material in rack
Picking	Pick the desired material
Walking	Mechanic walks back to machine with the materials

Warehousing and material handling
The last department which plays a significant role in the major processes is the logistics department. When it comes to warehousing and material handling, all the activities will be executed by the logistics department. In order to this, a lot of steps have to be done. Therefore, the activities are divided into sub-departments: incoming goods, logistics check, picker and runner. The detailed descriptions of the sub-departments can be found in Section 2.1.1. In Table 8, the main activities of the incoming goods, logistics check and the picker can be seen. The activities that need to be executed by the runner can be seen in Table 9. The runner is only necessary when bulk stock supplied by VDL warehouse is considered.

Table 8: Logistics activities at incoming goods and logistics check

Sub-department	Activity	Description
Incoming goods	Unpackaging	Unpack the incoming goods
	Administration	Administrate in Colli
	Stick stickers	Put stickers and label on package
	Booking	Book material in VBS
	Scanning and printing	Scan packing list
	Allocation	Allocate package in quality rack
Logistics check	Collecting	Take material out of quality rack
	Unpackaging and checking	Check if quantity is right
	Packing	Pack material in desired package
	Transportation and allocation	Put material on trolley and transport it to location and allocate material
Picker	Scanning	Scan the location and material
	Picking	Pick the material
	Identification	Change stock level and write handmade label to put on box
	Allocation	Allocate material in container to be able to transport

Table 9: Activities that need to be executed by the runner

Sub-department	Activity	Description
Runner	Walking	Runner takes empty boxes and walks to the warehouse
	Booking	Runner/logistics employer books material
	Mail sending	Runner/logistics employer sends mail to production control with information
	Walking	Runner walks to pick location and takes pick car
	Picking	Pick the material
	Walking	Walking back from pick location to production

5.1.4 Determining the cost of the activities

To identify the cause and effect relationship between the performance of activities, ABC uses the concept of cost-drivers. A cost driver is a factor that causes or influences the costs (Lin et al., 2001). Each cost has at least one cost driver. To determine the cost of each of the activities, the activities main cost driver are determined.

Besides that, the time it takes to execute the activity has been measured. Due to the fact that the focus of this thesis lied in identifying the TCO. Therefore, we wanted to know the time it takes to execute an activity. By using average hourly wage, the costs are calculated. The wages have been determined in cooperation with the financial department at VES.

For each of the activities, the involved time have been measured by observation study and by conducting interviews with the involved stakeholders. The time indications were unknown and not present at the company. Therefore, we observed the processes and measured the involved times. The times are based under the assumptions stated in 2.1.1.

In Table 10, the time indication based on the activities in the process of general stock can be seen. In the table, the average time indication is the most important time measurement. Besides that, the minimum and maximum time to execute the operation are reported to create a better insight in the fluctuations. The maximum times represent extreme situations when performing the activity. For example, the average time to unpack a package is 20 seconds. In an extreme situation, when the package is difficult to open, it can take 180 seconds. The time indication of the bulk stock supplied by VDL warehouse can be seen in Table 11. Lastly, the observation times of the VMI process can be seen in Table 12.

Table 10: General stock: time indication based on activities

Department	Main process	Activity	Average Time (s)	Min Time (s)	Max Time (s)	Cost driver
Procurement	Purchasing	Purchase of materials	262	191	360	Purchase quantity
Logistics	Incoming goods	Unpackaging	20	10	180	Purchase quantity
		Registration	30	15	40	Purchase quantity
		Stick stickers	10	10	10	Purchase quantity
		Booking	28	10	74	Purchase quantity
		Scanning and printing	10	10	10	Purchase quantity
		Allocation	20	10	60	Purchase quantity
	Logistics check	Collecting	20	10	60	Purchase quantity
		Unpackaging an checking	60	60	180	Purchase quantity
		Packing	15	10	60	Purchase quantity
		Allocation warehouse	20	10	60	Purchase quantity
	Picking	Scanning	9	8	10	Picking quantity
		Identification	30	27	30	Picking quantity
		Allocation	15	15	15	Picking quantity

Table 11: Bulk stock supplied by VDL warehouse: time indication based on activities

Department	Main process	Activity	Average Time (s)	Min Time (s)	Max Time (s)	Cost driver
Procurement	Purchasing	Purchase of materials	262	191	360	Purchase quantity
Logistics	Incoming goods	Unpackaging	20	10	180	Purchase quantity
		Registration	30	15	40	Purchase quantity
		Stick stickers	10	10	10	Purchase quantity
		Booking	28	10	74	Purchase quantity
		Scanning and printing	10	10	10	Purchase quantity
		Allocation	20	10	60	Purchase quantity
	Logistics check	Collecting	20	10	60	Purchase quantity
		Unpackaging an checking	60	60	180	Purchase quantity
		Packing	15	10	60	Purchase quantity
		Allocation warehouse	20	10	60	Purchase quantity
	Runner	Walking to warehouse	60	60	60	Bin size + #Bins
		Walking back to production	35	30	40	Bin size + #Bins
	Picking	Picking of the materials	*See table 12*	*See table 12*	*See table 12*	Bin size
Production control	Administrate	Booking materials by Runner	60	60	60	Bin size
		Sending mail to production control by runner	60	60	60	Bin size
		Booking materials in VBS by production control	300	200	400	Bin size
Production	Engineering	Walking to bulk stock location	50	10	90	Materials needed by mechanic
		Searching	30	10	120	Materials needed by mechanic
		Walking	50	10	90	Materials needed by mechanic

Table 12: VMI: time indication based on activities

Department	Main process	Activity	Average time (s)	Min time (s)	Max time (s)	Cost driver
Production	Engineering	Walking to bulk stock location	50	10	90	Materials needed by mechanic
		Searching	30	10	120	Materials needed by mechanic
		Picking	15	5	90	Materials needed by mechanic
		Walking	50	10	90	Materials needed by mechanic

Picking time measurements
When looking at the picking times, one can noticed that the exact picking times can be seen in Table 13. In the table, two abbreviations are mentioned. PQ stands for *picking quantity* and represent the amount of materials that need to be picked by the logistics employee in the warehouse. FPQ stands for *full package quantity* and represents the amount of materials which are in a full package. In case the amount to pick is equal to the amount of materials in the full package, it is easy for the picker to pick the materials. The process is simply opening the full package and place the materials in the bin. If PQ is not equal to FPQ, the materials need to be counted. After observation research, it turned out that this will take on average 0.96 seconds per piece. The observation and calculations about the picking process can be seen in Appendix B, Figure 19.

Table 13: Picking times observation

Situation	Average time (s)	Min time (s)	Max time (s)
PQ = FPQ	14 (for FPQ)	12 (for FPQ)	17 (for FPQ)
PQ ≠ FPQ	0,96/ piece	0,89/ piece	1,09/ piece

5.1.5 Tracing the costs to the cost object

Once we determined the times of performing each activity for a cost object, we better understood the profit potential of the cost object (Lin et al., 2001). To make a decision which logistics flow a material has to follow, based on the total costs of ownership, the potential costs of each flow are stated. The three different flows are defined as the cost objects in the ABC analysis. In general, the ability to trace costs to specific cost object has benefits in corporate decision-making roles (Lin et al., 2001). Out of these cost objects a decision is made which logistics flow the material group has to follow.

Based on the activities and cost drivers stated in Table 10, 11 and 12, three general formulas are defined to express the TCO of the logistics flows. In cooperation with VDL Energy Systems, we set up these equations using common sense and mathematical background. Equation 1 represents the TCO of the general stock. The formula has been made using the activities and the cost drivers. Equation 2 and 3 represents respectively the TCO of the bulk stock supplied by VDL warehouse and the VMI. In each of the formulas the fraction $\frac{Wage}{3600}$ can be seen. This fraction transforms the time indications into real costs in euros. The wage are the hourly costs for VDL for an employee and provided by VES' finance department. All the times are indicated in seconds, by dividing the hourly wage by the amount of seconds in an hour (3600), the times can be transformed into costs.

The formulas are made using the principles of the ABC approach by using the cost drivers. Each formula begins with the purchase price as basis of the TCO. This variable is independent of time and can therefore be stated in front of the formula. The rest of the formulas have been set up using the main process divided by the cost driver. By adding up the fractions and multiplying with the fraction $\frac{Wage}{3600}$, the total formula is defined. The description of the variables used in the formulas can be seen in Table 14.

$$TCO_{general\ stock} = PP + \frac{Wage}{3600} \cdot (\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Picking}{Picking\ quantity}) \quad (1)$$

$$TCO_{bulk\ stock\ VDL} = PP + \frac{Wage}{3600} \cdot (\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Administrate + Picking_{Bulkstock}}{Bin\ size} + \frac{Runner}{Bin\ size \cdot Bins} + \frac{Production}{MM}) \quad (2)$$

$$TCO_{VMI} = PP_{vmi} \cdot (1 + \frac{S_{vmi}}{100}) + \frac{Wage}{3600} \cdot (\frac{Production}{MM}) \quad (3)$$

Table 14: Description of the variables used in the formulas

Variable	Description
TCO	Total cost of ownership
PP	Purchase price (price per unit)
Wage	VDL costs of one man-hour
Incoming goods	Handling times at incoming goods (in seconds)
Logistics check	Handling times at logistics check (in seconds)
Procurement	Handling times at procurement (in seconds)
Purchase quantity	Amount of materials purchased
Picking	Handling times at picking process (in seconds)
Picking quantity	Amount of materials that need to be picked
Administrate	Handling times for VBS administration (in seconds)
Bin size	Amount of materials that are placed in a bin when bulk stock supplied by VDL warehouse is considered
Runner	Handling times by the runner (in seconds)
Picking bulk stock	Amount of materials that need to be picked in case of bulk stock supplied by VDL warehouse
Bins	Amount of bins that the runner is going to fill in the warehouse
Production	Handling times at production
MM	Amount of materials needed by the mechanic
PP VMI	Purchase price stated by the VMI supplier (price per unit)
S VMI	Percentage of additional VMI service costs stated by the VMI supplier

When analysing the formulas, it can be noticed that the purchase price per unit for the general stock and bulk stock are not the same as for VMI. When making a comparison between VMI and the other cost objects, it can occur that multiple suppliers are involved. For example, if the production control departments wants to make a decisions whether or not select the VMI process for a material, purchase prices of the involved suppliers can be compared. Therefore, it has been chosen to indicate different purchase prices in the formula. On top of that, a VMI supplier can also state a so-called VMI service percentage. For example, a supplier can calculate 5% additional costs on top of the purchase price when the material need to be treated as VMI.

5.1.6 Analyzing the final cost information from a total cost perspective

The final step of the ABC approach involves analyzes the costs which have been traced. When using a total cost approach, the goal of the organization should be to reduce the total cost of the activities instead of individual activity costs (Lambert et al., 1998). Due to the fact that focusing on only one area of the function may cause inefficiencies in other areas. For example, saving handling times in the picking activities may cause extra handling times at the procurement department when a material need to be purchased again.

Once we stated the TCO functions of the different logistics flows, the costs function were analyzed. In Figure 13, an overview can be seen of overlapping elements within the formulas. It is concluded that when choosing for bulk stock supplied by VDL warehouse, the most handlings need to be done. This can simply be seen on the length of the equation. Besides that, it can be seen that Equation 2 has some overlapping elements with both the equation of the general stock as for VMI. In Figure 13, a blue rectangle can be seen. This represents the activities that need to be done from procurement to the allocation of the materials in the warehouse. In case of general stock and bulk stock, these activities need to be executed. The red circles indicates the overlapping between the bulk stock supplied by VDL warehouse and VMI. In both cases, the mechanic needs to collect the materials, as stated in Table 6. The green oval represents the activities which only have to executed in case of bulk stock.

Out of Figure 13, it can be concluded the logistics flow of bulk stock supplied by VDL warehouse is a combination between the general stock and VMI. On top of that, it can be concluded, that in case of bulk stock the most activities need to be executed. Examples of using the formulas are described in the next chapter.

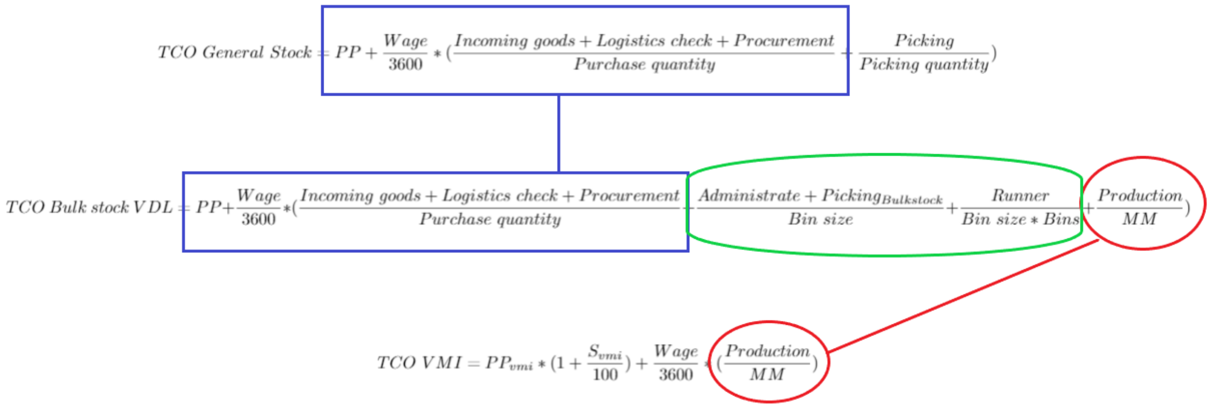


Figure 13: Comparison of elements within the costs functions

5.2 Material groups

In Section 5.1, a detailed cost analysis is given. After this we zoomed out a little bit. Due to the fact that not for all the material groups a comparison can be made for the different logistics flow. The relation between the different material groups and logistics flows are explained.

Quality
As described, all the materials which require a quality inspection will follow the general stock flow. Between the incoming goods and logistics check activities, the materials are inspected by the quality department. Because this is a necessary treatment, the *quality* material group will follow the general stock flow. We stated that therefore it is not possible to make a comparison between the flows when it comes to the quality group.

Goods of length
Goods of length will also follow the general stock flow. Long tubes, profiles, cables and bars are delivered on a pallet or even bigger. To take the pallet out of a truck, a forklift is needed. Because of these addition activities, this material group cannot be treated as bulk stock. Besides that, in the current factory, the storage location of this material group is on a different places than the general warehouse, where the small materials are allocated. To place the materials on that location, addition time is required. Therefore, the material group *goods of length* will also follow the general stock flow.

Bulk stock and exact quantity
For the last two material groups, the bulk stock and exact quantity, it is more interesting to make a decisions about the flows. Different logistics flows can be considered. Due to the fact that these materials do not require any additional handling times, like inspection or allocating in different buildings, a comparison can be made. As described in Chapter 4, we analyzed over more than 1500 materials. To make an appropriate comparison of costs, calculations have to be made. In the next chapter, we explained the design of the solution method and

what decisions can be made for the last two material groups.

5.3 Discussion and conclusions

Discussion

The activity-based costing method applied in this bachelor thesis focused on identifying the costs of the activities. Handling times are measured in order to do so. A discussion can be made when it comes to implementing the ABC method in such a way, because most of the ABC applications focuses on resources too (Lambert et al., 1998). This has not be done in this research. On the other hand, by using the ABC we were able to identify the costs in a structured way.

Another remark can be made by the fact that we designed the formulas based on common sense and mathematical background. This might cause errors. Out of literature review, we were not able to find standard formulas for identifying the total costs. Therefore, we made use of the concepts of ABC by dividing the main processes with the cost driver.

Conclusion

By executing the ABC analysis, the activities that need to be performed in case of the three logistics flows are indicated. Moreover, cost drivers for each of the activities are determined. Using the cost drivers and main processes we were able to define three cost formulas to calculate the total cost of ownership. After defining these formulas, the conclusion can be made that in case of bulk stock supplied by VDL warehouse, the most activities need to be executed. Besides that, it can be concluded that this type of flow has overlapping elements with the general stock and VMI flow. On top of that, we have seen that the optimal logistics flow for the *quality* and *goods of length* materials groups is the general stock. For the remaining material groups, an in depth analysis need to be performed. This is described in the next chapter.

6 Solution method

The aim of the thesis is to better understand the logistics flow and to make a decision for the material groups. In this chapter the designed method is explained. The following question is answered:

How should the solution approach for determining the most optimized logistics flow for the material groups look like, considering the related costs?

As described in the previous chapter, the focus lied on the material groups *Bulk stock* and *Exact quantity*. In order to calculate the TCO, a model is designed. Using *Microsoft Excel* and *Visual basic for applications* a model is programmed in which the costs can be calculated. A manual how to use the model is provided in Appendix D.

Solution model

The solution model is made using *Microsoft Excel*. The model is created so that the user can easily use it to calculate the TCO of different logistics flows to make a decision how to treat a stock material. Based on interviews, the following restrictions are stated by the company and were taken into account for designing the model.

1. TCO of a material can be calculated based on input parameters.
2. The model can be used to calculate multiple materials at once.
3. Data out of VBS can be loaded in.
4. The model is easy to use.

The data that have been used to make the model is based on the business process models provided in Chapter 2 and the activity-based costing method described in Chapter 5. The model is programmed using the *Visual Basic Application* tool within the developer function of *Microsoft Excel*. By programming the model, multiple calculations can be done at once using Macros. Buttons are used to execute the macros. This is described in detail in this chapter. The most important elements of the model are as follows.

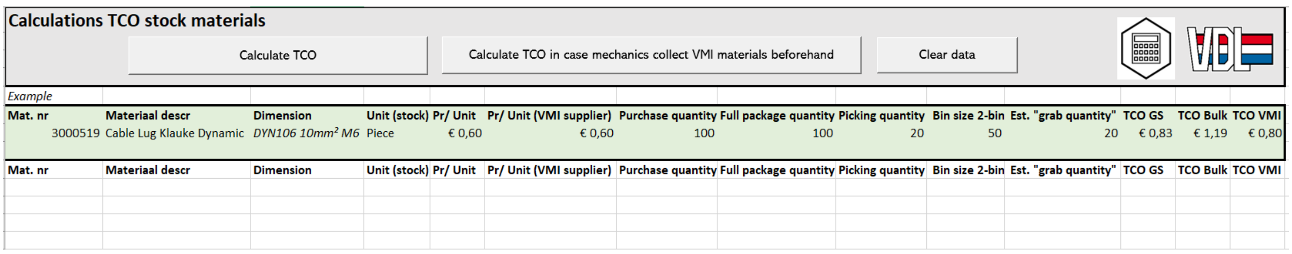
- TCO calculations (Section 6.1)
- Bulk stock supplied by VDL warehouse vs VMI (Section 6.2)
- TCO general stock (Section 6.3)

Material groups

The model starts with an overview sheet. In these sheets, all the relevant information for the user how to use the model can be found. The different sheets and variables are defined in the overview sheet. Moreover, Figure 12 can be seen with an explanation on which materials an addition calculation should be made in order to select the most optimized logistics flow. In Appendix E, the model is reported. In Section 6.1, the TCO calculations are explained. The comparison between the bulk stock supplied by VDL warehouse and VMI is described in Section 6.2. The TCO of the general stock is explained in Section 6.3. In Section 6.4 and 6.5, respectively the analysis of the model and conclusions about the chapter are given.

6.1 TCO calculations

For some of the materials, it is interesting to know what the TCO will be depending on the flows. Examples of these are materials which follow the general stock flow, but can perhaps be transformed to bulk stock for several reasons. In one of the sheets in the solution model it is possible to compare the TCOs for a material. Equations 1, 2 and 3 stated in Section 5.1.5 were programmed in order to make a comparison. In Figure 14, an overview of the sheet can be seen. The user needs to fill in the following data and indicators. A distinction between data and indicators is made. Data is information which can be downloaded out of VBS. Indicators are information on which the calculations are based on. This information can sometimes be unknown for the user. In such case, the user needs to make an estimation.


Calculations TCO stock materials

Calculate TCO | Calculate TCO in case mechanics collect VMI materials beforehand | Clear data

Example

Mat. nr	Materiaal descr	Dimension	Unit (stock)	Pr/ Unit	Pr/ Unit (VMI supplier)	Purchase quantity	Full package quantity	Picking quantity	Bin size 2-bin	Est. "grab quantity"	TCO GS	TCO Bulk	TCO VMI
3000519	Cable Lug Klauke Dynamic	*DYN106 10mm² M6*	Piece	€ 0,60	€ 0,60	100	100	20	50	20	€ 0,83	€ 1,19	€ 0,80

Mat. nr	Materiaal descr	Dimension	Unit (stock)	Pr/ Unit	Pr/ Unit (VMI supplier)	Purchase quantity	Full package quantity	Picking quantity	Bin size 2-bin	Est. "grab quantity"	TCO GS	TCO Bulk	TCO VMI

Figure 14: Designed model: Calculations TCO stock materials

6.1.1 Input TCO calculations

In this section, the input data to calculate the TCO is explained.

Data
The following data can be downloaded out VBS and be put in the model.

- Material number
- Material description
- Dimensions of the material
- Unit of material
- Price per unit

Sometimes it occurs that not all of the input data is present in the ERP system. It can be that the dimensions of the material are missing. This will not be a problem when using the model. Out of the input data, two elements are essential, the material number and the price per unit. These two elements are selected because these two are also key elements in VBS. Each material has an unique material number. Without filling in this number, the model will fail. Furthermore, it is impossible to calculate the TCO without the purchase price, therefore this data is also necessary. This because it is an crucial element in the formulas.

Indicators
To calculate the TCO of the different options, the following indicators have to be filled in the model by the user.

- Price per unit stated by the VMI supplier
- Purchase quantity; the amount of materials purchased in an order
- Full package quantity; the amount of materials in a full package (e.g., 200 bolts in a box)
- Picking quantity; the amount of materials that need to be picked
- Bin size 2-bin; the amount of materials in a bin, when using bulk stock supplied by VDL warehouse
- Estimation of "Grab quantity"; amount of materials that the mechanic collects.

To compare the general stock and bulk stock supplied by VDL warehouse with the VMI, the price per unit stated by the VMI supplier should be used. Due to the fact that the VMI supplier can have different prices than other suppliers for a specific material. Besides that, the full package quantity is needed to calculate the picking times. In case the required demand is equal to the full package quantity, the picking time is decreased, as can be seen in Figure 19

Estimations
Determining two indicators can be hard as they are based on estimations. This is in case of 'bin size 2-bin' and the 'estimation of the grab quantity'. The bin size in case of bulk stock supplied by VDL warehouse is needed to calculate the TCO, as stated in Equation 2. The 'estimation of the grab quantity' represents the variable MM in Equations 2 and 3. The user needs to make an estimation how much materials the mechanic will grab if the material will be placed as bulk stock.

6.1.2 Calculations possibilities

In this section the calculation possibilities are explained. Three buttons are placed in the TCO calculations sheet. The actions of these buttons are described.

Calculate TCO
The first button, as can be seen in Figure 14, is named "Calculate TCO". By filling in the eleven input parameters, the TCO of the three different flows can be calculated. By activating the button, the model will automatically calculate all the TCOs for the given materials. The model will produce three output parameters:

- TCO GS; the total cost of ownership of the general stock
- TCO Bulk; the total cost of ownership of the bulk stock supplied by VDL warehouse

- TCO VMI; the total cost of ownership of VMI

Collect materials beforehand
The second button is named "Calculate TCO in case mechanics collect VMI materials beforehand". When using this button, the user can tackle the problem of making estimations about the amount of materials that the mechanic collects when using bulk stock materials. When using this button, the calculations of the the bulk stock supplied by VDL warehouse and VMI will be done without taking into considering the grab estimation (i.g., red circles in Figure 13). In practise, this situation can occur the moment a mechanic will collect all the bulk stock materials at once. At the beginning of a project for example. A result of this will be that the variable MM will increase significant and will limit the fraction $\frac{Production}{MM}$ to zero. The model will automatically replace the TCO calculations for the new situation. In that case, Equation 2 and 3 change in respectively Equation 4 and 5.

$$TCO_{bulk\ stock\ VDL} = PP + \frac{Wage}{3600} \cdot \left(\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Administrate + Picking_{Bulkstock}}{Bin\ size}\right) \quad (4)$$

$$TCO_{VMI} = PP_{vmi} \cdot (1 + \frac{S_{vmi}}{100}) \quad (5)$$

Clear data
The third button in the TCO calculations sheet is named "Clear data". By activating this button, both input and output data will be deleted.

6.2 Comparison between bulk stock

In the model, a comparison between the bulk stock supplied by VDL warehouse and VMI can be made. This is a relevant calculation the moment the user wants to know whether to outsource the bulk stock material or not. The same input data as stated in Section 6.1 can be used. In Appendix E, the sheet can be seen.

Input data
The following indicators are important as input data when making the comparison.

- Price per unit stated by the VMI supplier
- Purchase quantity; the amount of materials purchased in an order
- Full package quantity; the amount of materials in a full package (e.g., 200 bolts in a box)
- Bin size 2-bin; the amount of materials in a bin, when using bulk stock supplied by VDL warehouse
- Expected order frequency per year; amount of materials that the mechanic collects

Output data
When calculating the TCOs, given the input data, the model will process the following output data.

- TCO bulk stock; total cost of ownership of the bulk stock supplied by VDL warehouse.
- TCO VMI; total cost of ownership of VMI.
- Delta; difference between the TCO bulk stock supplied by VDL warehouse and TCO VMI.
- Increasement VMI; percentage that VMI purchase price can increase to equalize TCO bulk stock supplied by VDL warehouse
- Break-even point VMI; purchase price for VMI materials to equalize TCO bulk stock supplied by VDL warehouse.
- Total savings per year; in case delta is positive, the savings per purchase order when transferring a material from bulk stock supplied by VDL warehouse to VMI.

6.2.1 Formulas

At three of the output parameters, calculations are needed. First of all the delta, which is the difference between the TCO bulk stock supplied by VDL warehouse and TCO VMI. Equation 6 represents the formula for calculating the delta. Secondly, the "increasement VMI", which is the percentage that VMI purchase price can increase to equalize TCO bulk stock supplied by VDL warehouse. Equation 7 represents the calculation. Thirdly, the "total savings per year", which is, in case delta is positive, the savings per purchase order when transferring a material from bulk stock supplied by VDL warehouse to VMI. Equation 8 represents the calculation.

$$Delta = TCO\ Bulk\ stock - TCO\ VMI \tag{6}$$

$$Increasement\ VMI = \frac{TCO\ Bulk\ stock - TCO\ VMI}{TCO\ VMI} \tag{7}$$

$$Total\ savings\ per\ year = Expected\ order\ frequency\ per\ year \cdot delta \cdot purchasequantity \tag{8}$$

Explanation
When executing the data, the model provides six columns of output data. The first two columns provide the TCO of the two options. The third one provide the difference between the bulk stock supplied by VDL warehouse and VMI. This value is termed "delta" in the model. If the user wants to know what price the VMI supplier can state to equalize the TCO of the other situation, it can be seen in the fourth and fifth column, where the potential increasement of the VMI price and the break-even point between the options are stated. In the sixth column, the total savings per year for a specific material can be seen. If this value is positive, for instance €100, it means that €100 can be saved when using for VMI. When is value is negative, it means that it is more beneficial to choose for the bulk stock supplied by VDL warehouse instead of VMI.

6.2.2 Example

An example is made to create a better understanding. In Figure 15, the input variables can be seen which have been used in the example. In this case a specific "cable lug" is analyzed, which followed the bulk stock supplied by VDL warehouse flow. We assumed in the example that the price per unit is equal to the price per unit stated by the VMI supplier. In this case the TCO of the bulk stock supplied by VDL warehouse is equal to €0,99, where VMI is €0,60. The increasement VMI represents 64,39%. This means that the purchase price given by the VMI supplier can increase with 64,39% to break-even. In case this material is ordered four times per year with an quantity of 100, €154,55 can be saved the moment this material will be transferred to the VMI.

Table 15: Example: Input data bulk stock supplied by VDL warehouse vs VMI

Input data	
Variable	Input
Material number	3000519
Dimension	DYN106 10mm² M6
Unit	Piece
Price per unit	€0,60
Price per unit (VMI supplier)	€0,60
Purchase quantity	100
Full package quantity	100
Bin size 2-bin	50
Expected order frequency per year	4

.

Table 16: Example: Output data bulk stock supplied by VDL warehouse vs VMI

Output data	
Variable	Output
TCO Bulk stock	€0,99
TCO VMI	€0,60
Delta	€0,39
Increasement VMI	64,39%
Break-even point VMI	€0,99
Total savings per year	€154,55

6.2.3 Mass data

The model is designed to calculate mass data. The user can calculate the costs for multiple materials at once. By doing this, the model will also provide two additional output parameters based on the mass data calculation. First of all, the potential total savings. This is the summation of all the total savings per year for the materials. Equation 9 gives an overview how the savings are calculated. The summation loops over all input data, starting from x = 1 (1 material as input) until x = n (n materials as input). If this value is positive, it means that transferring all the mass data to VMI will result in savings. If this value is negative, it means that from the mass data it will not be cheaper to transfer it to VMI. Secondly, the average increasement VMI is calculated. If this value is equal to 70%, it means that out of the mass data, on average the purchase price of the VMI supplier can increase by 70% in order to break-even, compared to the TCO of the bulk stock supplied by VDL warehouse.

For the mass data, there is a possibility to save the calculations. If the user wants to make a decision based on the calculations, the calculation can be saved in the "archive". This can be done, by executing the button "clear data and save it in archive".

$$Savings = \sum_{x=1}^{n} delta(x) \cdot purchase\ quantity(x) \cdot Expected\ order\ frequency\ per\ year \tag{9}$$

6.3 TCO general stock

In this section it is explained how the TCO of the general stock is used in the model. The third important sheet in the model is the one where the user can calculate the TCO of the general stock. In Figure 15, an overview of the sheet in which the TCO of the general stock is calculated can be seen.

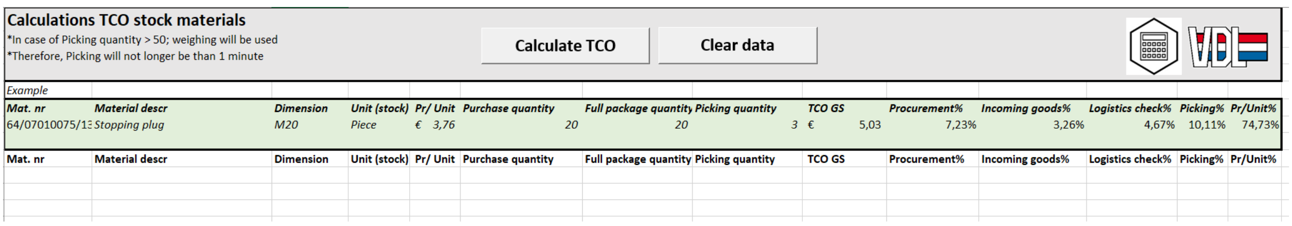
Input TCO general stock
The model uses the same input data as described before. The following indicators are the main input parameters in the model.

- Price per unit
- Purchase quantity; the amount of materials purchased in an order.
- Full package quantity; the amount of materials in a full package (e.g., 200 bolts in a box).
- Picking quantity; the amount of materials that need to be picked.

Output TCO general stock
The model provides the following output data when executing the calculations.

- TCO GS; total cost of ownership of the general stock.
- Procurement %; percentage of procurement costs at the TCO.
- Incoming goods %; percentage of incoming goods at the TCO.
- Logistics check %; percentage of logistics check at the TCO.
- Picking %; percentage of picking process at the TCO.
- Pr/Unit %; percentage of the price per unit at the TCO.

The user will be provided by the percentages of involvement of the different departments. In other words, the model shows for how much percentage procurement, incoming goods, logistics check, picking and the price per unit is responsible at the TCO.



Calculations TCO stock materials
*In case of Picking quantity > 50; weighing will be used
*Therefore, Picking will not longer be than 1 minute

Calculate TCO | Clear data

Example

Mat. nr	Material descr	Dimension	Unit (stock)	Pr/ Unit	Purchase quantity	Full package quantity	Picking quantity	TCO GS	Procurement%	Incoming goods%	Logistics check%	Picking%	Pr/Unit%
64/07010075/13	Stopping plug	M20	Piece	€ 3,76	20	20	3	€ 5,03	7,23%	3,26%	4,67%	10,11%	74,73%

Mat. nr	Material descr	Dimension	Unit (stock)	Pr/ Unit	Purchase quantity	Full package quantity	Picking quantity	TCO GS	Procurement%	Incoming goods%	Logistics check%	Picking%	Pr/Unit%

Figure 15: Designed model: Calculations of the TCO general stock

Example TCO general stock

In Table 17, input data for the example to calculate the TCO of the general stock can be seen. In Table 18, the output data can be seen. In this case a washer M5 zinc plated has been used. In this particular example, the TCO of the washer will be €0,11. Most of the handling costs will be made in the picking process in this case. The proportions of influences on the TCO in this example can be seen in Figure 16.

Table 17: Example: Input data TCO general stock calculation

Input data	
Material number	231122005
Material description	Washer M5 ZINC PLATED
Dimension	H0.1 X W1 X L1
Unit (stock)	Piece
Price per Unit	€0,0016
Purchase quantity	500
Full package quantity	250
Picking quantity	20

Table 18: Example: Output data TCO general stock calculation

Output data	
TCO GS	€0,11
Procurement %	13,42%
Incoming goods %	6,05%
Logistics check %	8,66%
Picking %	70,40%
Price per unit %	1,48%

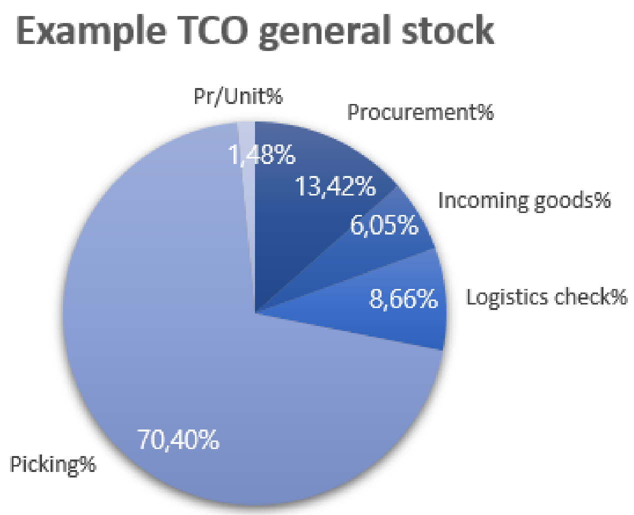


Figure 16: Example: Proportions of influences on TCO general stock

6.4 Analysis and improvements

After programming the model, it has been tested for multiple materials which have been purchased as stock at VES. We analyzed the TCOs of the materials and searched for improvements. Analysis are made for the general stock. The result of these analysis is an improvement suggestion when it comes to the picking process. This is described in Section 6.4.1. Moreover, analysis are made for the bulk stock supplied by VDL warehouse when comparing it to VMI. These analysis are described in Section 6.4.2.

6.4.1 Counting and weighing

After testing the model for multiple materials, some conclusions were made. First of all, for the general stock. For products with a low price per unit, the influence of the picking process on the TCO is significant. This is not a surprise, since Lambert et al. (1998) already stated that the picking process will significant have influence on the handling activities in a logistics warehouse. To decrease the handling times at the picking process, further research is performed.

In the warehouse, together with the involved employees, measurements are performed. The option to make use of weighing instead of counting in the picking process is proposed and investigated. This to find out if the picking process time could be decreased when multiple materials need to be picked. By making use of a logistics weight scale, picking activities have been done. The involved times have been measured and indicated. The extensive weighing data can be seen in Appendix B in Figure 20.

In Table 19, a short overview of the weighing measurements are reported. Respectively, multiple measurements are executed to indicate the time it take to weigh the materials and the average time for 5, 20, 50, 75, 100 and 150 pieces to pick. As can be seen in the table, it turned out, that on average it takes 31,88 seconds to weigh the materials, independent on the amount that need to be picked. Out of the counting measurements, we knew that on average it take 0.96 seconds to pick one components. This is described in Section 5.1.4.

In Figure 17, the measurements are plotted. In the graph, two lines can be seen. The solid line represents the connection between the measurements points. From this line, we searched for a trendline which represents an equation to calculate the average time per piece when weighing is applied. One can see in the graph that the more materials need to be weighed, the less time it takes on average per piece. In the beginning, the line declines strongly, where in the end it looks like the line comes to a limit. Therefore, we searched for a trendline which fits that description the best. I turned out that the an exponential equation fits the best with the data. Using the trendline tool within *Microsoft Excel* the general formula have been stated, this can be seen in Equation 10.

From Equation 10, we searched for the break-even point between counting and weighing. Filling in a y-value of 0.96 (Average time per piece when counting is applied), an x-value of approximately 51 is the result. To validate the equation, the R-squared value is calculated. The R-squared value is a statistical measure that represents the proportion of the variance for a dependent variable that is explained by an independent variable of variables in a regression model (Fernando, 2020). The closer the value to 1, the better the model fits the data. In our case, the calculated R-squared value is 0.7938. This means that approximately the model fits the data for 80%. This value is found using *Microsoft Excel*.

$$y = 2,3006e^{-0,017x} \tag{10}$$

$$R^2 = 0,7938$$

Intermediate conclusion
Out of the analysis at the picking process, we concluded that weighing instead of counting is interested the moment more than 51 materials need to be picked. This value is calculated out of a model that for 80% represents the measurements. The break-even point of 51 is discussed with the involved employees at the warehouse. Because of practical reasons, we concluded that the number 50 will be better to recognize. Taking this suggestion into consideration, we concluded that the moment 50 or more components need to be picked, weighing would be more beneficial.

Table 19: Weighing measurement: Average time per piece and time total weighing

Weighing measurements		
Pieces	Time total weighing (s)	Average time per piece (s)
5	21,0	4,2
20	28,3	1,4
50	32	0,66
75	33	0,44
100	34	0,34
150	43	0,29
Average	31,88	1,22

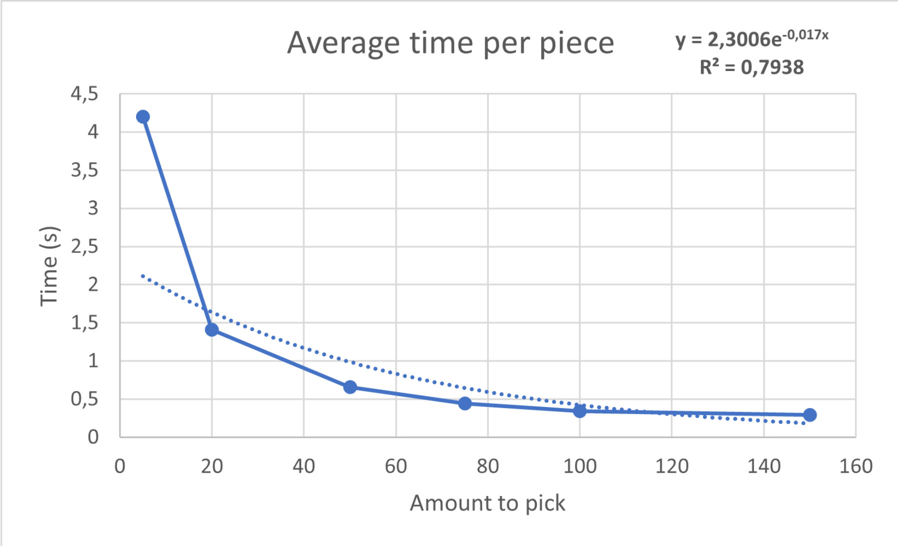


Figure 17: Weighing measurement in the warehouse: the average time per piece when weighing is applied

6.4.2 Bulk stock supplied by VDL warehouse

To validate the model, analysis are done when it comes to the calculations for the bulk stock. The main decisions that can be made by using this calculation, is whether the bulk stock should be outsourced or not. When executing this thesis, 87 materials were planned to follow the bulk stock supplied by VDL warehouse flow. Because not for all of these materials enough information was provided, 59 materials were analyzed using the model. These materials are called mass data in the remaining part of this section. When comparing bulk stock supplied by VDL warehouse and VMI, the formulas have been used as stated in Equation 4 and 5. Due to the fact that the time it takes for the mechanic to collect the materials (MM) will be the same in both situation, as both flows are bulk stock. Since the bulk stock supplied by VDL warehouse requires additional activities compared to VMI, the main difference will be in the purchase price of the material. In order to draw conclusions, analyses are done with respect to different purchase prices. Two scenarios are executed.

Scenario 1: Savings per year

In the first scenario, we analyzed the savings for the mass data. Given the stated input, each experiment the purchase prices of the VMI supplier have been increased with respect to VES' own purchase price. The results are shown in Table 20. In the first experiment, we stated the purchase price of the VMI supplier equal to VES own supplier, so 0% increasement. Out of this experiment it can be concluded that all of the materials should be outsourced, so added to the VMI. Moreover, in this case €3071.32 can be saved per purchase order of the mass data. Besides that, the average increasement VMI is 120.83%, which means that on average the VMI supplier can be 2.2 times as high as VES own supplier to break-even. Note that the savings per year have been calculated with the assumption that the purchasing will be done once a year. If this frequency increases, the savings per year will increase with the same factor.

When outsourcing all the materials, experiments are executed to find the percentage the moment the savings are negative. It turned out that when the purchase price of the VMI supplier is 47% higher than VES own price, savings will be negative. That means for the mass data that overall it will be better to follow the bulk stock supplied by VDL warehouse flow. One remark can be made. At this percentage, still it should be more beneficial for 44 out of 59 materials to be outsourced.

Table 20: Experiments based on scenario of increasing purchase price VMI supplier

Percentage of increasement VMI purchase price with respect to VES' price	Savings per year	Average increasement VMI	Amount of materials to outsource (out of 59)
0 %	€3071,32	120,83%	59
10 %	€2408,38	100,75%	54
20 %	€1745,44	84,02%	51
30 %	€1082,50	69,87%	48
40 %	€419,56	57,73%	47
45 %	€88,08	52,30%	44
46 %	€21,07	51,25%	44
47 %	-€44,50	50,22%	44

Scenario 2: Amount of materials to outsource
In the second scenario, we analyzed the amount of materials to outsource. Given, the stated input, each experiment the purchase prices of the VMI supplier have been increased. In Table 21, the results can be seen. It turned out that in the most extreme situation, the purchase price of the VMI supplier can be 650% higher than VES the moment no materials should be outsourced. When more realistic experiments are analyzed, such as a reducing of 10%, it can be stated that 54 out of 59 still need to be outsourced. Out of the experiment, we concluded that in case of a small increasement, significant savings per purchase order can be made when outsourcing the materials.

Table 21: Experiments based on scenario of outsourcing materials

Percentage of increasement VMI purchase price with respect to VES' price	Amount of materials to outsource (out of 59)
0 %	59
10 %	54
50 %	43
100 %	19
150 %	10
300 %	5
500 %	2
650 %	0

6.5 Conclusion

In this chapter, the research question "How should the solution approach for determining the most optimized logistics flow for the material groups look like, considering the related costs" is answered. Based on the activity-based costing analysis, a model is programmed in *Microsoft Excel* using *Visual basic application*, to calculate what the optimal flow can be for the material groups exact quantity and bulk stock. Three calculations can be made in model. First of all, a comparison between the flows of the general stock, bulk stock supplied by VDL warehouse and VMI. This calculation can be used to calculate the options for the general stock. Secondly, in case of general stock, the proportions of influences on the TCO of each involved department can be calculated. Thirdly, in case of bulk stock, calculations can be made whether to outsource the material or not.

Analysis of the model are done. First of all, it turned out that in most cases the picking process at the general stock has the most influence on the TCO. Therefore, the picking process has been analyzed. It turned out when more than 50 components need to be picked, it is more beneficial to use weighing instead of counting. Secondly, the bulk stock have been analysed. After analysing the model, it turned out that when comparing the bulk stock supplied by VDL warehouse with the VMI, that the VMI process will be more beneficial. This under the assumption that the VMI price will not be that much higher than the normal purchase price. 59 materials which follow the logistics flow of the bulk stock supplied by the warehouse have been analyzed in the solution model. Out of the costs analysis of these materials, the conclusion can be made that the savings will be approximately between €3071.32 and €2408.38 per purchase order when the VMI price will be between 0% and 10% higher than VES own purchase price.

Discussion

A discussion can be made with regard to the conclusion. Using the model, break-even point can be calculated. Especially when it comes to the decision whether to outsource the materials or not, decisions can be made based on the calculations. The moment the TCO of the bulk stock supplied by VDL warehouse is lower than the one from VMI, a closer look has to be made to the margin. It should be taken into account that the bulk stock supplied by VDL warehouse consist out of significant more activities than VMI. This means, the probability of human failures, and therefore delays in the process, is higher. Besides that, a remark can be made when it comes to the savings. VES will not directly account the savings. In the model, savings should be transferred to working hours. A saving of €3000 means 3000 divided by 100, equals 30 hours for an employee to focus on other activities.

7 Implementation and evaluation

In this chapter, the practical implementation of the solution approach are described. It is explained how the solution can be evaluated. This is done by answering the following research question:

How can the solution be implemented and evaluated at VDL Energy Systems, taking the restrictions into consideration?

As described in Chapter 1, the company stated four restrictions on the solution. First of all, it had to be based on key performance indicators. Secondly, when implementing the solution, it had to create clarity for the involved stakeholders on what to do or what to change. Thirdly, if changes were needed in the ERP system, it should be addressed. Lastly, the solution had to be applicable at the new factory.

Literature review was executed to get more insights in the implementation phase. Out of literature, four elements of implementation are addressed in this chapter. First of all the current state and the need of implementation is explained in Section 7.1.1. Secondly, in Section 7.1.2 the social side is described. Thirdly, the technical side of the implementation is addressed in Section 7.2. Lastly, the future state is given in Section 7.3, an explanation of evaluation of the solution and in case of the assignment a closer look how to implement the solution at the new factory is made. The results of the research are presented for four involved stakeholder. After the presentation, the stakeholders filled in a survey. The outcomes of the survey are described in Section 7.4. Finally, Section 7.5 provides the conclusion of this chapter.

7.1 Current state and social side

In this section, based on the finding of Heerkens and Winden (2017) and Galli (2018), the current state and social side of the implementation phase are addressed. Section 7.1.1 addresses the current state, whereas Section 7.1.2 explains the social side.

7.1.1 Current state

According to Galli (2018), the need for change should be addressed to the stakeholders. It should be explained why implementation is needed at the company. As described in Chapter 1, the action problem has been described as follows:

"At VDL Energy systems, the total cost of ownership of stock materials, need to go from unidentified to identified and the logistics process should be optimized."

There was a gab between the norm and reality as stated in the core problem: 'There is no clear procedure on how to deal with the logistics flow of the product-related stock materials'. To solve this problem, the logistics flows were identified and the total costs of ownership can be calculated using the model. Especially when it comes to make a decision whether to outsource the materials or not, the tool is necessary and useful. By skipping the tool, decisions can be made on common sense, which may result in incorrect decisions. The model can be used as a decision support tool.

7.1.2 Social side

According the Galli (2018), the social side of the implementation should be addressed. It is possible that the solution itself can be perfect for the company, but without the willingness from employees and team members the process to implement change will almost always fail. The following statement by Galli (2018) addresses that perfectly:

"People are the changes, not the models"

The main departments that play a role in the implementation phase are as follows and are explained in more detail in Section 7.2.

- Procurement
- Production control
- Logistics
- Production

7.2 Technical side

In this subsection, technical details for the stakeholders on how to implement the solution are described. The effects for the four departments are given.

7.2.1 Procurement

First of all, the implementation impact on the procurement department is described. At this department, the tool will not directly be used. As described this will mainly be used by the production control department, since they have to make the strategic decisions. But when decisions will be made, this will have significant impact on the procurement of the materials. As can be read in Chapter 6, based on calculation, the decision can be made to outsource the materials, because of savings. When VMI is chosen, this will have impact on the organisation. To get better insights in the possible implementation issues when using VMI, research in literature is executed. VDL Energy Systems is currently using one VMI supplier. When in potential, more materials will be added to the product range of VMI materials, it can be possible to use multiple VMI suppliers. Literature review is executed to get better insights in the concept of VMI.

Vendor managed inventory is considered as an important option in a strategic alliance, because VMI not only has the ability to reduce costs, but also to improve service levels and create business opportunities for all parties in the supply chain (Fleuren et al., 2020). The concept of VMI can cause disadvantages and advantages. Out of literature study, the most important one have been summarized (Fleuren et al., 2020)(Beheshti et al., 2020)(Claassen et al., 2008). This is only from the customer perspective executed, since this is most relevant for VES.

Advantages/opportunities

- VMI can cut down or eliminate ordering costs by reducing paperwork for purchase orders and repetitive tasks
- Savings in labor costs as inventory levels will not have to constantly be monitored and they do not have to inspect incoming inventory for quality
- Buyer (in case of the assignment: VES) can place smaller and more frequent orders without concern for increased ordering costs
- VMI improves availability of products and eliminates the need for safety stock for the customer
- Reduction in administration costs
- Maximize the competitiveness of the supply chain
- Reduction of total costs

On the other hand, applying VMI could also bring some disadvantages and barriers. The most important ones are enumerated out of literature described by Fleuren et al. (2020), Beheshti et al. (2020) and Claassen et al. (2008).

Disadvantages/barriers

- Even highly developed VMI systems cannot account for large, unexpected fluctuations in demand.
- Confidentially of information between the customer and supplier (vendor)
- Change of ineffective ordering and fulfillment processing

Success factors in implementing VMI
When taking into account the advantages and disadvantages, VMI can be used. When it comes to implementing of the system, success factors are relevant. Claassen et al. (2008) executed a quantitative survey, conducting exploratory interviews with buyers and suppliers in order to investigate whether statements about VMI outcomes, enablers for success, and the design of VMI itself as found in the literature, also held in practice. Besides that, Beheshti et al. (2020) also described the enablers for successful VMI implementation. The most important items are enumerated.

- Information is the key of success of a VMI implementation. Information can be described in terms of, information sharing, availability, completeness and reliability.
- By sharing information about exceptions like promotions and campaigns, better forecasts can be made

- The higher the quality of ICT systems, the high the buyer-perceived VMI implementation success
- The more extensive the information that is shared, the higher the buyer-perceived VMI implementation success
- The higher the quality of the buyer-supplier relationship, the higher the buyer-perceived VMI implementation success
- The higher the buyer-perceived VMI implementation success, the more cost reduction, the more customer service level improvements and the more supply chain control improvements are achieved

To conclude, when it comes to the implementation process at the procurement department, VMI is a relevant concept. When selecting a VMI supplier, the stated advantages and disadvantages should be taken into account in order to make a right decision. When implementing VMI, the focus should lie on extensive information sharing. Multiple authors have addressed that is will be the key of successfully implementing VMI.

7.2.2 Production control

Secondly, the implementation steps for the production control department are explained. This department can make use of the model, as described in Chapter 6. In the model, a decision tree has been provided. This tree corresponds with Figure 12. When implementing the solution, the decision tree can be used to categorize the specific material and to know the possible options for the material. In the model, an explanation sheet is given, as can be seen in Appendix E. Besides that, a manual is written how to use the model. The manual is reported in Appendix D. By following manual, the model can be used as a decision support tool. By using the model, arguments can be made on which flow a material should follow.

7.2.3 Logistics

The third department are the logistics. When implementing the solution, this causes some effect at the logistics department. First of all, as described in Section 6.4, it is stated that from the moment the logistics need to pick more than 51 components, it will be more beneficial to weigh it. Interviews are conducted in the warehouse on how to implement this as a rule of thumb. Because of the probability to have some delays in the weighing process and because of practical reasons, out of the interviews it became clear that it is reasonable to use a weighing scale when more than 50 materials need to be picked.

To implement this strategy, a logistics weighing scale is necessary. Preferable, this will be a wireless one, which can be placed on the pick-car. Besides this, the logistics department is also responsible for the bins when using the bulk stock supplied by the VDL warehouse. Therefore, when products will be added to this stock by the production control department, it should be communicated with the logistics to implement this process in the right way. By doing this, the logistics can add a bin in the storage rack and assigning a location for it.

7.2.4 Production

Lastly, the implementation issues for the production department are discussed. This department will be the end-station of the process. When implementing the solution and making decisions based on the calculations, the production department will be faced with the effects. For example, the production control department can decide to add more materials to VMI. A consequence of this decision will be that the mechanics need to collect more materials by themselves at the bulk stock location. Products which normally will be delivered in exact quantities, should then be collected by the mechanics themselves. In this process communication will be the key in order to get no surprises. The second issue is that the TCO of the VMI materials will be calculated by using Equation 11. As explained in Chapter 5, MM stands for materials needed by the mechanic. The more materials the mechanic will collect at once, the bigger MM and the lower the outcome of the fraction $\frac{Production}{MM}$ will be. This will result in a lower TCO of the materials. To tackle these two issues, interviews are conducted with employees of the production department. Out of these interviews, it became clear that the production department wants to know which materials are placed as bulk stock for a specific project. Therefore, a so called 'bulk stock list' is preferred where all the materials are listed which are placed as bulk stock for a specific project. By following this list, materials can be collected as much as possible before the project and clearance has been made to the mechanics.

$$TCO_{VMI} = PP_{vmi} \cdot (1 + \frac{S_{vmi}}{100}) + \frac{Wage}{3600} \cdot (\frac{Production}{MM}) \tag{11}$$

7.3 Future state

In this section, the future state of the implementation phase is described. VDL Energy Systems will move to a new factory in the summer of 2021. This movement is a great opportunity to make processes in the factory more efficient. The current factory is namely over more than 100 years old. One of the restrictions stated in Chapter 1, is that the solution can also be implemented when moving to the new build factory. Interviews are conducted to get better insights on the concept of the new factory. The lay-out of the factory will be more efficient, therefore process times will decrease. Take for instance the time it takes for a mechanic to walk to the bulk stock location. In the new factory, this distance will significantly decrease. When process times will change at the new location, this can easily be implemented in the solution model by changing the process times of the activities. The model has been programmed in an hybrid way. This means, when process times will be changed in the model, the complete model will adapt this change. Therefore, if process times are identified, the model can be used in the new factory, as activities that need to be performed will be the same.

7.4 Evaluation

When implementing a solution, it is important to evaluate it over the long term (Heerkens and Winden, 2017). In Section 7.4.1, a list is described with focus points to evaluate the model in the future. Section 7.4.2 provides the results of a survey performed for four stakeholders at VES.

7.4.1 Focus points

- Communication between the production control and logistics department is important when new activities (and therefore involved times) need to be executed in the warehouse. If this is the case, the model should be adapted. This can be done by adding new activities, or increase time measurements.
- Production control and production department should evaluate the bulk stock materials over time. If the mechanics want new products added as bulk stock, because of practical reasons, this should be communicated.
- Information sharing is the key in the communication between the VMI supplier and the buyer. Therefore, evaluation is needed between them, to discuss the performances. In the beginning, this can be done for example once a quarter.

7.4.2 Evaluation of the research

We analyzed the research approach and applicability of the model by providing four stakeholders a survey. In this section, the evaluation of the results is given. In Appendix C the complete answers of the surveys are provided. During a presentation, the main conclusions and recommendations have been presented. The survey has been filled in after the presentation by four involved stakeholders of the following departments:

- Production control; The involved employee at the production control department (PC)
- Logistics: The head of the logistics (HoL) and logistics warehouse coordinator (LWC)
- Production: Team leader of the production facility (TLP)

Background
The four stakeholders have been selected to fill in the survey because of their high interests in the results of the research. The production controller will mainly use the model as a decision supporting tool for strategic decisions. If a decisions will be made, this will have consequences for the three remaining stakeholders. The head of logistics has to manage the goods issue in good way. One of the involved stakeholder in doing so is the logistics warehouse coordinator. Lastly, the team leader of the production facility will see the causes by materials which are delivered by the logistics.

Survey
The stakeholders have been asked to provide answers to the following statements:

1. I intend to make use of the conclusions and recommendations of the research.
2. The research gave me a better insight in the processes of the logistics flows.
3. The research will contribute in optimizing the logistics processes.
4. I intend to make use of the model where the total cost of ownership can be calculated (if this is applicable at your function).

5. The conclusions and recommendation can be applied at the new factory.
6. The approach of the research was efficient in order to achieve the goal (identification of the total cost of ownership of the stock materials and optimize the logistics processes)

Outcomes
The stakeholders were asked to provide grades for each statements running from 1 to 5. These grades represents an opinion. The grades respectively represents 'strongly disagree', 'disagree', 'neutral', 'agree' and 'strongly agree'. In Table 22, the results of the survey are reported. For each of the six statements, the minimum value, maximum value, average grade and the standard deviation between the grades are reported. The standard deviation represents the difference in opinions between the participants. The higher the value, the more participants do not agree in their opinions amongst themselves. The outcomes have been analyzed.

The first statements indicated if the stakeholders were intended to make use of the conclusions and recommendations of the research. Three out of four stakeholders answered with the opinion 'strongly agree'. This indicated that over the different departments the conclusions and recommendations can be used. The minimum value indicated 'agree'. Out of this, we concluded that the stakeholders were positive about the outcomes of the research

The average score of the second statement is a bit lower than the first one. Also the standard deviation of the answers is higher. This indicates that for the second statement, 'the research gave me a better insight in the processes of the logistics flows', the opinions differed. Two of the stakeholders were neutral to this question, due to the fact that they already had insights in the processes. This indicated that mapping the processes was a crucial part in order to execute the research, but for the stakeholders this was already known information. The other two stakeholders were strongly agree with the statements. One of them stated that due to the insights at the processes, it is now better to convince other employees of the potential costs when making certain decisions. This indicated that the insights might help when findings arguments to make a decision.

In the defined action problem it is stated that the logistics processes should be optimized. The third statements indicated how the research contributed to this. Three out of four stakeholders agreed with the statement 'the research will contribute in optimizing the logistics processes'. The last stakeholder strongly agreed. Out of these answers, it is concluded that from the performed research, the action problem can be solved. A critical note can be made from the feedback provided by one of the stakeholders. He stated that the ERP-system is a bottleneck for further improving the processes. As stated, improving the ERP-system is not taken into account in this research. It is concluded that this research is part of optimizing the processes in this case.

Not all stakeholders answered on the fourth statement, 'I intend to make use of the model where the total cost of ownership can be calculated'. This can be explained, since not all stakeholders are allowed to make strategic decisions about the stock materials. The average score out of this statement is 'agree', which indicates that the model will be used at the company. From the provided feedback, we can conclude that information sharing between the departments in important to make use of the model in an appropriate way. The moment decisions are based on the outcomes of the model, potential effects should be communicated between the departments, because of the expertise of the stakeholders.

One of the things that had to be taken into account the moment of performing the research, was the fact that the company will move to a new factory. The applicable factor of the research at the new factory is indicated with the fifth statement. The standard deviation out of the answers is low. This indicates that the stakeholders agreed to each other. The average answer of the statement is 4.24. From this, it is concluded that the research is applicable at the new factory.

The last statement measured the effectiveness of the research approach. Most of the stakeholders agreed on the fact the research approach was effective. Out of the feedback, it is once again noticed that the research did not take into account the optimization of the ERP-system. From this, it is concluded that this is a limitation of the research. Besides that, one of the stakeholders indicated that in the research multiple employees and departments are involved. This contributed to an effective approach.

To conclude, VDL Energy Systems wanted to identify the total cost of ownership of the stock materials and optimize the logistics processes by executing this research. It is expected that the conclusions and recommendations are useful for VES since all stakeholders agreed on the first statement. The conclusion can be made that the research is strongly accepted due to the fact that different departments and employees have been contributed in the research to get an complete overview. Therefore, support for the conclusions is found at different departments.

In general, the stakeholders concluded that the outcomes of the thesis will contribute to a further optimization of the logistics processes. Besides that, it is indicated that the model can be used as a decision-making tool when it comes to stock materials. The stakeholders were asked to given an answer to the statements between the range one to five. The average score of the statements is equal to 4.25, which represents an opinion between "agree" and "strongly agree". The average standard deviation close to zero means almost any variation in opinions between the participants. A value higher than one represents a strong deviation. The average standard deviation in this survey is 0.77. This means that on average there are no big variation between the opinions.

Table 22: Outcomes survey performed by four stakeholders at VDL Energy Systems

Statement	Min value	Max value	Average	Standard deviation
1	4	5	4,75	0,50
2	3	5	4	1,15
3	4	5	4,25	0,50
4	3	5	4	1
5	4	5	4,25	0,50
6	3	5	4,25	0,96
Average performance	3,5	5	4,25	0,77

7.5 Conclusion

In this chapter we discussed how the solution can be implemented and evaluated at VDL Energy Systems, taking the restrictions into consideration. We could conclude, that the need for implementation is addressed. The departments procurement, production control, logistics and production were mainly involved in the implementation phase. Out of literature review, we could conclude the focus points when it comes to the concept of vendor managed inventory. In this concept, the key lies in information sharing between the buyer and the supplier. The production control department can implement the solution by using the decision tree, stated in the model. The model can be used as a decisions supporting tool. For the logistics department, it is concluded that when more than 50 materials need to be picked, weighing can be used. At the production department, we concluded that by making use of a "bulk stock list" the TCO of the bulk stock materials can be reduced. It is concluded that in potential the model can be used at the new factory, taken into account the stated evaluation points. Out of the survey, it is concluded that the model will be used by the stakeholders. Moreover, it is said that the outcomes of the research will be used by the company.

8 Conclusions, recommendations and future research

Within this thesis, an activity-based costing method has been executed to identify the main processes at the procurement, production control, logistics and production department. Through analysing the processes and implementing the designed tool, suggestions were provided to optimize the logistics processes. Each chapter in this thesis was related to a research question, that was answered in the conclusions at the end of the chapters. All these conclusions have contributed to the goal of answering the main research question of the thesis. In this chapter, the main conclusions, recommendations and description of potential future research are described. The last research question which is discussed is as follows:

What recommendations and conclusions can be made from conducting the thesis at VDL Energy Systems?

The results of this thesis were presented at VES. The conclusions and recommendations are respectively given in Section 8.1 and 8.2. Section 8.4 outlines the limitations, simplifications and potential future research.

8.1 Conclusions

In this section, the main conclusions of this thesis are enumerated. We defined the total cost of ownership as the involved costs the moment the procurement department purchases a stock material, until the moment the material is used on the machine by the mechanic. The different logistics flows are identified by executing observation study and conducting interviews at VES' office, warehouse and production facility. Three logistics flows are identified and analyzed: General stock, bulk stock supplied by VDL warehouse and VMI. A value stream map has been made to map the major activities. The TCOs of the different flows are identified by time measurements. The stock materials are analyzed and categorized in four different groups. Out of literature review, the activity-based costing method is selected and executed at VES to describe the activities involved in the logistics flows. Based on the time measurements, formulas are stated to calculate the costs. A model is programmed to make decisions, based on costs, whether to outsource or not a bulk stock material. Research on the topic of VMI is done to create a better insight in the pros and cons of outsourcing. Based on the outcomes, a survey has been filled in by the involved stakeholders. To conclude, out of research the following main conclusions can be stated.

1. There are three logistics flows identified at VDL Energy Systems, considering PR, stock materials: general stock, bulk stock supplied by VDL warehouse and VMI. The flows and activities can be seen in the three business process models. To observe the major processes, the value stream map can be used.
2. The materials can be categorized in four different groups: quality, goods of length, exact quantity and bulk stock. The optimal logistics flow for the first three groups is the general stock. For the bulk stock, a decision can be made by making use of the designed model.
3. Comparing the three flows, when executing the bulk stock supplied by VDL warehouse, most activities need to be performed, which causes in most situation the highest TCO.
4. The general stock flow can be optimized. When more than 50 materials need to be picked, weighing would be less time consuming than counting.
5. When comparing the bulk stock supplied by VDL warehouse and VMI, assuming that the purchase price will be approximately the same, VMI will always result in lower TCO.
6. 59 current bulk stock supplied by VDL warehouse materials have been analyzed. The most advantages and saving can be made to outsource these materials when the VMI supplier's purchase price is between 0% and 10% higher than VES' own purchase price. In this case the savings will lie between €2400 and €3100 the moment these materials will be purchased again.
7. Using the model, the proportions of influences of the activities on the TCO of general stock can be determined.

8.2 Recommendations

Based on the performed research and stated conclusions, we set up a list with recommendations for VDL Energy Systems.

1. In order to calculate the TCOs of the different logistics flows, it is recommended to make use of the model explained in Chapter 6 and keep the data updated for future scenarios to make sure the model stays valid.

2. At warehouse activities, if more than 50 components need to be picked, it is recommended to weigh the components. The weighing scale should be wireless and placed on the pickcar to be used as efficient as possible.

3. If new materials will be used, it is suggested to categorize these materials in one of the four defined material groups, to make use of the designed model.

4. For the bulk stock supplied by VDL warehouse, it is suggested to minimize the use of this logistics flow. From the three logistics flows, at this flow most activities are involved. With the model, the exact break-even points can be calculated. We advise, when bulk stock supplied by VDL warehouse is more beneficial compared to VMI, but close to break-even, to make use of VMI. Significant more activities need to be performed when choosing bulk stock supplied by VDL warehouse, which increases the risk of delay and failures. We only advise to make use of bulk stock supplied by VDL warehouse in the following situation:
   - No single VMI supplier can supply a specific material.
   - By using the model, it will turn out that the TCO of bulk stock supplied by VDL warehouse is significant less than the one from VMI. This because of the high purchase price of the VMI supplier.
   - As temporary solution. For example, when contract agreements will be made with the VMI supplier, and the materials are yet not supplied.

5. When one of the above bullet points situations occurs, it is suggested to set the bin-size equal to the full package quantity. This to decrease picking times in the warehouse and reduce the TCO of the bulk stock supplied by VDL warehouse.

6. Due to the fact that in most situations it is more beneficial to make use of VMI instead of the bulk stock supplied by VDL warehouse, we suggest to search for a second or even multiple VMI suppliers in the future. By doing this, more materials can be transferred to VMI.

7. When searching for a new VMI supplier, we suggest to focus on information sharing and evaluation. It has been proven that VMI can be more successful when companies focus on these points. One evaluation per quarter with the supplier can for example be a good starting point. Besides that, we suggest to make use of the VMI contracts within the 'VDL groep' and learn from other VDL companies how to deal with the concept of VMI.

8. When materials will be transferred from general stock to bulk stock for several reasons, the need of information sharing is important. Moving materials will have consequences for the mechanics. Therefore, we suggest to provide the mechanics a "bulk stock list". On this list all the materials which are placed as bulk stock for a specific project are noticed. By doing this, the mechanics knows which materials they have to collect by themselves.

9. For the new factory, we advise to design a flexible system for the bulk stock location. If more and different materials will be placed as bulk stock, a standard procedure should be used, where easily bins can be added in the storage rack without causing problems.

10. If it will be chosen to make use of bulk stock supplied by VDL warehouse in one of the stated situation, we suggest to have a better look on the specific activities that need to be performed in VBS. Out of the measurements, it turned out that most of process times is caused by VBS activities. We suggest trying to optimize this by cooperation within the organization, production control and finance department.

11. We advise transparent information sharing between the departments procurement, production control, logistics and production to keep optimizing the processes and minimize waste.

8.3 Contribution

In this section, the theoretical and practical contribution of the research is described.

Theoretical contribution
In this research literature study is performed on the topics of logistics process mapping, cost accounting and vendor managed inventory. A value stream map has been made to map the logistics processes. This concept has already been stated by Rother and Shook (2003). The theoretical contribution of this research lies more in the field of cost accounting. The activity-based costing method has been performed in a logistics environment. Moreover, activities are identified at multiple departments, such as procurement, production control, logistics and production. (Gríful-Miquela, 2001) and (Xiao et al., 2009) already described that the ABC method is applicable in a logistics environment. We have proven that this is indeed possible. Moreover, a literature

contribution is made as we now can make strategic decisions about costs, based on the ABC analysis. Besides that, Everaert et al. (2008) described how cost modeling in logistics can be done using time-driven ABC when having multiple cost drivers. We performed the ABC method, by using time measurements, in a single driver environment. We have proven to successfully implement this time measurements method using the ABC analysis.

Practical contribution
This research is performed at VDL Energy Systems. The practical contribution to the company is the model described in Chapter 6. By using the model as a decision supporting tool, the company can make practical decisions based on the performed research. Besides that, we have proven that we transferred the theoretical insights out of the ABC analysis into a practical decision tool which can be used in the field.

8.4 Future research

This bachelor thesis has been executed in a scope of ten weeks. Extensive research was therefore not possible. Moreover the research is executed during the COVID-19 pandemic and the Brexit, which might causes some invalid time measurements. In this section limitations about the research are discussed and possible future research is described.

- This thesis focused on the logistics flows of product-related stock materials. Future research can be done to investigate what the optimal logistics flow will be for non product-related materials.
- The primary focus of this research is on identifying the total cost of ownership of stock materials and optimizing the logistics flows. Recommendations are made to increase the level of VMI materials. This will have consequences for VES and the agreement that has been made with the VMI supplier. Further research can be done in the field of VMI connected to the procurement department. What will be the best strategy when it comes to negotiating with suppliers and information sharing.
- In this thesis, four material groups are defined. One of the groups is "goods of length". Due to the fact that the research contained ten weeks, we were not able to do extensive research within this group. Research can be done in the future, how to deal with this group and to optimize the processes.
- During the research, a lot of activities need to be executed by using the ERP-system. The system was sometimes a bottleneck in the process. Because of the complexity, we did not focus on solving these issues. Future research can be done in optimizing the ERP-system.

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A Value stream map

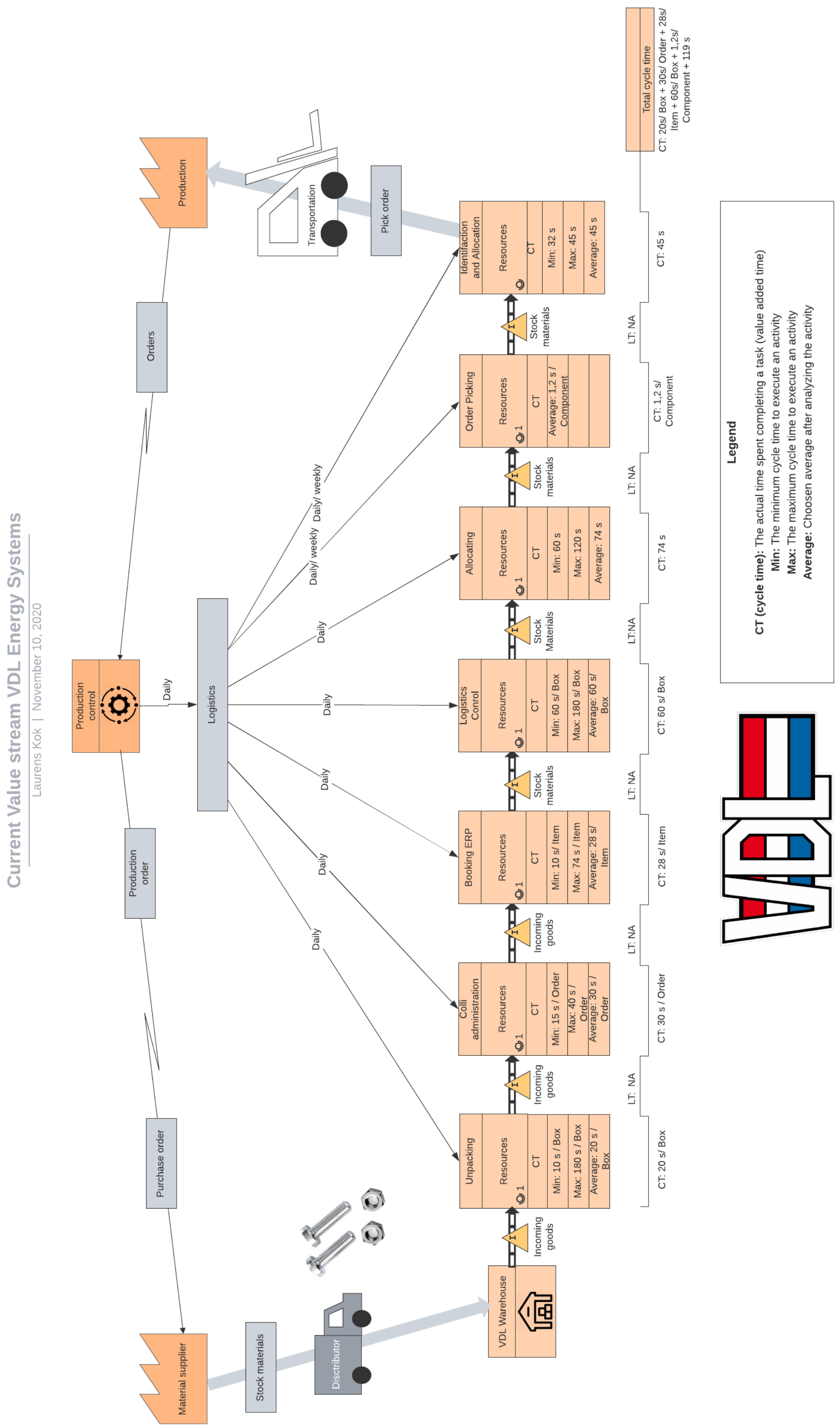


Figure 18: Value stream map of the general stock at VDL Energy Systems

B Picking times observation

Quantity				5,00	20,00	50,00	75,00	100,00	150,00
Material Number	**Material description**	**package quantity**	**time full package**	**Time #5**	**Time #20**	**Time #50**	**Time#75**	**Time #100**	**Time #150**
3000521,00	Cable lug klauke dynamic - DYN166	100,00	14,00	4,00	20,00	44,00	70,00	103,00	
3000513,00	Plakzadel 19mm	100,00	12,00	3,00	20,00	46,00	75,00		
231622010,00	Washer M10 zinc plated	200,00	17,00	6,00	20,00	45,00	64,00	88,00	134,00
117708060,00	Hexagon Head screw	200,00	10,00	5,00	15,00	43,00	66,00	90,00	
64/07010075/32	Locknut Brass NP 20MM			4,00	20,00	44,00	66,00	87,00	132,00
3000746,00	Spacer ext./ext. Thread	100,00		7,00	21,00	56,00			
115508040,00	Bolt M8 X 40 zinc plated	400,00	15,00	5,00	21,00	48,00	69,00	87,00	135,00
211166010,00	Nut M10 Zinc plated	500,00		5,00	16,00	47,00	69,00	92,00	131,00
64/07211012/5	Gland	20,00		10,00	32,00				
Average			13,60	5,44	20,56	46,63	68,43	91,17	133,00
Average per piece				1,09	1,03	0,93	0,91	0,91	0,89
Min picktime per piece	0,89								
Max picktime per piece	1,09								
Total average picktime per piece	0,96								
General stock pick data calculation					**Bulk stock pick data calculation**				
	Average	Min	Max			Average	Min	Max	
Picking time	9,60	8,87	10,89		Picking time	96,00	88,67	108,89	
if PQ = FPQ	14,00	14,00	14,00		if bin size = FPQ	14,00	14,00	14,00	
if PQ =/ FPQ	0,96	0,89	1,09		if bin size =/ FPQ	0,96	0,89	1,09	
Picking time									

Figure 19: Picking times observation study

Material Number	Material description	package quantity	time full package	Time #5	Time #20	Time #50	Time#75	Time #100	Time #150
231622010	washer M10 zinc plated - H0.3 x V			22	37	36	40	38	58
11708060	Hexagon head screw - M8 x 60			20	24	33			
	Washer M10 zinc plated - H0.2 x V			23	30	33	26	30	28
	Nut M10- H0.8 x W1.7 x L1.9			19	22	26			
	Average			21	28,25	32	33	34	43
	Time per piece (s)			4,20	1,41	0,64	0,44	0,34	0,29

Figure 20: Weighing times observations

C Evaluation of thesis results at VDL Energy Systems

In this section, the evaluation of the results are given. An survey has been made and filled in by four involved stakeholders of the following departments:

- Production control; The involved employee at the production control department (PC)
- Logistics: The head of the logistics (HoL) and logistics warehouse coordinator (LWC)
- Production: Team leader of the production facility (TLP)

Survey
The aim of this survey is to get feedback on the conclusions and recommendations provided to VDL Energy Systems. The feedback is based on the research and given presentations to the stakeholders. Answers are given in a range from 1 to 5 according to the following definitions:

1 = Strongly disagree
2 = Disagree
3 = Neutral
4 = Agree
5= Strongly agree

The results are combined and average scores are calculated.

Statement 1
I intend to make use of the conclusions and recommendations of the research.

Answer: 4,75

Additional feedback: The TLP stated that when using the conclusions and recommendations will create standard logistics flows where less and less input will be necessary out of the production department.

Statement 2
The research gave me a better insight in the processes of the logistics flows.

Answer: 4

Additional feedback: The TLP stated that he had already insight in the processes. Besides that, the PC stated that his suspicion is confirmed and that the results of the thesis will make it easier to convince colleagues of the non-value added activities and involved costs. Emotions will be changed into facts.

Statement 3
The research will contribute in optimizing the logistics processes.

Answer: 4,25

Additional feedback: The TLP stated that eliminating activities will probably create a higher turnover rate of the materials, which creates less waiting times at the production facility. The HoL stated that the ERP-system has to much influence on it.

Statement 4
I intend to make use of the model where the total cost of ownership can be calculated (If this is applicable at your function)

Answer: 4

Additional feedback: The TLP stated that it is necessary that the production department will help in an active way, but they will not use the model by itself.

Statement 5
The conclusions and recommendations can be applied at the new factory

Answer: 4,25

Additional feedback: The HoL stated that the optimization of the floor plan in the new factory will also contribute. Besides that, the TLP stated that it can be applied in the factory for sure. The bulk stock will now be designed, such that it can be moved to the new factory at once.

Statement 6

The approach of the research was efficient in order to achieve the goal (Identification of the total cost of ownership of the stock materials and optimize the logistics processes)

Answer: 4,2

Additional feedback: The PC stated that maybe it could be more efficient, but that is hard to judge.

General feedback

PC: During the research, a lot of interest has been showed in conversation with employees and in mapping the processes. Due to the fact of making notes, asking questions, and observation study with help of the stakeholders, a lot of employees are involved in the research. A result of that is support. A well and applicable calculation model has been made. Conclusions and recommendations are presented in a clear way.

LWC: The research is well done, I agree with all the statements.

HoL: As explained, the not optimal functionality of the ERP-system is a bottleneck for the real optimization. This model can bring a solution for the production control department, but it should be taken into account that the model can be a tool in the decision-making process.

TLP: In the research, a lot of employees are involved of different levels and departments. Also, different interests are taken into account. This has been investigate in an objective way and the results can be applied for the team leaders at the operations department.

D Manual designed model

Introduction
Dear reader, in this Chapter, a manual in order to use the designed model in an appropriate way is given. The model is designed using *Microsoft Excel* and programmed making use of *Visual basic applications*. The different sheets and their functions are described in this manual respectively to the order in the designed model.

Overview
The model starts with the 'overview' sheet. In this sheet, the model is introduced. In the model, the following sheets can be found.

- TCO calculations
- Bulk stock vs VMI
- TCO general stock
- Archive
- Process general stock
- Process bulk stock VDL
- Process VMI
- Picking data
- Weighing data
- Assumptions

In the overview page, the variables used in the model are introduced. In Table 23, the variables and their descriptions used in the model are presented. All the calculations are based on the wage of the employees. This value is defined in the overview sheet. If the user changes this value, the entire model will adapt this change. No additional programming is needed.

Table 23: Variables used in the model

Variable	Description
Pr/unit	Purchase price per unit; e.g., €0,10/piece
Pr/unit (VMI supplier)	Purchase price per unit stated by the VMI supplier; e.g., €0,12/piece
Purchase quantity	The amount of materials purchased at once; e.g., 600 bolts
Full package quantity	The amount of materials within a full package; e.g., 200 bolts per package
Bin size 2-bin	The amount of materials using the two bin system of the bulk stock supplied by VDL warehouse
Est. "Grap quantity"	Estimation of the amount of materials mechanic will collect when using bulk stock; e.g., 20 rings
TCO GS	Total cost of ownership of the general stock
TCO Bulk	Total cost of ownership of the bulk stock supplied by VDL warehouse
TCO VMI	Total cost of ownership of the VMI
Expected order freq-year	The expected order frequency of the material per year; e.g., 4 times per year a box of 200 bolts M10
Total savings per year	Total savings per year for the material in case it will be outsourced. If this value is negative, savings can be made when the material will not be outsourced
Delta	The difference between the TCO bulk stock and TCO VMI
Increasement VMI	Percentage that the VMI purchase can increase in order to break-even the TCO bulk stock and TCO VMI
Break-even point VMI	Purchase price of VMI supplier to break-even the TCO bulk stock and TCO VMI

TCO calculations
The first calculation sheet in the model is the sheet in which the TCO of all the three logistics flows can be calculated at once. In this sheet input data is needed. In Table 24, the variables used within this sheet is presented. Moreover, the restrictions for each of the variables are described in the table. Three buttons are created in the sheet and can be used by the user.

- 'Calculate TCO'
  The first button that can be used in the sheet is the button 'Calculate TCO'. By executing this button, the TCO of the general stock, bulk stock supplied by VDL warehouse and VMI will be calculated using the following formulas.

$$TCO_{general\ stock} = PP + \frac{Wage}{3600} \cdot \left(\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Picking}{Picking\ quantity}\right)$$

$$TCO_{bulk\ stock\ VDL} = PP + \frac{Wage}{3600} \cdot \left(\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Administrate + Picking_{Bulkstock}}{Bin\ size} + \frac{Runner}{Bin\ size \cdot Bins} + \frac{Production}{MM}\right)$$

$$TCO_{VMI} = PP_{vmi} \cdot \left(1 + \frac{S_{vmi}}{100}\right) + \frac{Wage}{3600} \cdot \left(\frac{Production}{MM}\right)$$

- 'Calculate TCO in case mechanics collect VMI materials beforehand'
  The second button is the button 'Calculate TCO in case mechanics collect VMI materials beforehand'. When executing this button, the model will use other formulas than used when executing the first button. This button is interesting when the user wants to know what the effect on the TCOs will be the moment mechanics will collect the bulk stock materials at once to reduce walking times. The model will use the following formulas to calculate the TCOs. As can be seen, the fraction $\frac{Production}{MM}$ has been left out in the bulk stock formulas.

$$TCO_{general\ stock} = PP + \frac{Wage}{3600} \cdot \left(\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Picking}{Picking\ quantity}\right)$$

$$TCO_{bulk\ stock\ VDL} = PP + \frac{Wage}{3600} \cdot \left(\frac{Incoming\ goods + Logistics\ check + Procurement}{Purchase\ quantity} + \frac{Administrate + Picking_{Bulkstock}}{Bin\ size}\right)$$

$$TCO_{VMI} = PP_{vmi} \cdot \left(1 + \frac{S_{vmi}}{100}\right)$$

- 'Clear data'
  The last button is named 'Clear data'. When executing this button, the input data will be deleted; the user can start again with a clean sheet.

Table 24: Variables and their restriction to calculate the TCOs

Variable	Restriction
Material number	Key element
Material description	-
Dimension	-
Unit (stock)	Piece
Pr/ Unit	Greater than zero
Pr/ unit (VMI Supplier)	Greater than zero
Purchase quantity	Greater than zero
Full package quantity	Greater than zero
Picking quantity	Greater than zero
Bin size 2-bin	Greater than zero
Est. "Grab quantity"	Greater than zero

Bulk stock vs VMI

The third sheet provides answers when the user wants to know whether bulk stock should be outsources or not. If outsourcing is considered, this is called vendor managed inventory (VMI). In Table 25 the input variables and their restrictions are presented which have to be used when making the calculations.

Table 25: Variables and their restriction to calculate the TCO of the bulk stock supplied by VDL warehouse and TCO VMI

Variable	Restriction
Material number	Key element
Material description	-
Dimension	-
Unit (stock)	Piece
Pr/ Unit	Greater than zero
Pr/ unit (VMI Supplier)	Greater than zero
Purchase quantity	Greater than zero
Full package quantity	Greater than zero
Bin size 2-bin	Greater than zero
Expected order freq/ year	Greater than zero

The model will present the following output data.

- TCO bulk stock
- TCO VMI
- Delta
- Increasement VMI
- Break-even point VMI
- Total savings per year

Besides these output data, the model will also present two additional output parameters, based on all the materials which have been used in the calculations. These two parameters are defined as follow.

- Savings per year; the total savings per year for all the materials. In case this value is positive, values can be made to the moment all the materials will be outsourced. In case this value is negative, savings can be made the moment the materials will not be outsourced.
- Average increasement VMI; the average increasement that the VMI purchase price can have to break-even the TCO of the bulk stock supplied by VDL warehouse.

Two buttons are placed in the sheet. The first button, named 'calculate' will execute the calculations, using the defined formulas. The second button, termed 'Clear data and save it in Archive'. By executing this button, the data will be delete and saved in a separate sheet, named ´Archive´.

TCO general stock

In the fourth sheet, 'TCO general stock', the total cost of ownership of the general stock can be calculated. Table 26 provides an overview of the variables used in the model and their restrictions.

Table 26: Variables and their restriction to calculate the TCO of the general stock

Variable	Restriction
Material number	Key element
Material description	-
Dimension	-
Unit (stock)	Piece
Pr/ Unit	Greater than zero
Purchase quantity	Greater than zero
Full package quantity	Greater than zero
Picking quantity	Greater than zero

When executing the calculation, the model will present the following output data.

- Procurement %; the proportion of influence on the TCO of the procurement department.
- Incoming goods %; the proportion of influence on the TCO of the incoming goods.
- Logistics check %; the proportion of influence on the TCO of the logistics check.
- Picking %; the proportion of influence on the TCO of the picking process in the warehouse.
- Pr/unit %; the proportion of influence on the TCO of the price per unit

Archive
In the Archive sheet, the calculation data out of the sheet 'Bulk stock vs VMI' is stored. The calculations can be found and the date on which the calculations have been executed.

Process general stock
Calculations are based on time measurements. The time to execute an activity has been measured by observation study in the warehouse and production facility. In the sheet 'Process general stock', the data of the activity-based costing analysis of the general stock can be found. For each of the departments, the time measurements are shown. The model uses the subtotals of the time measurements to execute the formulas. To be more specific, the model uses the weighted average times. The user can change these values when changes are done in the warehouse for example. By doing this, the model will automatically uses the new values. Therefore, this model can be used when the time measurements are changed.

Process bulk stock VDL
In the sheet 'Process bulk stock VDL', the activity-based costing analysis of the bulk stock supplied by VDL warehouse can be seen. The explanation is the same as for the general stock.

Process VMI
In the sheet 'Process VMI', the activity-based costing analysis of the vendor managed inventory can be seen. The explanation is the same as for the general stock.

Picking data
In the sheet 'Picking data', the observation study of the picking data can be seen. Research has been done in the warehouse to indicate the picking times at the picking process. The model uses the total average picktime per piece, as can be seen in the sheet. In case the picking quantity is equal to the full package quantity, the picking time is 14 seconds. The user can change this. By doing this, the model can will automatically use the new value.

Weighing data
In the sheet 'Weighing data', the observation study of the weighing data can be seen. Research has been done in the warehouse to indicate the moment weighing would be better than counting. This is when more than 50 materials need to be picked.

Coding
The model has been programmed using *Visual basic applications.* Within one module, seven 'subs' have been made in which the programming is stated. Within each sub, a short explanation is given about the context of the programming. For each of the variables, a description is given in pseudo code.

E Solution model

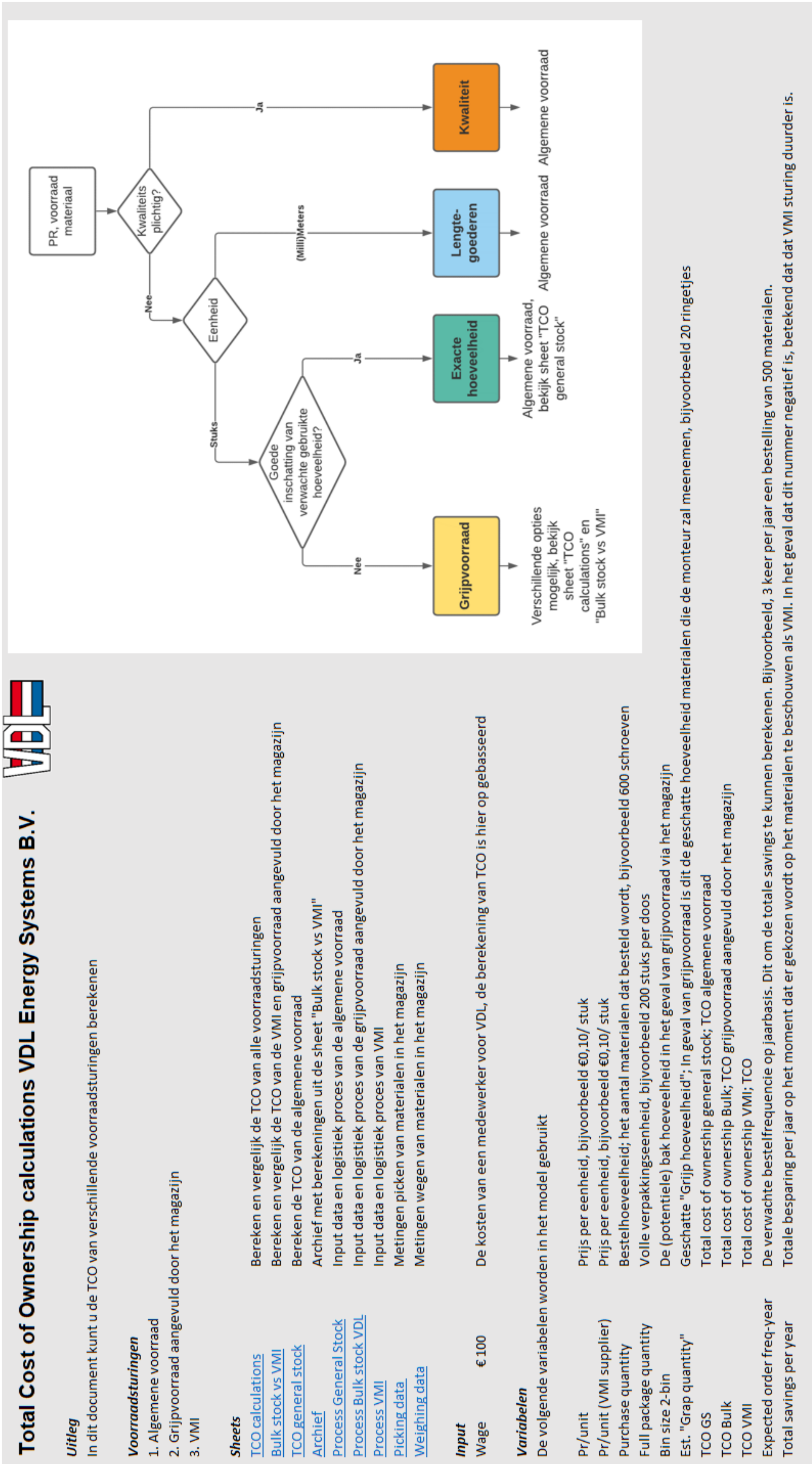
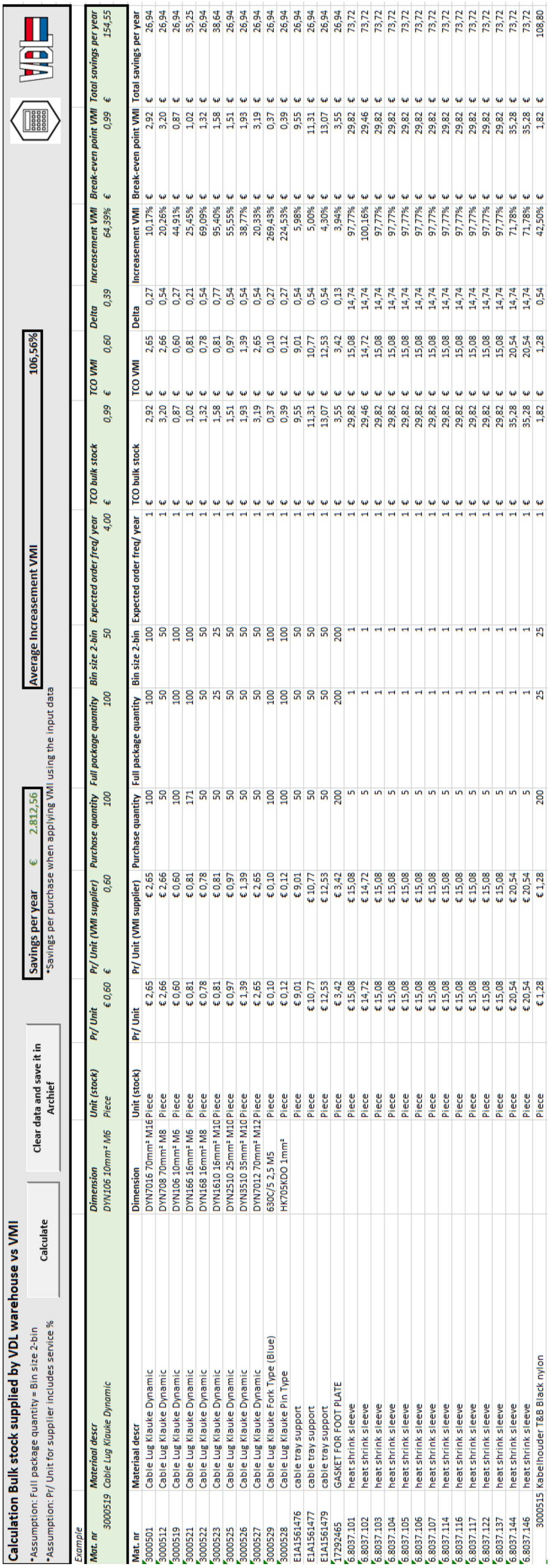


Figure 21: Overview page of the model consisting out of dutch explanation



Calculation Bulk stock supplied by VDL warehouse vs VMI

*Assumption: Full package quantity = Bin size 2-bin
*Assumption: Pr/ Unit for supplier includes service %

Calculate | Clear data and save it in Archief

Savings per year € 2.812,56
*Savings per purchase when applying VMI using the input data

Average Increasement VMI 106,56%

Example

Mat. nr	*Materiaal descr*	*Dimension*	*Unit (stock)*	*Pr/ Unit*	*Pr/ Unit (VMI supplier)*	*Purchase quantity*	*Full package quantity*	*Bin size 2-bin*	*Expected order freq/ year*	*TCO bulk stock*	*TCO VMI*	*Delta*	*Increasement VMI*	*Break-even point VMI*	*Total savings per year*
3000519	*Cable Lug Klauke Dynamic*	*DYN106 10mm² M6*	*Piece*	*€ 0,60*	*€ 0,60*	*100*	*100*	*50*	*4,00*	*€ 0,99*	*€ 0,60*	*0,39*	*64,39%*	*€ 0,99*	*€ 154,55*

Mat. nr	Materiaal descr	Dimension	Unit (stock)	Pr/ Unit	Pr/ Unit (VMI supplier)	Purchase quantity	Full package quantity	Bin size 2-bin	Expected order freq/ year	TCO bulk stock	TCO VMI	Delta	Increasement VMI	Break-even point VMI	Total savings per year
3000501	Cable Lug Klauke Dynamic	DYN7016 70mm² M16	Piece	€ 2,65	€ 2,65	100	100	100	1	€ 2,92	€ 2,65	0,27	10,17%	€ 2,92	€ 26,94
3000512	Cable Lug Klauke Dynamic	DYN708 70mm² M8	Piece	€ 2,66	€ 2,66	50	50	50	1	€ 3,20	€ 2,66	0,54	20,26%	€ 3,20	€ 26,94
3000519	Cable Lug Klauke Dynamic	DYN106 10mm² M6	Piece	€ 0,60	€ 0,60	100	100	100	1	€ 0,87	€ 0,60	0,27	44,91%	€ 0,87	€ 26,94
3000521	Cable Lug Klauke Dynamic	DYN166 16mm² M6	Piece	€ 0,81	€ 0,81	171	100	100	1	€ 1,02	€ 0,81	0,21	25,45%	€ 1,02	€ 35,25
3000522	Cable Lug Klauke Dynamic	DYN168 16mm² M8	Piece	€ 0,78	€ 0,78	50	50	50	1	€ 1,32	€ 0,78	0,54	69,09%	€ 1,32	€ 26,94
3000523	Cable Lug Klauke Dynamic	DYN1610 16mm² M10	Piece	€ 0,81	€ 0,81	50	25	25	1	€ 1,58	€ 0,81	0,77	95,40%	€ 1,58	€ 38,64
3000525	Cable Lug Klauke Dynamic	DYN2510 25mm² M10	Piece	€ 0,97	€ 0,97	50	50	50	1	€ 1,51	€ 0,97	0,54	55,55%	€ 1,51	€ 26,94
3000526	Cable Lug Klauke Dynamic	DYN3510 35mm² M10	Piece	€ 1,39	€ 1,39	50	50	50	1	€ 1,93	€ 1,39	0,54	38,77%	€ 1,93	€ 26,94
3000527	Cable Lug Klauke Dynamic	DYN7012 70mm² M12	Piece	€ 2,65	€ 2,65	50	50	50	1	€ 3,19	€ 2,65	0,54	20,33%	€ 3,19	€ 26,94
3000529	Cable Lug Klauke Fork Type (Blue)	630C/5 2,5 M5	Piece	€ 0,10	€ 0,10	100	100	100	1	€ 0,37	€ 0,10	0,27	269,43%	€ 0,37	€ 26,94
3000528	Cable Lug Klauke Pin Type	HK705KDO 1mm²	Piece	€ 0,12	€ 0,12	100	100	100	1	€ 0,39	€ 0,12	0,27	224,53%	€ 0,39	€ 26,94
E1A1561476	cable tray support		Piece	€ 9,01	€ 9,01	50	50	50	1	€ 9,55	€ 9,01	0,54	5,98%	€ 9,55	€ 26,94
E1A1561477	cable tray support		Piece	€ 10,77	€ 10,77	50	50	50	1	€ 11,31	€ 10,77	0,54	5,00%	€ 11,31	€ 26,94
E1A1561479	cable tray support		Piece	€ 12,53	€ 12,53	50	50	50	1	€ 13,07	€ 12,53	0,54	4,30%	€ 13,07	€ 26,94
17292465	GASKET FOR FOOT PLATE		Piece	€ 3,42	€ 3,42	200	200	200	1	€ 3,55	€ 3,42	0,13	3,94%	€ 3,55	€ 26,94
6.8037.101	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.102	heat shrink sleeve		Piece	€ 14,72	€ 14,72	5	1	1	1	€ 29,46	€ 14,72	14,74	100,16%	€ 29,46	€ 73,72
6.8037.103	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.104	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.105	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.106	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.107	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.114	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.116	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.117	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.122	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.137	heat shrink sleeve		Piece	€ 15,08	€ 15,08	5	1	1	1	€ 29,82	€ 15,08	14,74	97,77%	€ 29,82	€ 73,72
6.8037.144	heat shrink sleeve		Piece	€ 20,54	€ 20,54	5	1	1	1	€ 35,28	€ 20,54	14,74	71,78%	€ 35,28	€ 73,72
6.8037.146	heat shrink sleeve		Piece	€ 20,54	€ 20,54	5	1	1	1	€ 35,28	€ 20,54	14,74	71,78%	€ 35,28	€ 73,72
3000515	Kabelhouder T&B Black nylon		Piece	€ 1,28	€ 1,28	200	25	25	1	€ 1,82	€ 1,28	0,54	42,50%	€ 1,82	€ 108,80

Figure 22: Example of calculations in the bulk stock vs VMI sheet

Calculations TCO stock materials

Calculate TCO | Calculate TCO in case mechanics will collect VMI materials beforehand | Clear data

Example

Mat. nr	Materiaal descr	Dimension	Unit (stock)	Pr/ Unit	Pr/ Unit (VMI supplier)	Purchase quantity	Full package quantity	Picking quantity	Bin size 2-bin	Est. "grab quantity"	TCO GS	TCO Bulk	TCO VMI
3000519	Cable Lug Klauke Dynamic	*DYN106 10mm² M6*	Piece	€ 0,60	€ 0,60	100	100	20	50	20			

Mat. nr	Materiaal descr	Dimension	Unit (stock)	Pr/ Unit	Pr/ Unit (VMI supplier)	Purchase quantity	Full package quantity	Picking quantity	Bin size 2-bin	Est. "grab quantity"	TCO GS	TCO Bulk	TCO VMI

Figure 23: Sheet in which the TCO of the different flows can be calculated

Calculations TCO stock materials

*In case of Picking quantity > 50; weighing will be used
*Therefore, Picking will not longer be than 1 minute

Calculate TCO | Clear data

Example

Mat. nr	*Material descr*	*Dimension*	*Unit (stock)*	*Pr/ Unit*	*Purchase quantity*	*Full package quantity*	*Picking quantity*	*TCO GS*	*Procurement%*	*Incoming goods%*	*Logistics check%*	*Picking%*	*Pr/Unit%*
64/07010075/132	*Stopping plug*	*M20*	*Piece*	*€ 3,76*	*20*	*20*	*3*	€ 5,03	7,23%	3,26%	4,67%	10,11%	74,73%

Mat. nr	Material descr	Dimension	Unit (stock)	Pr/ Unit	Purchase quantity	Full package quantity	Picking quantity	TCO GS	Procurement%	Incoming goods%	Logistics check%	Picking%	Pr/Unit%

Figure 24: Sheet in which the TCO of the general stock can be calculated

Data ABC-analysis General Stock

Department	Activity	Desciption	Weighted average	Min Time	Max Time	Dependent factor	Cost driver
Procurement	Purchasing	Purchase of the materials	262	191	360	Amount of orders	
Incoming goods	Unpackaging	Unpack the incoming goods	20	10	180	How packaged	#packages; #purchase quantity
	Administration	Administrate in Colli	30	15	40	System	#packages lists
	Stick stickers	Put stickers and label on package	10	10	10	System	#packages
	Booking	Book material in VBS	28	10	74	Speed VBS	#packages lists
	Scanning and printing	Scan packing list	10	10	10	Distance to printer	#packages lists
	Allocation	Allocate package in quality rack	20	10	60	Distance to rack	#packages
Subtotal			118	65	374		
Logistics check	Collecting	Take material out of quality rack	20	10	60	Distance to rack	#Packages
	Unpackaging and checking	Check if quantity is right	60	60	180	How packaged	#packages; #purchase quantity
	Packing	Pack material in desired package	15	10	60	How should be packag	#packages; #purchase quantity
	Transportation and allocati	Put material on trolley and transport it to location + allocate	74	60	120	Distance to location	#purchase quantity
Subtotal			169	140	420		
Picking	Scanning	Scan the location and material	9	8	10	Speed scanner	#distance to scan location
	Picking	Pick the material	0,959980159	0,88667	1,088889	Type of picking method	#materials to be picked
	Identification	Change stock level and write handmate label to put on box	30	27	30	Availability of resource	#materials to be picked
	Allocation	Allocate material in container to be able to transport	15	15	15	Distance to container	#materials to be picked
Subtotal			54,95998016	50,8867	56,08889		
Total			*341,9599802*	*255,887*	*850,089*		

Figure 25: Process overview general stock in solution model

Data ABC-analysis Bulk stock supplied by VDL warehouse

Department	Activity	Desciption	Weighted average	Min Time	Max Time	Dependent factor	Cost driver
Procurement	Purchasing	Purchase of the materials	262	191	360	Amount of orders	
Incoming goods	Unpackaging	Unpack the incoming goods	20	10	180	How packaged	#packages; #purchase quant
	Administration	Administrate in Colli	30	15	40	System	#packages lists
	Stick stickers	Put stickers and label on package	10	10	10	System	#packages
	Booking	Book material in VBS	28	10	74	Speed VBS	#packages lists
	Scanning and printing	Scan packing list	10	10	10	Distance to printer	#packages lists
	Allocation	Allocate package in quality rack	20	10	60	Distance to rack	#packages
Subtotal			118	65	374		
Logistics check	Collecting	Take material out of quality rack	20	10	60	Distance to rack	#Packages
	Unpackaging and checking	Check if quantity is right	60	60	180	How packaged	#packages; #purchase quant
	Packing	Pack material in desired package	15	10	60	How should be packaged	#packages; #purchase quant
	Transportation and allocati	Put material on trolley and transport it to location + allocate	74	60	120	Distance to location	#purchase quantity
Subtotal			169	140	420		
Runner	Transportation	Employer takes empty box and walks to warehouse	60	60	60	Distance to warehouse from bulk stock location	#bins to fill
	Booking	Runner/logistics employer books material	60	60	60	System VBS	#Materials needed
	Mail sending	Runner/logistics employer sends mail to production control	60	60	60	System Mail	#Materials needed
	Walking	Runner/logistics employer walks to pick location and takes r	35	30	40	Distance to picklocation and resources	#Materials needed; Bins to f
	Picking	Pick the material	0,959980159	0,886667	1,088889	Type of picking method	#materials to be picked
	Transportation	Walking back from location to production	85	80	90	Distance from warehouse to	#Materials needed; Bins to fill
Subtotal			300,96	290,89	311,09		
Production contro	VBS Production control	Production control change stock levels	300	200	400	System VBS	#Materials needed; Bins to fill
Production	Walking	Mechanic walks to VMI materials	50	10	90	Distance to VMI location	#Materials needed by mechar
	Searching	Mechnic search for right material	30	10	120	Location of bin in rack	#Materials needed by mechar
	Picking	Pick the material	15	5	20	Size of material	#Materials needed by mechar
	Walking	Mechanic walks back to machine	50	10	90	Distance back to workpla	#Materials needed by mechar
Subtotal			145	35	320		
Total			732,96	530,89	1425,09		

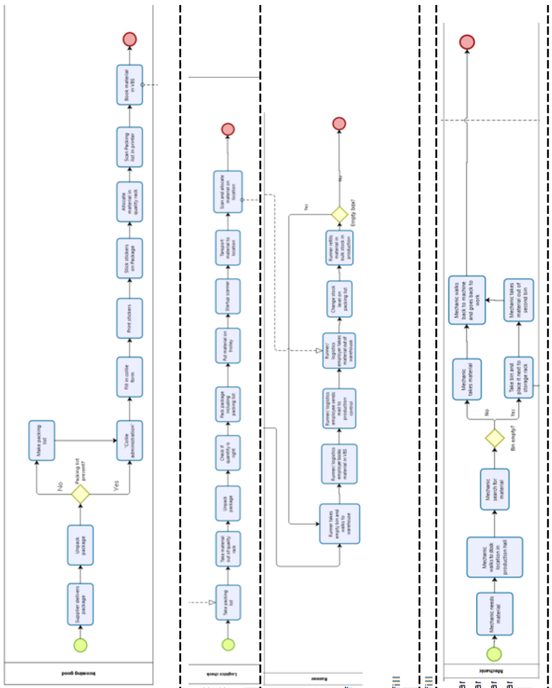


Figure 26: Process overview bulk stock supplied by VDL warehouse in solution model

Data ABC-analysis VMI

Department	Activity	Description	Weighted average	Min Time	Max Time	Dependent factor	Cost driver
Production	Transport	Mechanic walks to VMI material	50	10	90	Distance to VMI location	#Materials needed by mechanic
	Searching	Mechnic search for right materia	30	10	120	Location of bin in rack	#Materials needed by mechanic
	Picking	Pick the material	15	5	20	Size of material	#Materials needed by mechanic
	Transport	Mechanic walks back to machine	50	10	90	Distance back to workplace	#Materials needed by mechanic
Total			145	35	320		

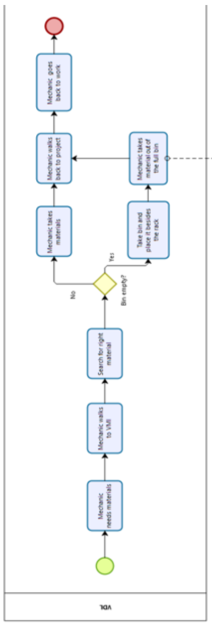


Figure 27: Process overview VMI in solution model