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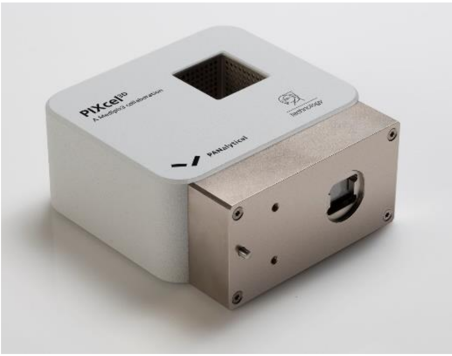
Analysing the supply chain of high-tech detectors based on activity-based costing



Malvern Panalytical

UNIVERSITY OF TWENTE.

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Preface

The report that lays in front of you is the final version of my bachelor thesis on analysing the supply chain of high-tech detectors based on activity-based costing. The host company, Malvern Panalytical, allowed me to do my research during the first half of the study year 2019-2020. This report concludes my bachelor studies Industrial Engineering and Management at the University of Twente.

At the start of my research, I was welcomed with open arms by the staff at Malvern Panalytical. The colleagues were very interested in my research and were always willing to help me. The relaxed working atmosphere and openness have ensured that I enjoyed my time at Malvern Panalytical. I want to thank all employees who helped me during my research.

I would like to take the opportunity to thank Luc Hendriks in particular. Luc Hendriks was my supervisor from Malvern Panalytical, thank you for all your guidance and feedback. During my research you have always helped me closely with obtaining and processing information. In addition, you have always set me free in my own schedule, which I really enjoyed.

Of course, I also want to thank my supervisors from the University of Twente, Wouter van Heeswijk and Ipek Seyran Topan for the guidance during my research.

Finally, I would like to thank my friends and family for supporting me throughout this journey. I hope the final report is worth the read.

With kind regards,

Martijn Ma

09-02-2020

Management summary

Introduction

Malvern Panalytical (MP) is a leader in the materials characterization market and is active in different end markets. MP's X-ray technologies are designed to obtain high quality diffraction data. Together with extensive industry knowledge and technical- and applications expertise, MP's instruments are designed to help users better understand a wide variety of materials.

This research is focused on a component of the x-ray devices from MP, called a detector. There are three different detectors in production: Product X, Product Y and Product Z. A high-tech detector is one of the most important components of these x-ray devices. Such a device works as follows: An x-ray tube radiates x-ray on the sample that is being analysed. The radiation is reflected from the sample and received by the high-tech detector in the angle of reflection. The received radiation is translated to information about the characteristics of the sample by the detector. This information is as output of the detector received by a computer, where the user can see the characteristics of the material. The technology behind many parts of the detectors require high-cost equipment and specialized knowledge in combination with low demand. Therefore, it is too expensive for MP to research / buy all technology themselves. This also applies to many supply partners in the world. This means that many parts can only be manufactured by a few or even only one company in the world. The detectors therefore have a global supply chain.

Problem description

The set-up of the supply chains for detectors was done by 'subcontracting'. Subcontracting is a method of managing the supply chains based on the idea of maintaining control over every process step in the supply chains. Each supplier is in contact with MP, instead of directly with each other. Keeping control through subcontracting is successful but leads to a very high operational management burden.

To reduce the management burden, MP should shift the management of parts of the supply chain over to the supply partners. If the management of parts of the supply chains are outsourced, the management burden will decrease. The supplier who takes over part of the management of the supply chains, will charge an additional price for this. In order to determine whether outsourcing is attractive, insight must be gained into all own costs for the supply chains of the detectors.

MP has a value stream map (VSM) for each supply chain. A VSM is a tool that allows you to create a detailed visualization of a process from raw materials to a customer product. The VSMs of the detectors only contain financial data of the steps that add value to the product. This results in a cost price per detector after the final assembly, which is based on material costs and direct labour. This cost price lacks important cost factors such as indirect man-hours and yield loss. The consequence of the calculation only based on value adding financial data is that the cost price currently known within MP is not proportional to the costs incurred for the product.

The core problem of this research is therefore as follows:

There is no insight into the costs which are incurred for managing the supply chains of the detectors within Malvern Panalytical.

Methodology

The method used for this research is the Activity-based costing (ABC) method. The ABC method makes no distinction between value-adding activities and other activities, because all activities are important for a cost overview. By applying the ABC method, there will not only be more activities identified but also more cost factors for each activity. These cost factors consist of direct and indirect cost factors. A total overview of all cost factors per activity gives a total overview of all incurred costs for each supply chain.

The implementation of the ABC method is done according to the cost assignment view. A combination of two different frameworks has been used for implementing the ABC method according to literature. The framework used in this research is a five-step framework:

1. Define all activities in the supply chain.
2. Define links between the activities and output
3. Identifying all consumed resources and cost factors for each activity.
4. Identify costs of the consumed resources and cost factors.
5. Charging activity costs to the products.

During the identification of all consumed resources and cost factors, step 3, many different factors were found. The majority of the cost factors found could be determined per activity. Some cost factors could not be determined per activity in the scope of this research. For these cost factors assumptions have been made. These cost factors are: transport costs, Room/Risk/Rent percentage of stock value and overhead costs. The consumed resources mainly consist of man-hours. For the man-hours, the experience of the employees is used and is therefore not accurate to the minute. The determined man-hours are therefore also seen as an assumption. The assumptions have ensured that all cost factors could be determined per activity.

The total costs per activity was determined next, based on the consumed resources and all cost factors. With the costs per activity mapped, the costs per detector could be calculated. To calculate the cost price of one detector, total activity costs is divided by the number of detectors that the costs are incurred for. These calculations resulted in a cost price per detector.

The assumptions made are uncertainties in the input of the calculations. With uncertainties in the input, the output can never be certain. A sensitive analysis is performed for all assumptions, to test whether the assumptions have a big impact on the cost price per detector. The sensitivity analysis has shown that only the Room/Risk/Rent percentage of stock value has much influence on the cost price.

The results

All activities found have been added to the VSM's of MP. The three different overviews that emerged from this are all called an activity stream map (ASM). The ASM of Product X consists of 44 activities. The ASM of Product Z is the smallest chain with 23 activities and the ASM of Product Y is the largest chain with 52 activities.

Three other overviews contain the cost calculations per detector. These overviews show the total costs and the costs per detector per activity. The found cost prices per detector are at least 60% higher than the cost prices known by MP. With this overview, MP can compare its own costs with the additional price a supplier will ask for managing parts of the supply chain. It is also mapped per activity how many man-hours are freed up of employees of MP, when these activities are outsourced. These hours can be used for other activities and can therefore be decisive for outsourcing.

Recommendation and future work

Apply the method of this research to future detectors. By displaying the activities in the same way in an ASM, there is unity in the overviews for all detectors within MP. The main reason for applying the method of this research is the large difference in cost price. The cost prices that are only based on value-adding activities, are not proportional to the actual incurred costs.

The sensitivity analysis has shown that the Room/Risk/Rent percentage of stock value has much effect on the cost prices of the detectors. To determine the prices of the detectors even more accurately, the assumption must be replaced by an accurate calculation of the percentage.

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Glossary of terms

Abbreviation	Meaning
ABC	Activity-Based Costing
ABM	Activity-based Management
ASM	Activity Stream Map
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
MP	Malvern Panalytical
MPSM	Management Problem Solving Method
R/R	Risk/Rent
R/R/R	Room/Risk/Rent
SLR	Systematic Literature Review
VSM	Value Stream Map
WACC	Weighted Average Cost of Capital

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1. Introduction

1.1. Introduction of Malvern Panalytical

The company which allowed me to do my Bachelor thesis is called Malvern Panalytical. The content below is a general introduction of the company.

Malvern Panalytical (MP) was formed by the merger of the businesses Malvern Instruments and PANalytical in 2017 and employs over 2000 people worldwide. MP is a leader in the materials characterization market and is active in different end markets, ranging from building materials to pharmaceuticals and from metals and mining to nanomaterials.

MP's X-ray technologies are designed to obtain high quality diffraction data, see Figure 1 for an example of MP's technologies. They are used by scientists and engineers for chemical, physical and structural analyses of materials. Together with extensive industry knowledge and technical- and applications expertise, MP instruments are designed to help users better understand a wide variety of materials. Highly reliable and robust characterization of the properties of the materials is fundamental for optimizing its performance and achieving manufacturing excellence when used. These materials vary from M&M's candy to Viagra pills, particle, nanoparticle suspensions and emulsion, through to sprays and aerosols and many more.

Figure 1, XRD Diffractometer.

MP technologies are used to solve challenges associated with maximizing productivity, developing better quality products and getting them to market faster. The focus of MP is creating innovative, customer-focused solutions and services to enhance efficiency and deliver tangible economic impact through their technology. Worldwide sales and service presence supported by a strong distributor network ensure unrivalled levels of customer support.

MP is part of Spectris plc, the productivity-enhancing instruments and controls company (Malvern Panalytical, n.d.).

1.2. Detectors introduction

This research is focused on a component of the x-ray devices from MP, called a detector. In this section, there is a general explanation of the detectors.

For the characterization of materials various x-ray machines are used. These machines are built and sold by MP. Figure 2 shows the basic configuration of these machines. The x-ray tube radiates x-ray on the sample that is being analysed. The radiation is reflected from the sample and received by the high-tech detector in the angle of reflection. The high-tech detector is one of the most important components of these machines. The received radiation is translated to information about the characteristics of the sample by the detector. This information is as output of the detector received by a computer, where the user can see the characteristics of the material.

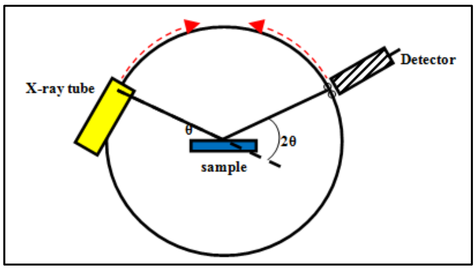


Figure 2, The basic configuration of an x-ray device (ResearchGate, 2013).

There are different types of detectors used within MP: Product X, Product Z and Product Y. They are all intellectual property of MP. The three detectors are the focus of this research.

The technology behind many parts of the detectors require high-cost equipment and specialized knowledge in combination with low demand. Therefore, it is too expensive for MP to research / buy all technology themselves. This also applies to many supply partners in the world. This means that many parts can only be manufactured by a few or even only one company in the world. This has two consequences. First, the materials are transported throughout the world for different process steps until MP receives all materials and can start the final assembly. Second, strategic stock must be created and managed. 'Strategic stock' is stock that MP implements multiple times in each supply chain, based on a combination of risk and preventing a production stop. The strategic stock should cover the time between losing a supplier and finding a new one, without a production stop. This stock often covers half a year of production due to the few suppliers in the world who can manage certain process steps for MP. It differs with regular safety stock, because the strategic stock does not function as a buffer when demand exceeds expectations (Averkamp, n.d.).

Detectors are a product in the high-mix low-volume market, which means that there is a large variety of products in small quantities. In this case, there are not that many different detectors, so the variety is not that high. However, the low volume fits perfectly with the technology of the detectors. They are produced in small numbers and the technology continues to develop regularly, which changes the production process again. A regular change of a production process fits well with the high-mix low-volume market (High-Mix Low-Volume Contract Manufacturing, 2019). After a conversation with a colleague from MP who has been working with the detectors for years, it came to light that a product's lifecycle in this market consists of three different phases (Figure 3).
1) The first phase is the 'Time to technology' phase. In this phase, it is examined if the required technology to make the product already exists or can be developed. The supply chain is set-up based on the process steps needed to make this technology available.
2) When the product is made, you talk about the 'Time to customer' phase. In this phase, the products are being sold and improved according to the opinion of the customers.
3) The third phase is called the 'Time to market' phase, in which the product reaches a mature supply chain. During this phase, the management of the supply chain should become less time consuming.

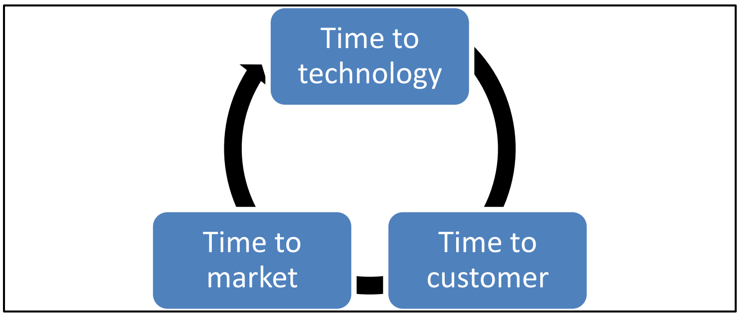


Figure 3, Lifecycle of a detector

2. Methodology

This chapter is about the research design (2.1.), problem identification (2.2.) and the approach (2.3.).

2.1. Research design

This research is designed according to the theoretical framework called 'Management problem solving method' (MPSM) of the book 'Geen Probleem' (Winden, 2012). The MPSM is a systematic method with room for creative input into each step to resolve action problems. The MPSM consist of the following seven successive steps:

1. Problem identification
2. Approach
3. Problem analysis
4. Alternative solutions
5. Decision
6. Implementation
7. Evaluation

The following sections will elaborate on the steps: Problem identification and the approach. The problem analysis can be found in chapter three. Steps four and five of the MPSM were carried out in chapter four. In chapter four, a systematic literature review was carried out into concepts that can be applied to this research. The best matching concept has been implemented in chapter five. Finally, the evaluation of the results can be found in chapter 6.

2.2. Problem Identification

During an introduction meeting at MP, the subject of this research was discussed briefly. It emerged that the management of the detectors supply chains is very time consuming. The results of a research based on activity-based costing (ABC) should ensure that management takes less time, according to MP. This was not yet been discussed in detail during this first meeting. The start of this research focused on getting an inventory of the problem through meetings with employees of MP. The collected information gave more insight in the problem.

The supply chains consist of one main line in which process steps are carried out one after the other until the final assembly at MP. However, not all steps can follow each other without adding other products. Figure 4 shows a general overview of a supply chain, where the main line is clearly displayed. To keep the delay in the mainline as small as possible, the throughput time needs to be as small as possible. The throughput time is the time needed to convert raw materials into a finished good (Welker, n.d.). Therefore, it is important that products required for process steps are delivered on time. To achieve running supply chains all sorts of variables and processes should be considered, for example: lead time, yield, contact with suppliers, quality, competition and optimisation.

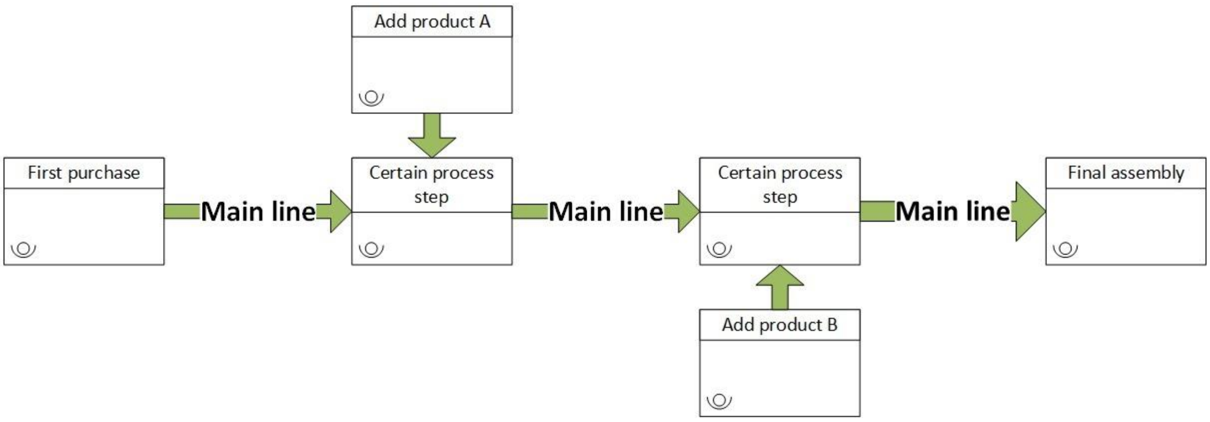


Figure 4, General overview supply chain

The set-up of the supply chains for detectors was done by ‘subcontracting’ during the time to technology phase. Subcontracting is a method of managing the supply chain based on the idea of maintaining control over every process step in the supply chain. This means that MP has control over the supply chain from start to finish. The suppliers do not deliver directly to each other but are all in contact with MP. The supplier communicates the needs to finish a certain process step in the supply chain to MP. MP ensures that this supplier receives the needed products and MP receives the product after the process step of the supplier has been executed. This process repeats itself for all involved companies which execute a process step. The supply chains of the different detectors do not have any similar process steps, which means that each supply chain requires its own management. Keeping control through subcontracting is successful but leads to a very high operational management burden. In addition to this management, there is also time spent on strategic stock management. Strategic stock management requires a lot of time because strategic stock is created after almost every step in the supply chains.
The three different detectors have reached the final time to market phase. The previously mentioned management burden and strategic stock management should become less time consuming. MP believes this can be achieved by reducing the amount of subcontracted process steps. This will result in less control over the supply chains of the detectors. To achieve this, suppliers should get in contact with each other and manage their product needs themselves. A supplier will charge an additional price for managing any part of the supply chain. The amount of this additional price will determine whether it is attractive for MP to implement this shift in control.
Before this additional price can be analysed, there must be insight into own costs. These costs depend on the number of hours spent on the supply chain management and strategic stock management, transport costs, yield and many more cost factors. All cost factors are stated in fifth point of the next section. This research must provide insight into all incurred costs for each detector.

2.2.1. Problem cluster

Figure 5 provides a summarization of the relations between the found problems.

The following eight sections explain the problems that occur with controlling a supply chain and their relations according to the problem cluster. The numbers in the problem cluster correspond with the numbers before each section.

1) When a supply chain is not optimized, improvement is possible. These improvements can be in the areas of management, purchasing, transport, etc. To find areas where improvement is possible, time must be made available for an analysis of the current situation. This analysis will have to be continued with research into possible improvements. Ultimately, a supply chain can be improved with the found solution. All these steps require a lot of time. In the current situation, there are no available hours for these types of projects.

2) As mentioned before, the supply chain is managed through subcontracting. This is the result of the first layout of the supply chain. Keeping control of the supply chains through subcontracting is time consuming. In the current situation, it requires almost all available hours of the employees involved in managing the supply chains. Therefore, there is no time left for optimization projects.

3) The management of the supply chains are planned to be shifted over to suppliers, in the time to market phase of the detectors’ lifecycle. This phase will be reached when MP can start outsourcing. Managing the supply chains in the time to market phase requires less management burden than managing through subcontracting.

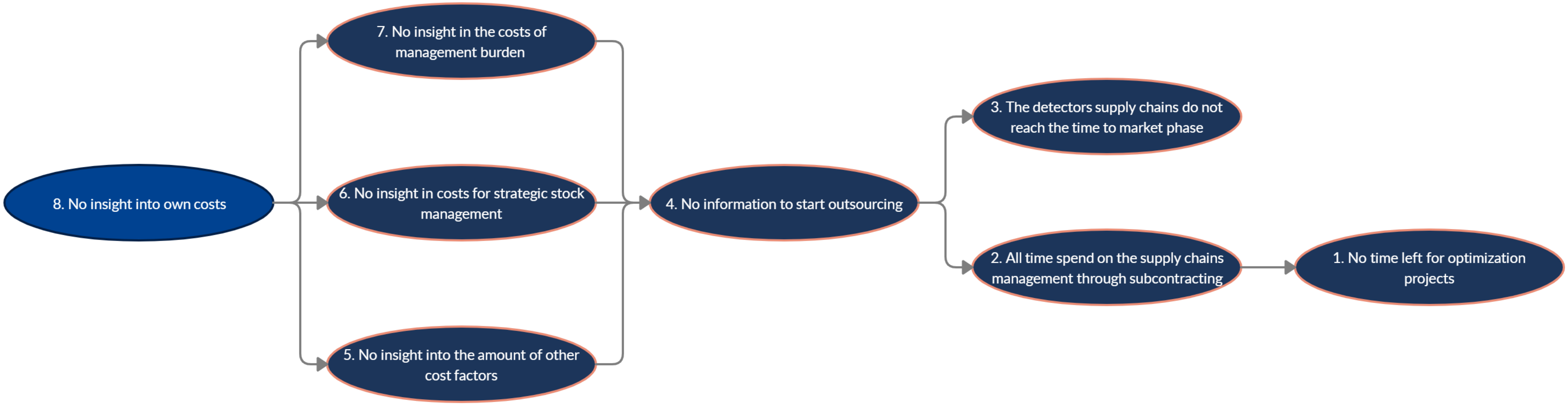


Figure 5, Problem Cluster

4) Subcontracting consists of two time-consuming cost factors, the strategic stock management (point 6) and management burden (point 7). In addition to these two cost factors, there are many other cost factors (point 5). Insight in the total amount of costs incurred for each supply chain, provide the needed information to start outsourcing.

5) The following cost factors, besides strategic stock management and management burden, influence the total incurred costs per detector: Hourly wage, overhead costs, cost price of all products and process steps, yield, percentage of inventory costs, rent for using facilities of other companies, transport costs and direct man-hours. These Cost factors have been found during the conversations about the supply chains with the employees involved in managing the supply chains.

6) There are three important reasons for the strategic stock. The first reason is caused by failure. Some of the parts of a detector are so high-tech, that there is no guarantee that all parts are working. For example, the supply chains start with so called wafers which contain multiple chips. These chips, see Figure 6, contain many pixel read-out cells which are a key compartment for analysing any material. On average 30% of these chips do not work, this is called yield loss. Because there is an average yield loss of 30%, there is a possibility that a badge of chips has a much higher yield loss. The strategic stock ensures that there is enough stock, such that there is no production stop.

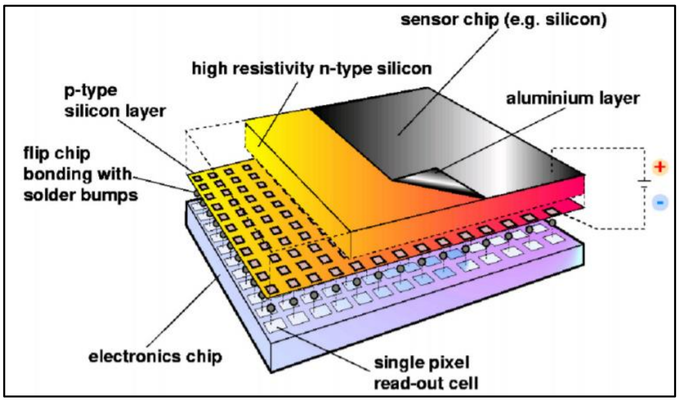


Figure 6, inside Product Z (Pinsky, 2006)

The second important reason is the risk to lose a supplier due to whatever reason. The technology that some process steps require can only be provided by a few suppliers. When one of those suppliers is lost, there must be a large enough stock that fills the time until there is a new supplier.
The third reason is loss of stock/materials. Because the materials are transported over the world, they could for example get checked by customs. Some products in the supply chain are ordered in small batches and have a long production time. These batches are always sent in two shipments to reduce the risk of a production stop being caused by customs for example. If one of the deliveries gets stopped, it will not have major consequences for the supply chain. Also consider the loss of stock due to, for example, fire or other unfortunate causes. So, the stock storage should be divided as well, which causes more complicated stock management.
The time spend on all processes for strategic stock belongs to the strategic stock management. The number of hours spent on these processes, should become clear in this research.

7) Managing the supply chains requires man-hours. These are hours that are spent on standard management and the hours that are spent on special events such as a lost shipment. Standard management burden of the supply chains arises from the time spent on purchasing, negotiating, meetings, updating etc. The man-hours found in combination with the financial data provide insights into the management burden costs.

8) *The core problem*

Point 8 is the first problem in the problem cluster of Figure 5. Solving this problem will have consequences for the entire problem cluster. When the costs of points 5, 6 and 7 are known, it becomes possible to change the management method of the supply chains. This will be done in the time to market phase: subcontracting will be substituted by a method of management with less control for MP. Less control in the supply chains will reduce the time spend on managing the supply chains. This shift in method of management will also free up time for optimization projects. Therefore, the core problem of this research is:

There is no insight into the costs which are incurred for managing the supply chains of the detectors within Malvern Panalytical.

The variable 'costs' depends on all Cost factors. These Cost factors are the key performance indicators of the core problem. The amount and frequency of occurrence of these cost factors provides insight into the total incurred costs.

Key performance indicators:

- Man-hours of MP's employees
- Hourly wage of employees
- Overhead costs
- Cost price of all purchasing products
- Cost price of all process steps
- Yield
- Percentage of inventory costs
- Rent for using facilities of other companies
- Transport costs

Section '5.2.2. Additional cost factors' further explains how these costs influences the costs of the supply chains.

2.3. Approach

The approach of this research consists of six general steps. These steps will be executed successively and form a conclusion for this research. As mentioned before, there is no overlap in the supply chains of the three different detectors. Therefore, the three supply chains have been mapped separately.

1. Employee analysis:
   get an overview of all employees involved in managing the supply chains.
2. Get to know the ABC method:
   becoming familiar with the ABC method through a systematic literature review.
3. Determine all activities:
   map all activities in the supply chain.
4. Gain insight to management burden:
   connect management burden to all activities.
5. Collect information:
   collect data of all costs which are incurred in the supply chain, besides management burden.
6. Check for completeness:
   discuss the results and check if all Cost factors have been mapped.

In the next sections, every step of the approach is explained.

2.3.1. Employee analysis

Start with an overview of all employees who are involved in the supply chains of the detectors. This is called the 'Employee analysis'. The supply chains coordinators should be able to tell which employees are involved in managing the supply chains. This overview is used to obtain targeted information about each detector. This step does not yet look at the working hours that each employee spends per detector. The employee analysis is used at a later stage to look at these hours.

Knowledge problem

Which employees of MP are involved in what supply chain?

2.3.2. Get to know the ABC method

MP wants the research to be based on the ABC method. The systematic literature review (SLR) in section '5. Theoretical Framework' will provide the research to this method. The SLR should provide the knowledge needed to apply a concept of the ABC method to this research.

Knowledge problems

How does the theory of the ABC method provide knowledge for this research?

Which concept of the ABC method can be implemented?

2.3.3. Determine all activities

MP has an overview map of the general steps of all three supply chains. Two of these maps are not UpToDate and all three do not contain all activities. To apply any concept of the ABC method, all activities that take place in each supply chain must be mapped. The old overview maps form the basis for identifying all activities that take place. In this step there is no need to look at financial data or man-hours.

Knowledge problems

Which activities does the supply chain consist of?

2.3.4. Gain insight to management burden

All found activities should be presented to the involved employees according to step 1 of the approach. Go through the supply chain with each employee and write down the hours the employee spends on each activity. Also map the hours that the employee spends on the supply chain in general and therefore cannot be linked to one activity. During this step, other cost factors will likely emerge in addition to man-hours. Write these down as well, these are needed for a complete overview of the costs in the supply chains.

Knowledge problems

How many hours does which employee spend on which activity?

How many hours are incurred and cannot be linked to any activity in the supply chain?

2.3.5. Collect information

After all man-hours are allocated to the supply chain, it is time to calculate how much these hours costs. For some activities in the supply chain, other costs besides man-hours are incurred according to step 3 and 4 of the approach. Transport costs and storage costs for example. Data of those costs should be collected. After all data is collected, there should be a near complete overview of all costs incurred in the supply chain. The research will have to get an overall picture from this step. The total costs per detector can be calculated with the insight into all incurred costs per supply chain.

Knowledge problems

In what parts of the supply chains are other costs besides man-hours incurred?

What is the cost price of one detector?

2.3.6. Check for completeness

After finishing step 5 it is time to discuss all findings with the employees involved in managing the supply chains. The focus of these meetings will be on completeness of the research. Should cost factors still be found that were not previously specified, the necessary data will be collected and added to the overview.

3. Current insights

This chapter is about the current insights of the supply chains that are available within MP. The reader must keep in mind that the research focuses on three different supply chains. This is important for understanding figures and explanation.

3.1. Employee analysis

To gain new insights, it is important to map out which insights are present within MP. Through conversations with all involved employees, this insight can easily be gained. Therefore, it should become clear which employees are involved in which supply chain: the 'Employee analysis'. In a conversation with the supply chain coordinator, it was made clear which employees are involved in the various supply chains. Table 1 contains an overview of these employees. In addition to the involvement of employees in the supply chains, their abbreviation and position is shown. This table answers the first knowledge problem: *Which employees of MP are involved in what supply chain?* This overview has been used for gathering information per detector. The knowledge of the position per employee ensures that the necessary information can be found quickly and efficiently.

Because of confidential data, real names and abbreviation are not shown.

Table 1, Employee analysis

Employee	Abbreviation	Product Y	Product X	Product Z	Position
xxxxxxx	AB	x	x	x	Manager Operations
xxxxxxx	AC	-	-	x	Planner
xxxxxxx	AD	-	-	x	Operational buyer
xxxxxxx	AF	x	x	-	Supply chain coordinator
xxxxxxx	AG	x	x	x	Physics engineer
xxxxxxx	AH	-	-	x	Material handling
xxxxxxx	AK	x	-	-	Supply chain coordinator
xxxxxxx	AL	x	x	x	Mechanic
xxxxxxx	AM	x	x	x	Mechanic
xxxxxxx	AN	x	x	-	Buyer

3.2. Value stream map

MP has a value stream map (VSM) for each supply chain. A VSM is a tool that allows you to create a detailed visualization of a process from raw materials to a customer product (Pearson, n.d.) (What is Value Stream Mapping?, n.d.). These VSMs were made in the Microsoft Visio program. Visio can be used for many things that utilize layouts, diagrams and charts (Hope, 2019). Standard figures are used as graphics in flowcharts, decision diagrams, playbooks etc.

Because these VSMs contain confidential data, they have not been added to this thesis.

The VSM of each supply chain contain all steps from wafer production to the final assembly in MP, indicates stocks and indicates transport. However, only the VSM of Product Y is up to date. Besides the problem of the outdated VSMs of Product X and Product Z, all three VSMs only include financial data of the main steps of the process. The main steps of the process are all steps in the supply chain where value that the customer pays for is added. This means that costs for managing the supply chain, transport and stock are not included. The following two sections describes how this financial data is structured.

3.3. QAD

The financial data that MP implemented in their VSMs is stored in an application called QAD. The software of the application QAD is from the company QAD. QAD is a company founded in 1979 that provides enterprise resource planning (ERP) software to manufacturing companies of which MP is one (Systems, 2017) (QAD, n.d.). An ERP is a process used by companies to manage and integrate the important parts of their businesses (Labarre, 2019). The software application of an ERP system is often important for companies. They integrate all processes needed to run a company in one application. When employees of MP refer to their ERP system application, they refer to the application QAD. For the remainder of this report, 'QAD' refers to that application. QAD is central to the daily work of employees at MP, the application is the source of knowledge for all systems. This also includes the data relating to the supply chains of the detectors. To keep an overview in QAD, MP uses product codes that are called the '12nc'. This is a 12-digit code that refers to a specific product. Every product that MP buys has its own 12nc. In the supply chains of the detectors, the 12nc changes after every process step.

3.3.1. Financial data in QAD

As mentioned before, the VSMs of the detectors only contain financial data of the steps that add value to the product. These costs can all be found in QAD. This results in a cost price per detector after the final assembly, which is based on material costs and direct labour. However, this cost price lacks two cost factors that belong to the detectors:

Within MP, indirect man-hours are not allocated to the products. The reason for this is the lack of insight into the number of indirect hours per product. By mapping this, the cost price of the detector can be calculated more accurately.

The same applies to yield, which is expressed as a percentage. QAD makes it possible to use a yield percentage as a parameter for the demand of a product. Suppose you need 5 items from a certain process step and that process step has a yield of 50%, then QAD indicates that ten products are needed as input to make those five products. The costs that were in the first 10 products must be divided among the five new products. This makes the product more expensive. QAD, on the other hand, does not use yield when calculating the cost price. So, the costs of those ten products are not divided over five products.

The consequence of the calculation in QAD is that the cost price currently known within MP is not proportional to the costs incurred for the product.

4. Theoretical framework

Now that the current situation has been mapped out, it has become clear which information is missing. To fill the gap of information, the following theoretical framework is used which is based on the systematic literature review (SLR). An overview of the structure of the SLR and the articles used can be found in Appendix A. The SLR is carried out to find answers for the knowledge problem:

How does the theory of the ABC method provide knowledge for this research?

MP has indicated that they want to apply the ABC method in this research. Answering this question should make it clear whether this method is suitable and what kind of knowledge it will provide. This literature review about the ABC method will also look after the knowledge question: *Which concept of the ABC method can be implemented?* The literature contains various examples of implementation of the ABC method. These implementations of the method follow various concepts. After this literature review, it must be clear which concept fits in with this research.

4.1. Integration of the theory

All gathered information of the systematic literature review is shown beneath in the following nine paragraphs: Introduction, history, concept of management accounting, methodology of ABC, activity-based management, concept of ABC, comparison with traditional costing methods, advantages and disadvantages and implementation according to literature.

4.1.1. Introduction

"Independent of the economical climate, there is an increasing necessity for companies to have transparency of cost in general and insight in the aspects influencing these costs. The world is getting smaller and competition is growing." (Zondervan, 2009). "Cost accounting system should accomplish cost efficiency without a negative impact on the quality of service delivery, provide information for management to maximize resources, and assist in continuous quality improvement. Activity-based costing accomplishes all three of these aims." (Baker, 1998). "Activity-based costing was developed and has been advocated as a means of overcoming the systematic distortions of traditional cost accounting and for bringing relevance back to managerial accounting." (Mahal & Hossain, 2015).

4.1.2. History

ABC was first known by the term 'activity accounting' in the early 1970s. During the early 1980s ABC gained favour for industrial entities in the United States. Cost accountants began to share their experiences in the 1980s which caused implementation by service entities and health care organizations over the years (Baker, 1998). "The method has eliminated insufficiencies of conventional methods due to its ability to provide more accurate cost information." (Yuksel Pazarceviren & Celayir, 2013). Cooper and Kaplan were one of the accountants who shared their experiences, they published a number of articles in the Harvard Business Review around 1988. The main focus of ABC was on production companies. Nowadays it is implemented in all kind of businesses, like telecom firms, libraries, hospitals etc. Even in logistics, there are developments around ABC, yet it is often considered as a financial tool. Although ABC is a cost analysis tool, it can be a great help for operational managers (Zondervan, 2009).

4.1.3. Concept of management accounting

For decision making, managements use management accounting. In contrast to financial accounting, which is used for creating statements for third parties, management accounting has an internal focus. Cost accounting is a subset of this management accounting and ABC is a certain type of the cost accounting methodology. Cost accounting can give information about the costs of a whole department or a specific product or service. The more detailed the required information need to be, the more difficult the tracing and measurement of the costs will be. Besides cost accounting, different disciplines from multiple sources are used to assist managements with internal problem solving. Management accounting does not have any particular set of rules, which causes a great deal of philosophical flexibility for the organization's management. The implementation will therefore differ for each company (Baker, 1998).

4.1.4. Methodology of ABC

The ABC methodology has two major elements, cost measures and performance measures. The methodology focusses on measuring the cost and performance of activities, resources, and cost objects. "The basic concept of ABC is that activities consume resources to produce an output." Resources are assigned to activities, then activities are assigned to cost objects based on their use. Figure 7 shows the causal relationships of the activities with the products and resources.

The services or products are called 'cost drivers', which are the cause of the activities. Activities are an aggregation of actions performed within an organization. These activities consume the resources in order to produce an output. Resources are an economic element that is applied or used in the performance of activities. The expenses of these consumed resources are then assigned to 'cost objects'. These cost objects are patients, contracts, products or services for example. The expenses of activities should be divided over the total units they are incurred for during that activity. Expenses that are needed to produce individual units should be separated from the expenses that are incurred to produce multiple units. This separation should be independent of how many units are produced or sold before. So, activities are driven by cost drivers and the activities have effect on multiple cost objects (Baker, 1998).

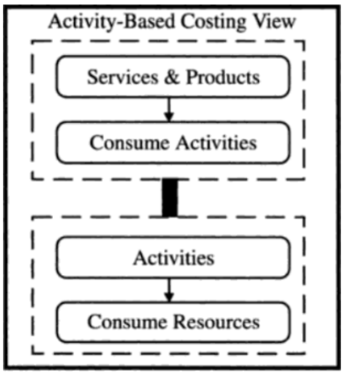


Figure 7, Activity-based costing view

4.1.5. Activity-based management

Management based on information gathered from ABC is called activity-based management (ABM). ABM is used in different situations, for example: improving efficiency and reducing cost for a value chain study or investigation of customer/product profitability. The goals of ABM can be split in two main groups. It is either to allocate the costs as fair as possible or to reduce the costs and analyse how the results of ABC can be used within the department/business itself as well.

One of the main purposes of ABM is the allocation of costs. All costs of a department could for example be allocated to the products. Back in the days, overhead costs was mainly covered in prices via a mark-up based on a fixed percentage decided by controllers. ABC can be used for the cost allocation of overhead costs and give insight if the mark-up used results in under or over coverage.

Understanding the costs of businesses is a vital prerequisite of being able to reduce costs. ABC can provide this knowledge, but that is maybe not even the most important aspect. ABC also provide knowledge for resource utilization, customer/product profitability, departmental cost drivers, what-if analysis, customer support costs reduction and internal benchmarking (Zondervan, 2009).

4.1.6. Concept of ABC

"Activity-Based Costing method uses the following types of costs: production cost, fixed cost, variable cost, total cost, direct cost, indirect cost (overhead). Correct determination of production cost requires appropriate monitoring of consumption of inputs used by an enterprise." (Briciu & Capusneanu, 2010).

ABC has two basic concepts. The 'Cost assignment view' and the 'Process view'. The process view summarizes what has or is happening (Figure 8). Cost drives are the cause of activities. Activities are an aggregation of actions performed within an organization. So, this is the same as in the general methodology of ABC. The process viewpoint measures the performance and results achieved in each activity. The performance measures may be financial or nonfinancial (Baker, 1998). The process view shows non-value-adding activities and waste within a process (Mahal & Hossain, 2015). This concept is most likely used for reducing costs and analyse for which the outcome of ABC can be used.

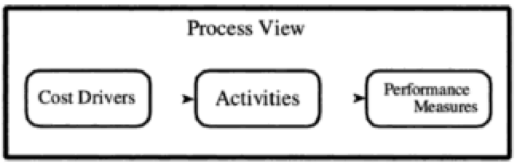


Figure 8, Process view

The cost assignment view can be seen as a vertical process instead of the horizontal process of the process view (Figure 9). Resources are connected to activities, which are connect to cost objects. Instead of visualising the process, the cost assignment view focusses on dividing the total costs over all cost objects (Baker, 1998).

Figure 9, Cost assignment view

With the required knowledge of the two different concepts, the following knowledge problem can be answered: *Which concept of the ABC method can be implemented?*

The concept 'Cost assignment view' fits better than the 'process view' concept in this research. This concept fits better because there is no performance measure required after the execution of each activity. Due to the technology incorporated in the detectors, it is not possible to test the result after each activity. These tests can sometimes only be executed after multiple activities took place. In addition, the cost driver of the supply chain in this research are the three products. Each supply chain has its own cost driver. The process view implementation is based on multiple cost drivers and therefore less suitable for this research.
To implement the 'cost assignment view' concept, a three-step plan must be executed successively. First, examine the activities that take place in the process. Next, we look at the resources that are used per activity. Finally, the financial details of the activities are linked to all cost objects.

4.1.7. Comparison with traditional costing methods

The traditional cost accounting systems are often based on job costing, process costing or a combination of both. ABC is not an alternative costing system to these three systems, but it is an approach to develop the cost numbers for these systems.
Traditional methods state that the resources are consumed by the product, where ABC states that the activity consumes the resources. Traditional costing methods allocate all indirect costs to a single cost pool, often based on product volume or a fixed percentage. "A cost pool is a grouping of individual costs, typically by department or service centre. Cost allocations are then made from the cost pool. For example, the cost of the maintenance department is accumulated in a cost pool and then allocated to those departments using its services." (Bragg, 2019). ABC allocates such costs to multiple cost pools and cost drivers, which results in a better distribution of the costs (Baker, 1998). "In conventional cost accounting, only the production costs are included in the product costs. R&D, Sales, Distribution, Marketing, General Administrative Expenses are recognized as running expenses and they are not

charged to the products." The allocation of indirect costs according to the ABC method, eliminate the miscalculations caused by traditional costing method which undercharge the cost to small-scale products and overcharges the cost to large-scale products (Yuksel Pazarceviren & Celayir, 2013).

The main differences between the traditional costing method and the ABC method have been summarized in table 2.

Table 2, Summary main differences traditional costing and ABC method

Traditional costing method	ABC method
The resources are consumed by the cost driver.	The resources are consumed by activities.
Based on direct activities.	Bases on both direct and indirect activities.
Indirect costs allocated to a single activity based on product volume or a fixed percentage.	Indirect costs allocated to multiple activities and cost drivers.
Only production costs are included in the product costs.	Production costs and running expenses are included in the product costs.

4.1.8. Advantages and disadvantages

Advantages

The main advantages of ABC is the detailed information about what resources are consumed and by what activity. These insights provide more knowledge about the production process of the companies and therefore more information for management decisions (Baker, 1998). As mentioned in 4.1.4. Activity-based management, implementation of ABC provides information that is usable in many different situations for a company. So, implementing ABC can provide knowledge for multiple problems at once (Zondervan, 2009). "It helps industrial marketers in three ways; it results in cost estimates to use in pricing, guides industrial marketers to adjust in negotiations to yield significant cost reductions and indicates areas for change in operations to permit cost reductions that will allow the company to satisfy customer wishes better." Because ABC can identify weaknesses in a product line, efficiency and profitability can be improved. For example, bottlenecks could be removed which causes capacity growth or a non-value-adding activity can be removed which causes cost reduction (Mahal & Hossain, 2015).

Disadvantages

One of the disadvantages of ABC could be the required precise knowledge. The required precise knowledge depends on the detailed level of information for which the ABC method is implemented. If the implementation gets to complicated, changing to a different level of detail or making some assumptions based on available operational experience can solve this problem. By doing this the problem can be avoided, but the requested level of detail will not be obtained (Zondervan, 2009).

Not all companies are willing to release detailed insight into their financial data. This can ensure that the implementation of the ABC method must be based on many assumptions and therefore does not provide reliable information. If none of the above mentioned situations causes a problem, then there is still one big disadvantage left. Implementing the ABC method takes a lot of time (Baker, 1998).

Due to the large amount of information, it costs more to maintain the ABC system than traditional costing systems. In addition, not all information is relevant for managers. All insights that can be obtained through ABC can also ensure that there is more resistance from employees. The threat of improving their work could be the cause of this resistance (Mahal & Hossain, 2015).

4.1.9. Implementation according to literature

To implement ABC systems different frameworks are used in literature.

One of them is a three step framework by (Baker, 1998). It starts with defining all activities that support the output, then defines links between the activities and output and finally develops the costs of the activities. Finding out the costs per activity is a time-consuming occupation which is only possible if there is access to detailed financial information. The three step framework of (Briciu & Capusneanu, 2010) is in line with this set-up.

Other frameworks consist of more than three steps but use a similar setup. The framework of (Mahal & Hossain, 2015) start figuring out the costs associated with a certain activity during the second phase. This means that the phase requiring the most time is brought forward.
The five step framework of (Yuksel Pazarceviren & Celayir, 2013) starts with identifying activities, followed by classifying the activities, identify costs of the activities, selecting accurate cost factors for allocating costs to the products and finally charging activity costs to products.

The different frameworks represent the possibilities within the methodology of the ABC method.

4.2. Answer to knowledge questions

How does the theory of the ABC method provide knowledge for this research?

With all the information obtained from this literature research it can be concluded that the ABC method is suitable for this study. As mentioned earlier, the current cost price structure within MP only contains the value-adding processes and the VSMs only focuses on those processes as well. Indirect cost factors are not assigned to products in the current situation. The ABC method makes no distinction between value-adding activities and other activities, because all activities are important for a cost overview. By applying the ABC method, there will not only be more activities identified but also more cost factors for each activity. These cost factors consist of direct and indirect cost factors. A total overview of all cost factors per activity gives a total overview of all incurred costs for each supply chain. An overview of all incurred costs for each supply chain answers the core problem of this study.
To implement the cost assignment view, the three step framework of (Baker, 1998) is combined with the five step framework of (Yuksel Pazarceviren & Celayir, 2013). The framework used in this research is a five-step framework:

1. Define all activities in the supply chain.
2. Define links between the activities and output
3. Identifying all consumed resources and cost factors for each activity.
4. Identify costs of the consumed resources and cost factors.
5. Charging activity costs to the products.

5. Implementation of the ABC method

The concept of 'cost assignment view' is now being implemented in the research according to the mentioned five-step framework. This has been done separately for each supply chain.

5.1. Identification of all activities

To map out all activities that take place, the knowledge of the employees has been used. The outdated VSMs served as base for this step. To keep the overview in the long supply chains, as few figures as possible were used to map all activities. The result is the use of three different figures:

Figure 10, Supplier shape

Figure 10 on the left is used when one of the following three activities takes place: The purchase of a product, product processing at a supplier or assembly of the product. The supplier of the product or the company managing a product process/assembly is stated instead of 'Supplier'. Which product is purchased or which process is carried out is stated in the figure instead of 'Process step'.

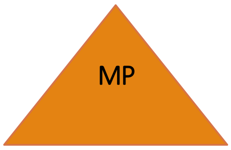


Figure 11, Stock shape

Figure 11 on the left is used when products are stored in the supply chain. This can be storage of work stock and strategic stock. Not all products are stored at MP. Therefore, it could occur that there is another companies name stated instead of 'MP'.

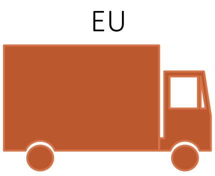


Figure 12, Transport shape

Figure 12 visualizes when transport takes place. When the transport is within the European Union, 'EU' is above the truck. If the transport comes or goes out the European Union, the area of origin and destination is visualized.

By using the above three figures, all activities of the supply chains have been mapped. With the use of arrows, which are called 'connectors', the flow of the products is visualized. The three different overviews that emerged from this are all called an activity stream map (ASM). The ASM of Product X consists of 44 activities. The ASM of Product Z is the smallest chain with 23 activities and the ASM of Product Y is the largest chain with 52 activities. The ASMs answers the knowledge problem: *Which activities does the supply chain consist of?*

Because the ASMs contain confidential data, they are not added to this thesis.
Figure 13 is used as an example; this example shows the first nine activities of the supply chain of Product Z.

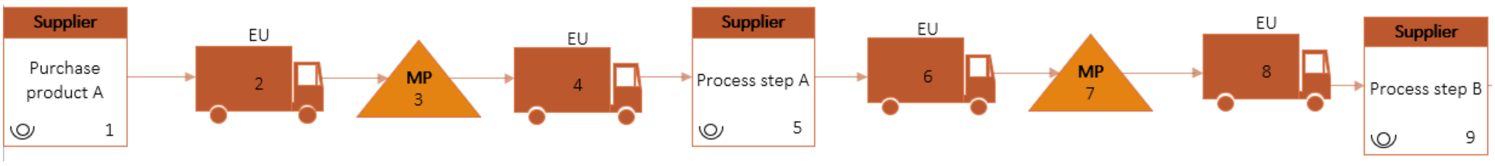


Figure 13, Start of Product Z ASM.

5.2. Identification of consumed resources

Now that all activities have been mapped, we look at the resources consumed by the activities. The connectors play a major role in this step. The next section explains why the connectors are important when determining the consumed resources.

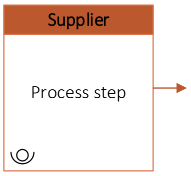


Figure 14, Only outgoing connector

When a figure only contains connectors that move away from the figure, it is a purchasing product. The resources used for purchasing a product are all man-hours needed to purchase that product.

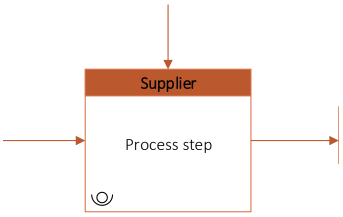


Figure 15, Incoming and outgoing connectors

If a figure has one or more incoming connector(s), all resources added before that/those connector(s) is/are consumed by this activity. In addition, all man-hours needed to make this activity happen are consumed.

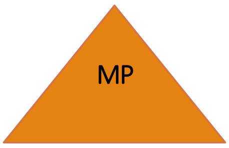


Figure 16, Stock

The man-hours needed for receiving products, move them, store them, pick them up and send them are consumed during the stock activity. If products are in stock at a supplier, there are no man-hours for MP consumed. So, it depends on location instead of the connectors.

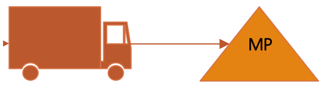


Figure 17, Transport to MP

When transport takes place towards MP, there are no resources consumed. This is because the transport is managed by the supplier who sends the product.

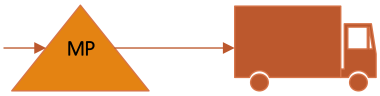


Figure 18, Transport to supplier

If the transport is from MP to a supplier, man-hours for managing the transport are used.

For all three supply chains it is now known where which consumed resources are expected. In the next paragraph, the identified man-hours will be quantified.

5.2.1. Quantity of consumed man-hours

To gain insight into the man-hours per activity, the complete ASMs were presented to all employees involved in the supply chains according to the employee analysis. In addition, it was explained at which activities consumed resources were expected. This was based on all connectors per activity, according to the previous section. The employees have been given three weeks to keep track of how much time they spend on which activity. The time per activity is based on an average routine execution of the activity. During this period, not all activities took place. This may for example be caused by a low frequency of that activity or stock which covered this period. For these activities the time is estimated as accurately as possible by the employees. After these weeks, all results have been collected and discussed with the employees. These conversations answered the knowledge problem: *How many hours does which employee spend on which activity?* Appendix B elaborates on the results from these conversations. The man-hours have now been mapped for each activity based on a routine execution of the activity.

Every activity can have exceptions, which means that the activities require additional man-hours. For example, in the case of a lost shipment, additional man-hours are used to retrieve the shipment. It can also happen that a supplier delivers a wrong batch size of a product. Communication to rectify this delivery requires additional man-hours. These exceptions are not included in the specified hours per activity but have been written down.

In addition to the man-hours per activity and the exceptions per activity, there are also hours spent on general issues that relate to the entire supply chain. An overview of these hours answers the knowledge problem: *How many hours are incurred and cannot be linked to any activity in the supply chain?* These hours were also mapped out as a result of the conversations with the employees.

For each supply chain, the man-hours per activity, the man-hours of the exceptions per activity and the man-hours for general issues have been mapped. These are all hours that employees spend on the supply chains of the three detectors. The hours per activity have been processed in Excel for the calculation of the cost price per detector, which is explained in '5.4. Costs of all activities'.
The overviews obtained from the exceptions per activity and man-hours for general issues have been combined in one overview. This overview contains the following information: employee name, activity, type of operation, hours, frequency and detector type. Subsequently, a distinction was made between hours that can be outsourced and hours that cannot. Outsourceable hours are hours that employees free up when the whole supply chain, except the final assembly, is managed by another supplier. For all three supply chains together, employees could on average free up four hours a week. This is less than two hours a week per detector. The man-hours which cannot be outsourced are not interesting for this research, because the associated activities must continue to be carried out within MP. The sensitivity analysis in '6. Validation' has shown that the man-hours have little effect on the total cost price. The average time that an employee frees up is less than two hours per week per supply chain. These two hours should be distributed over the average number of detectors produced per week. Since the man-hours have little effect on the cost price and the remaining time is less than an hour per detector, these hours are not included in the cost price calculation. The overview can still be used for information purposes.

5.3. Additional cost factors

In the previous section, it was mapped out for each activity how many man-hours are consumed. In addition to the man-hours per activity, there are several cost factors which are also linked to the activities. For example: transport costs, rent and hourly wages. These cost factors were also mapped out during the meetings with the employees. This answers the following knowledge problem: *In what parts of the supply chains are other costs besides man-hours incurred?* The following cost factors are determined per activity according to the ABC method:

- Hourly wages, the hourly wage affects the costs of the man-hours per activity. The hourly wage of an employee is used whenever that employee is involved in managing an activity.
- Prices for purchasing products. In the current cost price structure, the price is known for each purchasing product. These prices can be found in QAD and be directly linked to the matching activity in the supply chains.
- Prices for process steps. The prices of the process steps that are known in QAD can also be directly linked to the corresponding activity.
- Yield. The yield percentage was used as the latest data from QAD. This is included for every activity where there is yield loss, according to QAD.
- Rent for using facilities of other companies. MP annually rents the facilities of a supplier to perform certain process steps there. Part of these process steps relate to the detectors. The ratio of the process steps relating to the detectors to all process steps has been determined. Based on this ratio, the rental costs related to the detectors have been calculated.

There are also cost factors for which an assumption has been made. The assumptions and the reason why they were made are explained below. The effect of these assumptions on the cost price is explained in chapter 6. Validation.

- Transport costs. The transport costs depend on volume, weight, sort of transport and travel distance. For each activity 'transport' the four variables should be determined. Together with the contracts between MP and a transport company, the four variables determine the transport costs. The agreements between MP and the transport company determine the cost price based on these four variables. During this research no insight was obtained into the agreements between the transport company and MP. As a result, the costs were not determined according to the ABC method. An average rate has been taken for all transport costs.
- Room/Risk/Rent (R/R/R) percentage of stock value. The cost of all stock activities depends on the holding costs of capital, space and warehouse design. 5 years ago, an employee of MP did research into economic order quantity (EOQ) according to the Camp formula (Beerens, 2015). For the calculation of the optimal order size, the holding costs were calculated per location. These holding costs depend on the size of the space, costs of the storage cabinets, average service costs, labor costs per location, weighted average cost of capital (WACC) and insurance as a percentage of the total average stock value. During the research of the EOQ, the R/R/R percentage was calculated for two different locations. The components of the detectors are besides those two locations, stored in two other locations. The percentages for 2017 must be updated and the percentage for the other two locations must be calculated. The required data for these calculations have not been obtained during the scope of this research. For that reason, the average of the two calculated percentages for the locations from 2017 was used.
  The total WACC depends on the average stock and the product value per storage activity. To calculate the WACC per detector, the total costs are divided over the average annual sales. Because the WACC percentage has a large share in the total R/R/R percentage, the R/R/R costs are calculated in the same way. As a result, the cost price per detector depends on the average annual sales.

- Risk/Rent (R/R) percentage of stock value. In some supply chains it happens that storage takes place at a supplier. MP remains responsible for this stock and therefore they pay interest and risk as a percentage of the stock value. Since it is not stored within MP, the percentage part for space can be deducted. The percentage that has been deducted is also based on the data from 2017.
- Overhead costs. Overhead costs are all expense incurred to support the business and are not directly related to any product or service (Tuovila, 2019). Overhead costs can be fixed, variable, or a hybrid of both. To determine overhead costs for the detectors according to the ABC-method, all incurred expense to support the business producing detectors should be mapped. Although the detectors are an important component of the x-ray devices, it is only a small part of these devices. The ratio of, for example, warehouse use to the detectors and other products is not known within MP. This also applies to many other incurred expenses. Because this data cannot be calculated during this research, a standard percentage over all man-hours has been used. This percentage is used for all overhead costs within MP.

All cost factors besides man-hours per activity are now known as well. The data are listed in an overview in Excel. Each detector has its own overview. The next sections explain the structure of those overviews.

5.4. Costs of all activities

All Cost factors per activity have been collected and visualized in Excel. *Due to confidential data, the overviews of the detectors are not added to this thesis.* To show the structure of the Excel overviews, an overview has been made (Table 3) based on the generalized start of the supply chain of Product Z (Figure 13). The financial data in Table 3 is not accurate with reality, because of confidential reasons.

Table 3, Generalized overview of the supply chain of Product Z

Process step	12nc	Cost price	Employee A (hours)	Employee B (hours)	Overhead	R/R(/R)
1.Purchase product A	0004 123 45678	€ 500.00	1	1	13%	
2. Landed costs MP		€ 25.00				
3. Stock			1.5		13%	15%
4.Landed costs Supplier		€ 25.00	1		13%	
5. Process step A	0004 123 56789	€ 200.00	1	1	13%	
6. Landed costs MP		€ 25.00				
7. Stock			1.5		13%	15%
8. Landed costs supplier		€ 25.00	1		13%	
9. Process step B	0004 123 67890	€ 15.00	1	1	13%	15%

The man-hours, prices of purchasing products (Cost price column), prices for process steps (Cost price column), rent for using facilities of other companies (Cost price column), transport costs, R/R/R percentage and overhead percentages are shown in Table 3. The 'Cost price' column is used for these three cost factors because these factors can never occur at the same time in an activity. Yield loss and hourly wages are not yet included.

With the costs per activity mapped, the costs per detector can be calculated. A distribution has been made between direct and indirect costs. This distribution was made to clearly show in the overview which of those costs has the most influence on the total cost price. The man-hours used for managing activities are indirect costs and man-hours involved in the assembly of the product are direct costs, for example. This distribution has been made for all cost factors per activity. The hourly wages per employee are used to calculate a price for the man-hours. To calculate the cost price of one detector, it is important to divide any costs incurred by the number of detectors that the costs are incurred for. Table 4 shows over how many detectors the costs should be distributed. Table 4 is linked to the overview of Table 3.

To explain the use of Table 4, purchase product A is used as an example: Product A can be used for 50 detectors and is bought in batches of 4. QAD contains the price of one product, therefore the cost price of product A should be divided over 50 detectors and the manhours over 50 x 4 = 200 detectors.

Table 4, Cost allocation

Process step	(In)direct	Cost price	Employee A	Employee B	Overhead	R/R/R
1	Direct	50				
	Indirect		200	200	200	
2	Direct	200				
	Indirect					
3	Direct					
	Indirect		200		200	1
4	Direct	200				
	Indirect		200		200	
5	Direct	50				
	Indirect		200	200	200	
6	Direct	200				
	Indirect					
7	Direct					
	Indirect		200		200	1
8	Direct	200				
	Indirect		200		200	
9	Direct	1				
	Indirect		100	100	200	1

The result of this step is an overview of the costs per activity for one detector divided into direct and indirect costs. The sum of these two costs is the total costs of the activity for one detector. According to QAD, yield loss occurs at some activities. Yield loss is the last cost factor that influences the cost price. As mentioned earlier, yield loss determines how much input is needed to produce one product. Yield loss is included in the cumulation of all costs found for the activities per detector. This cumulation shows all costs incurred in the supply chain per activity. This calculation therefore shows for the 10th activity all costs of the nine previous activities plus the costs of the 10th activity. This calculation shows the costs per detector for the very last activity in the supply chain. This answers the knowledge problem: *What is the cost price of one detector?* The calculated cost prices are between 65% and 149% higher than the cost prices known in QAD.

5.4.1. Frequency of activities

To calculate the frequency of the activities, the batch size, yield and average annual sales were considered. The last activity must at least produce the number of detectors that is equal to the average annual sales. When calculating the frequency of the activities, yield has a lot of effect. The yield factor indicates how many percent more input is required for the desired output. For each activity it is then possible to calculate how many products are needed to achieve the annual sales volume. For almost all purchasing and process activities (Figure 10), a certain batch size applies. This batch size is often determined by the supplier. The number of products required to achieve the average annual sales and the batch size of the activities reflects the frequency of the activities.

5.5. Expansion activity stream maps

The aforementioned ASMs contain no data in addition to a sequence of activities. As a result, the ASMs are not very informative. To make the ASMs more informative, two components have been added. First, data grids are added per activity. This data grid is placed under each activity in the ASM. To keep the ASM organized and clear, the three different activities all have their own data grid. These data grids are made based on all information that can be useful for every activity. These are then processed in the ASMs of the detectors. The added information does not contain any financial data. Prices of products or process steps are more sensitive to changes than the structure of the supply chain. To allow the ASMs to last for a long time, financial data has therefore been omitted. All data grids and the activity they belong to are listed below.

12nc	xxxx xxx xxxxxxx
Batch	size
Employees	x hours
Yield	100%

Figure 19, Data grid supplier

The data grid of Figure 19 is displayed under all activities represented by Figure 10. 12nc stands for product code. Batch size for standard order size and yield for percentage of approved articles on average.

Ship. Cost	xx
Ship. Doc.	Yes/No
Batch	size
Employee	x hours

Figure 20, Data grid transport

The data grid of Figure 20 is displayed under all transport activities. This data grid contains information about transport costs, transport documents and standard transport size.

Str. Stock	Batch
Work. Stock	Batch
R/R/R	
Employee	x hours

Figure 21, Data grid stock

The data grid of Figure 21 is displayed under each stock activity. This data grids contains information about strategic stock and average work stock.

The data grids above contain two specifics.

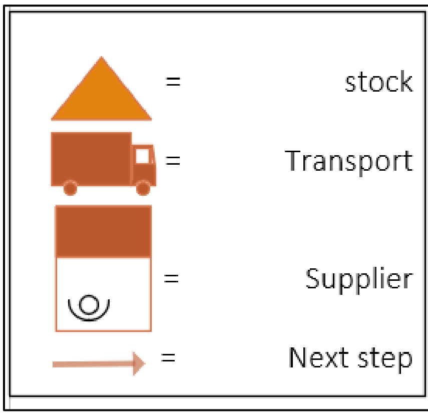
1. For privacy reasons, the abbreviations of the involved employees are not shown in the data grids above. The abbreviation of the employees would be displayed in the data grid instead of 'Employee'. The hours per employee in the data grids are the hours that an employee need for the routine execution of an activity.

2. Every time products are stored, the data grid shows R/R/R. This R/R/R is a percentage of the stock value. According to chapter 6. Validation, the R/R/R percentage has a lot of influences on the cost price. For this reason, the ASMs visualize how often this percentage occurs. The percentage is not mentioned here.

Figure 23 shows a generalized ASM of Product Z with data grids. All 23 activities have their own data grid and the flow of the supply chain is visualized. The same has been achieved for the supply chain of Product X (44 activities) and for Product Y (52 activities).

The second component which is added to the ASMs, is a legend. This legend contains the explanation for the abbreviations and symbols in the ASMs. Figure 22 is a generalized example of the legend of Product Z. All ASMs have their own legend, adapted to the information displayed in the ASMs.

Because the ASMs contain confidential data, they are not added to this thesis.



AA	= XXX XXXXX
AB	= XXX XXXXX
AC	= XXX XXXXX
AD	= XXX XXXXX
AE	= XXX XXXXX
EEA	= European Economic Area
EU	= European Union
MP	= Malvern Panalytical
R/R	= Risk/Rent
R/R/R	= Room/Risk/Rent
Ship. Costs	= Shipment costs
Ship. Doc.	= Shipment documents
Str. Stock	= Strategic stock
Work. Stock	= Working stock

Particularities:
1) Working stock is the average stock throughout a year
2) Over all man hours, 13% overhead costs is included
3) R/R/R equals 22% of added value
4) R/R equals 18% of added value

Figure 22, Generalized legend in Visio

5.6. Implementation blueprint

All steps taken to implement the ABC method have now been explained in detail. Below is a brief summary of all steps. This summary functions as a blueprint for the implementation of the ABC method for supply chains. By following the blueprint, you end up per supply chain with an overview of all activities and an overview of the cost price calculation.

- Step 1 Determine all activities that occur in the supply chain and visualize them.
- Step 2 Identify all consumed resources for each activity.
- Step 3 Identify all other cost factors.
- Step 4 Calculate for each activity the costs per detector based on all cost factors.
- Step 5 Expand the visualization with data for each activity.
- Step 6 Validate the results.

The validation of the results can be found in the chapter ‘6. Validation’.

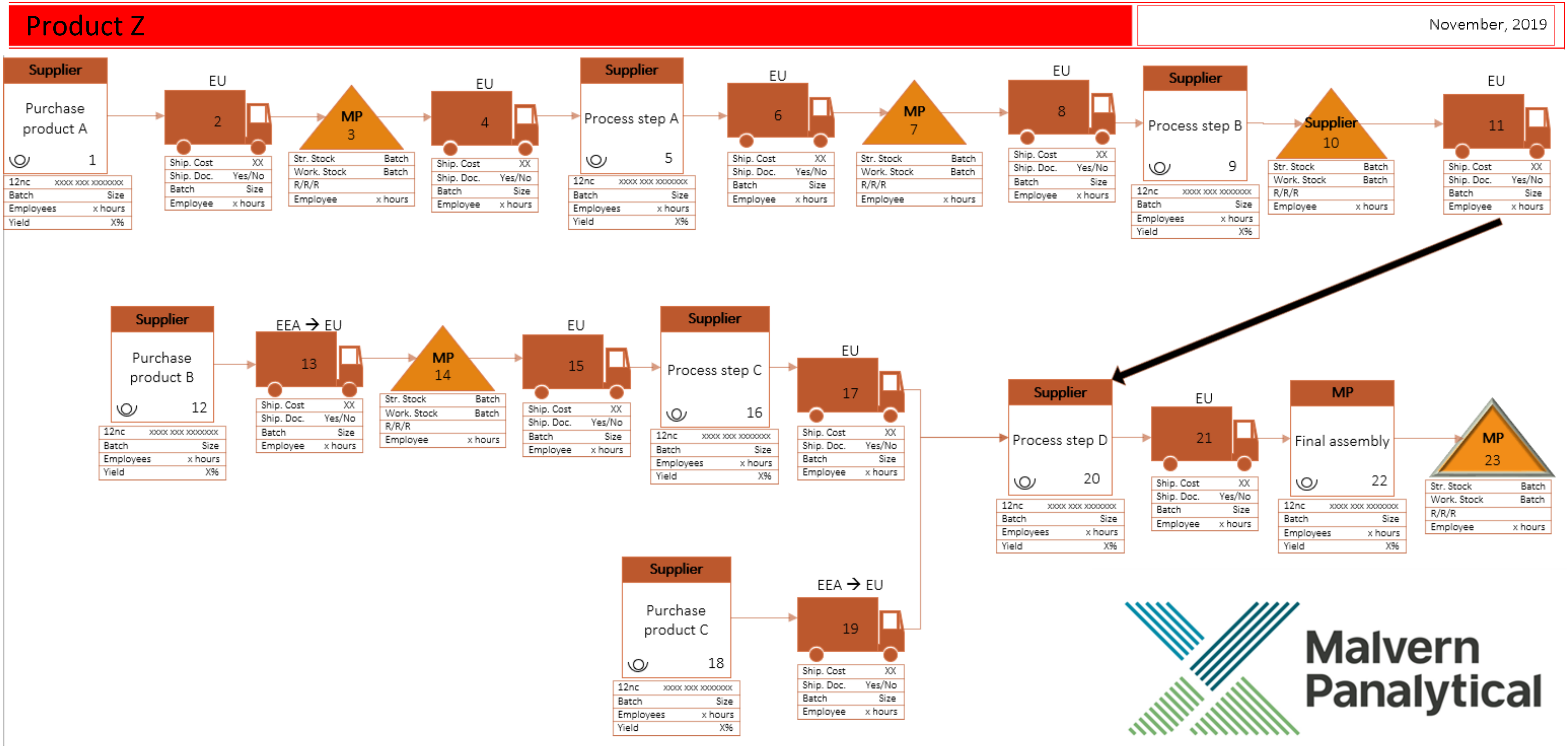


Figure 23, Generalized overview of Product Z

6. Validation

A cost price is calculated for each detector based on the ABC method. The calculated cost prices are between 61% and 147% higher than the cost prices known in QAD. This means that the costs that MP had in mind did not correspond to reality. Paragraph '6.1. Human error' explains some basic implemented steps to minimize the risk of human error. Paragraph '6.2. Effect of cost factors on cost price' elaborates on the different cost factors. In paragraph '6.3. Sensitivity analyses', the uncertainty in the cost prices are allocated to the uncertainty in the cost factors.

6.1. Human error

The following two steps have been taken to minimize the risk of human error:

The full overview of the mapped costs per activity were presented to all employees involved in managing the supply chains. To check that no costs were overlooked, these complete overviews were discussed with these employees. All missing cost factors have been added to the overview.

Many calculations have been made to calculate the cost price per detector. Each activity has different cost factors that all influence the costs per activity and therefore also the total costs per detector. To keep the chance of human error as small as possible, all three overviews were checked by a financial officer within MP. All calculations have been checked and adjusted where necessary.

6.2. Effect of cost factors on cost price

Determining the cost price using the ABC method has brought several new insights compared to previous knowledge. The cost price from QAD consists of the sum of all material costs and the direct man-hours required for the final assembly. The percentages of yield, which are known in QAD, are not included. This also applies to the costs of the specified man-hours, overhead costs and R/R/R percentage. For all detectors, the effect of each cost factor was examined. *This is explained by using percentages, because the prices may not be displayed due to confidentiality reasons.*

Since the yield factor often occurs at the end of the supply chain, it means that there is already a lot of value in the products that are lost. For this reason, the expectation is that yield is responsible for a large part of the increase in the cost price. For all detectors, the cost prices from QAD were compared to the cost prices from QAD plus the yield factor. The found cost prices are between 12% to 57% higher.

Apart from the final assembly, multiple detectors are processed during an activity. The costs of the man-hours are therefore distributed over all these detectors. As there is an average of two man-hours per activity, it is expected that the costs of man-hours are not responsible for a large part of the calculated cost price. The overhead costs are calculated as a percentage of the man-hours and therefore have even less influence. The cost price rises between 3% and 13% by adding the costs of man-hours. The overhead costs lead to an increase of 1% for all detectors. The 13% increase can be explained by the large number of activities in the supply chain and the low total costs of one detector.

Finally, the responsibility of the R/R/R percentage has been determined. In the current structure of the supply chain, stock is created on average per four activities. The R/R/R is a percentage of the product value and depends on average annual stock and average annual sales. The higher the product value and average annual stock, the higher the costs of this percentage. The R/R/R is responsible for an increase in the cost price between 48% and 78%.

The increase in the cost price of Product Z due to the various factors is shown in Figure 24. The effect of the cost factors to the cost price of Product X and Product Y can be found in Appendix C.1.

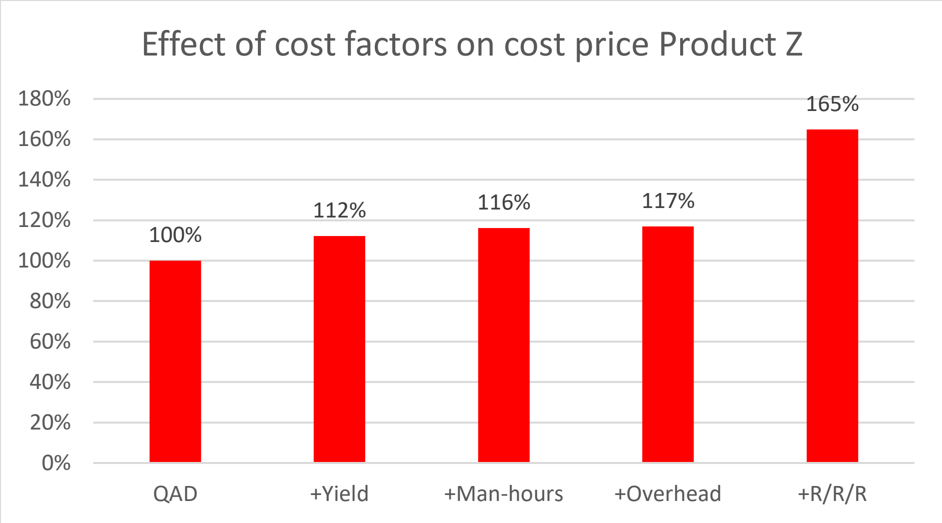


Figure 24, Cost factors effect Product Z

6.3. Sensitivity analyses

Several assumptions have been made for the calculation of the cost price according to the ABC method. These assumptions are uncertainties in the input of the calculations. With uncertainties in the input, the output can never be certain. A sensitive analysis is performed for all assumptions in chapter 5.3. Additional cost factors, to measure the effect of the assumptions on the cost price (Kenton, 2019). Assumptions have been made for man-hours, transport costs, R/R/R and overhead costs. For the analyses, one variable is changed at a time, then the effect on the total cost of the detector is determined.

The first variable to be looked at is the man-hours. The hours that employees spend per activity are largely estimated and rounded off per quarter of an hour. If this variable has a great effect on the cost price, it is advisable to determine these hours more precisely. Table 5 is the sensitive analysis of Product Z, the sensitive analyses of Product Y and Product X can be found in Appendix C.2. The analyses show that with a 10% increase of all man-hours, there is an average of 0.5% increase in the cost price. In other words, a doubling of all man-hours results in a 5% increase in the cost price. The man-hours therefore have little effect on the cost price and therefore do not have to be determined more precisely. Because the overhead costs are calculated based on a percentage of the costs of man-hours, the effect will be even smaller. This can also be seen in the results of the analyses.

A large part of the newly calculated cost price comes from the R/R/R. A change in this percentage appears to have a lot of influence on the total cost price as well. A 10% increase of the R/R/R percentage causes more than 3% increase of the total cost per detector.

The results of the sensitivity analysis for the transport costs are not included in the tables. If the estimated value of the transport costs is doubled for all transport activities, the cost price does not even increase by 1%. Because the transport costs have little effect on the cost price, it is not necessary to determine them more precisely.

Table 5, Sensitivity analysis Product Z

Variables	-20%	-10%	+10%	+20%
Hourly rate	-0.97%	-0.49%	0.49%	0.97%
Overhead	-0.11%	-0.05%	0.05%	0.11%
R/R/R	-7.14%	-3.51%	3.51%	7.14%

7. Conclusion

This chapter contains the deliverables, discussion points, contribution to theory and practice and limitations and future work.

7.1. Deliverables

In this chapter the results and deliverables of this research are discussed. The deliverables of this research consist of seven different overviews. The insights of these overviews answer the core problem:

> *There is no insight into the costs which are incurred for managing the supply chains of the detectors within Malvern Panalytical.*

To map the costs, all activities in each supply chain has been identified. Subsequently, it was examined for each activity which cost factors occur. With an overview of all cost factors, the cost price of the activity for a detector could be calculated. Finally, the cost price of all activities for one detector was calculated. This has been done for all three detectors separately. The following seven overviews provide insight into the costs which are incurred for managing the supply chains of the detectors within Malvern Panalytical.

7.1.1. Activity stream map

All activities found per supply chain are displayed in an activity stream map. Each detector has its own ASM. These ASMs have been supplemented with data to make them informative. This data does not contain any financial data so that the ASMs do not get outdated quickly.

7.1.2. Insight in all costs

For each activity in the ASM, all cost factors have been determined. The activities and the cost factors are listed in an Excel overview. All costs incurred per activity are visible in this overview. The costs are divided between indirect and direct costs, to show the effect of these variables. A cost price has been calculated for each detector. By entering the annual expected sale in the overview, the frequency for each activity is shown.

7.1.3. Overview of all man-hours

All man-hours spent on managing the supply chain have been mapped. All hours for the routine execution of the activities are visualized in de ASMs and used for the cost price calculation. The hours that employees spend on exceptions per activity and general matters have been processes in a different overview.

7.2. Discussion

The overhead costs are calculated within MP as a percentage of the costs of the man-hours. Because in the scope of this research the overhead costs could not be determined per activity, this percentage is used in the cost price calculations. According to the ABC method, the overhead costs should be assessed per activity. The sensitivity analyses show that the implementation of a standard percentage on the costs of man-hours has little effect on the cost price. However, the overhead costs could be much higher if they are not calculated as a percentage over the costs of man-hours. Although the detectors are an important component of the x-ray devices, it is only a small part of these devices. That is why overhead costs are likely to be low, but this cannot be said with certainty. Calculating the overhead costs per activity, could determine the cost price per detector more accurately.

During the problem identification, it emerged that insights into own costs could make it possible to compare cost prices with supplier. The equalization of these costs can be decisive for the choice to outsource. The costs are currently determined by the ABC method. If a supplier takes over a supply chain, they will have to manage it according to MP preferences, because the technology of the detectors is intellectual property of MP. The structure of the supply chain will therefore probably not change much, causing no difference in the total costs per detector according to the ABC method. A supplier will charge a profit margin on top of these costs and therefore have a higher cost price than MP has when they manage the supply chains themselves. If the supplier can change the structures of the supply chains and manage it more efficient for example, these costs do not have to be higher.
Regardless of the cost price, outsourcing could still be attractive when many hours of employees are freed up within MP. Freed up hours allow employees to work on something else, optimization projects for example, which are valuable for MP. If all three supply chains are fully, except the final assembly, managed by another supplier, an average of four hours per employee per week is freed up. These are the hours from the overview of exceptions per activity and general matters. Depending on which part of the supply chain is outsourced, hours are also freed up from the routine execution of activities. The more activities are outsourced, the more hours of employees are freed up. Especially for the supply chains with many activities, many hours can be freed up by outsourcing large parts of these supply chains. The number of hours which could be freed up per activity is easy to evaluate due to the man-hours per activity and the frequency of the activities based on annual sales in the overviews.
So, the decision to outsource depends on the costs of the supplier, the agreements with the suppliers about the management of the supply chains and the amount of freed up man-hours. Because of all these variables, it is not possible to decide which parts of the supply chains should be outsourced with the current knowledge.

7.3. Contribution to theory and practice

Contribution to theory

This research is practice-oriented, but that does not mean that it has no added value for literature. This research has achieved a successful implementation of the ABC method for a global supply chain. The combination of two different frameworks has resulted in a new 5-step framework. The explanation of this 5-step framework in this thesis is generally written and does not focus on products of MP. This means that this framework can easily be applied to the supply chains of other companies.

Contribution to practice

Apply the method of this research to future detectors. By displaying the activities in the same way in an ASM, there is unity in the overviews for all detectors within MP. This makes the supply chains easier to understand for all employees. The main reason for applying the method of this research is the large difference in cost price. The cost prices that are known in QAD do not come close to the actual incurred costs. If decisions must be made for outsourcing parts of the supply chain, the data from QAD is not reliable.

The second recommendation is to use the created overviews. From the overviews of the cost price calculation, the frequency and man-hours per activity can easily be retrieved. Together with the information from the overview regarding general matters, it is possible to calculate exactly how many hours per week are freed up per employee when parts of the supply chains are outsourced. Regardless of the cost difference, the number of freed up man hours can be decisive for the decision whether to outsource.

The final recommendation is to take yield into account when determining the cost price. In QAD it is already known for which products there is a yield percentage. This percentage is used to determine the demand of a product. In this research it has been shown that the yield percentage has a lot of influence on the cost price of a product. By using the yield percentage, the cost prices in QAD are determined more accurate than in the current situation.

7.4. Limitation and future work

Limitation

The sensitivity analysis has shown that the R/R/R percentage has much effect on the cost prices of the detectors. In 2017, the R/R/R was determined for two of four locations where products from the detector supply chains are stored. To determine the prices of the detectors even more accurately, the storage location of the stock activities must be known, and the R/R/R must be calculated for each location. This R/R/R depends on size of the space, costs of the storage cabinets, average service costs, labor costs per location, weighted average cost of capital (WACC) and insurance as a percentage of the total average stock value. Since the research has already been carried out within MP, only the numbers in the calculation need to be adjusted to calculate the correct R/R/R for each location. When the results of these calculations are processed in the cost price calculations, the total cost price is determined more precisely.

This research is based on a lot of confidential information that cannot be shared outside of MP. As a result, it is not possible to discuss certain decisions or results in this theses. The depth of this research can therefore not be properly described in this thesis.

Future work

It is explained in 7.2. Discussion that the decision to outsource depends on a lot of variables: the costs of the supplier, agreements with the suppliers about the management of the supply chains and the amount of freed up man-hours. Because of all these variables, it is not possible to decide which parts of the supply chains should be outsourced with the current knowledge.

The results of this research can be found in various overviews. These overviews provide a lot of information, but it takes time to understand all the information. To determine whether or not to opt for outsourcing, the overviews must be thoroughly reviewed and other variables must be determined. A topic for a follow-up study could be the creation of a dashboard. This dashboard should implement the results of this research and should have room for the implementation of the other variables. Depending on the different variables, the dashboard should show which parts of the supply chain are most profitable to outsource. This dashboard can be expanded with various options, for example by showing in which part of the supply chain the most man-hours could be freed up or compare the costs of different suppliers and show the most profitable option.

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Appendix A: Systematic literature review

A.1. Database

The database 'Google Scholar' is used to find scientific articles for this systematic literature review. Google scholar is easily accessible and user friendly. The biggest advantage of Google Scholar is that it allows the use of Dutch search terms, where databases like 'Web of Science' or 'Scopus' for example do not.

A.2. Criteria

Before looking up random search terms which are associated to the ABC method, it is critical to think about criteria which you want to exclude from you research. 'Table 6, Criteria' shows included and excluded criteria for this SLR.

Table 6, Criteria

Inclusion criterium	Reason
Articles about the use and theory of the ABC method	The goal is to understand and apply the method
Article is written in Dutch or English	I can read both languages comprehensively
Exclusion criterium	**Reason**
All articles/sections which are not freely accessible	There is no budget for this literature review
Article is written in a language other than English or Dutch	I cannot read other languages with sufficient comprehension
Content of articles focused on healthcare	This research is focused on product manufacturing

A.3. Articles

Appendix A.4. shows an overview of the number of entries found and the number of entries used per search term. Looking up the search term 'Activity based costing' resulted in thousands of entries. Therefore, more detailed search terms were necessary to come with less entries. Unfortunately, there were no Dutch articles with an introduction about the topic. Between the final four entries, there were no duplicates. I ended up with 5 useful articles. Appendix A.5. shows an overview of the used articles. After reading the five articles I made the conceptual matrix which can be found in Appendix A.6. The matrix is based on similarities between the articles. Subjects which were only mentioned in one article, are not shown.

A.4. Use of Google Scholar

Table 7, Use of Google Scholar

Search term	**Additional search options**	**Number of entries**	**Number of entries used**
allintitle: introduction to activity based costing	-	11	1
Allintitle: “Activity-based costing method” filetype:pdf	Since 2009, PDF	21	2
Allintitle: “activity based costing” AND “supply chain”	Since 2009	13	1
all in abstract: "activity based costing" AND "overhead" AND "supply chain"	Since 2009	14	1
Total entries	**Additional information**	**59**	
Duplicates		0	
Removed due to inclusion/exclusion criteria	Removed based-on comparison between title and criteria	46	
Removed after first impression of article		8	
Total used		**5**	

A.5. Articles used

Table 8, Articles used

Article	Author(s)	Publishing year	Source
1. Activity-Based Costing and Activity-Based Management for Health Care	Judith J. Baker	1998	(Baker, 1998)
2. Target costing based on the activity-based costing method and a model proposal	Selim Yuksel Pazarceviren, Duygu Celayir	2013	(Yuksel Pazarceviren & Celayir, 2013)
3. Effective cost analysis tools of the activity-based costing (ABC) method	Sorin Briciu, Sorinel Capusneanu	2010	(Briciu & Capusneanu, 2010)
4. Activity-Based Costing and management in the supply chain. An expired hype or an undervalued tool?	Arthur Zondervan	2009	(Zondervan, 2009)
5. Activity-Based Costing (ABC) – An Effective Tool for Better Management	Ishter Mahal, Akram Hossain	2015	(Mahal & Hossain, 2015)

A.6. Conceptual matrix

Table 9, Conceptual matrix

Article/year The numbers refer to articles in 'Appendix A.5.'	History of ABC	ABC in comparison with traditional costing methods	Concept of ABC explained	Model for ABC method	Advantages vs disadvantages of the ABC method	Focus on overarching method instead of ABC
1. 1998	x	x	x	x	x	
2. 2013	x		x	x		x
3. 2010			x	x		
4. 2009			x		x	x
5. 2015	x	x	x		x	

Appendix B: Quantification of man-hours

Most of the time, it appears if an activity occurs multiple times it consumes the same number of resources. For example, sending a product to a company requires a transport document (Figure 18). The destination of the product does not change the time for making this document. So, the consumed man-hours are on average the same every time. This also applies to several other activities:

1. Communication to another company on average takes an hour. This communication can be focused on purchasing a product or having process steps carried out (Figure 10).
2. If the activity at a supplier has at least one incoming connector, the activity requires a work order. A work order is a document used internally in MP, so that employees know that the order has been set in motion (Figure 15). It takes 45 minutes to make a work order.
3. Creating the shipping document to send products to a supplier takes one hour.
4. To receive products, move them, store them, pick them up and send them again, 90 minutes are consumed in total.

According to the ABC method, every activity needs to be carefully examined. The above points therefore do not apply to all activities and have not been used as standard. All activities were discussed with each employee involved in managing the supply chains in order to chart how much time is spent on each activity. The information gained through these conversations answered the knowledge problem: *How many hours does which employee spend on which activity?*

Appendix C: Validation visualisation

C.1. Effect of cost factors

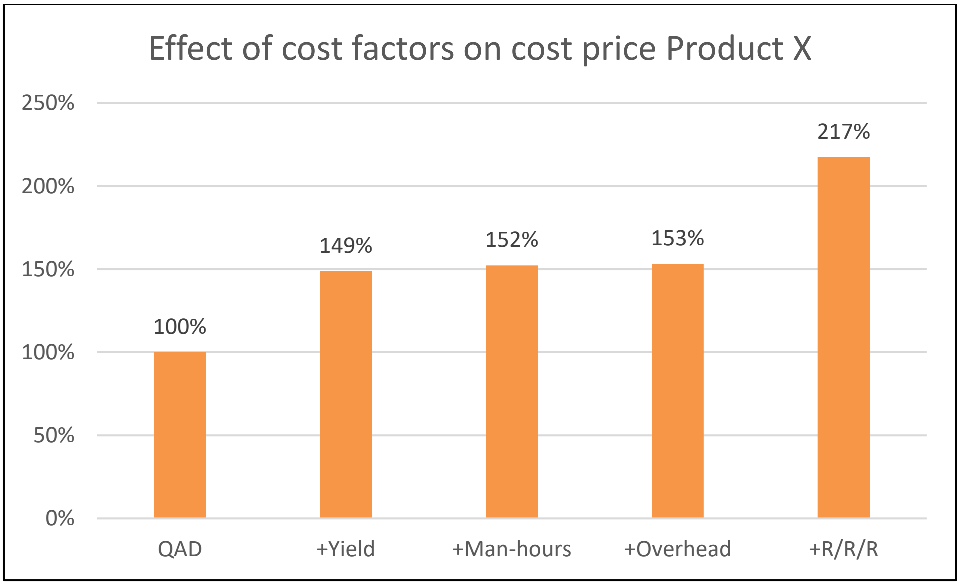

Figure 25, Cost factors effect Product X

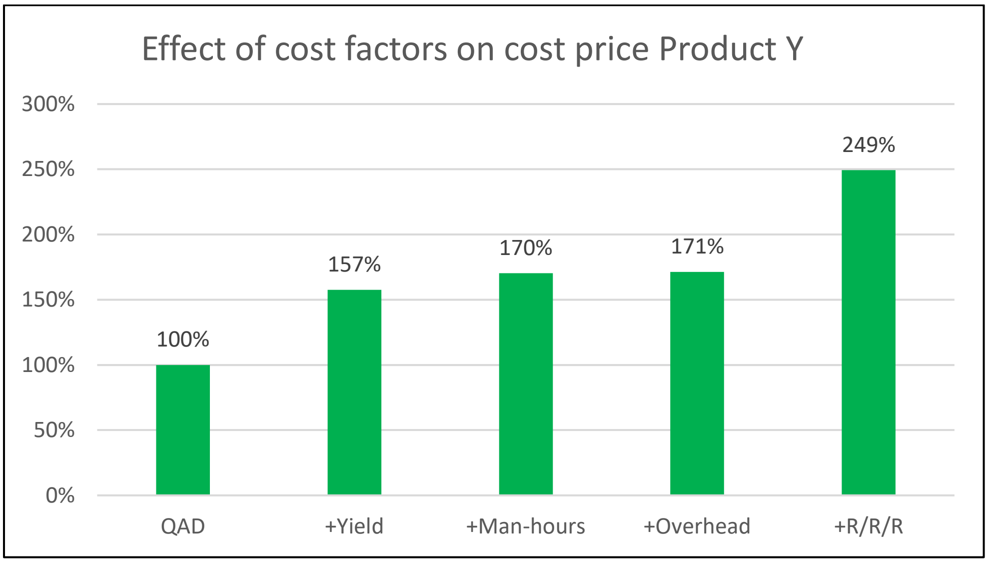

Figure 26, Cost factors effect Product Y

C.2. Sensitive analysis

Table 10, Sensitivity analysis Product X

Variables	-20%	-10%	+10%	+20%
Hourly rate	-1.16%	-0.58%	0.58%	1.16%
Overhead	-0.12%	-0.06%	0.06%	0.12%
R/R/R	-8.12%	-3.95%	3.95%	8.12%

Table 11, Sensitivity analysis Product Y

Variables	-20%	-10%	+10%	+20%
Hourly rate	-1.11%	-0.55%	0.55%	1.11%
Overhead	-0.11%	-0.05%	0.05%	0.11%
R/R/R	-8.17%	-3.98%	3.98%	8.17%