MASTER

Improvement of inventory performance by incorporating the risk of obsolescence in a dynamic MTO/ATO environment at VDL ETG

Simons, J.A.M.

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Improvement of inventory performance by incorporating the risk of obsolescence in a dynamic MTO/ATO environment at VDL ETG

by Jan Simons
Student number 0877884

Master of Science in Operations Management and Logistics
keywords: assemble-to-order, make-to-order, item, production environment, demand process, obsolescence, sudden death obsolescence, inventory control, inventory policy
Abstract

In general, high tech items are characterized by high prices, and rapid technological changes. This may result in obsolete inventory and high obsolescence costs, which negatively influences a company’s inventory performance. In this master thesis project, we have analyzed the causes of obsolescence within the production environment of VDL ETG. We have interviewed multiple employees and analyzed data related to inventory. We have analyzed VDL ETG’s definition regarding obsolescence, and we concluded that this definition has several shortcomings. Currently, VDL ETG classifies an item as obsolete if it has not ‘moved’ during the past four months (i.e., change of location or no decrease or increase of stock levels). Therefore, we adjusted the definition: an item is classified as obsolete if no demand has occurred during the past two years. By means of the adjusted definition and real demand data we have estimated the risk of obsolescence, based on the model of Jaarsveld and Dekker (2011). Furthermore, we have analyzed the item characteristics and their association with obsolescence. Finally, we have proposed an improved inventory model that incorporates the risk of obsolescence, the model of Cobbaert and Van Oudheusden (1996).

Our analyses showed that the obsolescence risk is clearly present in VDL ETG’s production environment. The expected time for an item to become obsolete is 1.9 years. Furthermore, we were not able to identify item characteristics that are independent predictors of obsolescence. This implies that each item type may become obsolete. However, the numerical analysis, based on real demand data, shows that VDL ETG can improve their current inventory model by incorporating the risk of obsolescence.
Management summary

This report presents results of a master’s thesis project on obsolescence within the assemble-to-order (ATO) and make-to-order (MTO) production environment of VDL ETG.

Problem statement

VDL ETG produces highly complex and innovative mechatronic systems. It is a tier-one manufacturer partner of multiple original equipment manufacturing companies worldwide, which are active in different markets (e.g., semiconductor industry, health care). In 2014, Kamps and Arts have identified several issues that complicate VDL ETG’s supply chain. Subsequently, they set up several projects to address these issues. Their aim was to improve the performance of the supply chain.

One of these issues is obsolete inventory within the production environment of VDL ETG. All inventories are managed by the department Integral planning. They release production and purchase orders to keep inventory at a sufficient level, to ensure continuity of the operations in the departments Parts and Systems. However, high tech systems are characterized by high prices, and rapid technological changes. This may result in obsolete stock and high obsolescence costs. Therefore, we are interested in the impact of obsolescence on the performance of VDL ETG’s supply chain. The main research question of this master’s thesis project yields practical value for the Systems department, and contributes to the scientific field of obsolete inventory:

*How should VDL ETG incorporate the risk of obsolescence within their purchasing policy, to decrease obsolescence costs and to increase inventory performance?*

As-is situation regarding obsolescence

At the moment, VDL ETG classifies an item as obsolete if it has not ‘moved’ during the past four months (i.e., change of location or no decrease or increase of stock levels). We analyzed the impact of the purchase policies MOQ and EOQ, and long lead time items on the obsolescence costs in the as-is situation. Next, we analyzed the quantities of obsolete items that are purchased according to the EOQ policy. This showed us that a large fraction of the obsolescence costs is represented by items that are purchased according to this policy (81%). In most cases, the quantity of these obsolete items is equal or larger than EOQ (63%), which is due to a lack in monitoring of purchase parameters in BaaN. We concluded that the impact of MOQ and long lead time items on the obsolete inventory is negligible.

The systems of VDL ETG’s customers are produced within the ATO or MTO environment. Therefore, we divided the obsolescence costs per customer and production strategy. From this, we concluded that a large fraction of the obsolescence costs (65%) is represented by two largest customers. Furthermore, this analysis showed us that within the MTO environment the obsolescence costs are higher, compared to the ATO environment, because the ATO environment is more stable (i.e., more constant demand over time), compared to MTO.

During our analysis on the as-is situation regarding obsolescence, we identified several shortcomings of the current definition. This definition classifies an item as non-obsolete when it changes of location, or when its inventory level increases. Furthermore, this definition classifies an
item as obsolete, even if it has been reserved for production or assembly. We analyzed the fraction of items that has been classified as obsolete, while it has been reserved. We concluded that 25% of the total obsolete inventory has been incorrectly classified as obsolete.

**Estimation of the obsolescence risk**

Due to the shortcomings of the current definition regarding obsolescence, we proposed a new definition which we used in all successive analyses. Analysis of the data and conversations with multiple employees have led to the following definition: an item is classified as obsolete if no demand has occurred during the past two years. Based on this definition, we used the model of Jaarsveld and Dekker (2011) to estimate the obsolescence risk. We conclude that the risk of obsolescence is clearly present with the production environment of VDL ETG. The expected time until an item becomes obsolete is 1.9 years.

Additionally, we performed a statistical analysis to analyze item characteristics and their association with obsolescence (i.e., logistic regression analysis). However, the Goodness of Fit Test shows that our model has a poor fit. This implies we were unable to identify item characteristics that predict obsolescence. This implies that each item type may become obsolete in the subsequent two years.

We performed a numerical study to compare VDL ETG’s current inventory model, and a similar inventory model that incorporates the risk of obsolescence, based on real demand data. From this, we concluded that incorporating obsolescence risk results in cost savings for VDL ETG. In some cases, VDL ETG purchases more than two years in advance. This is not preferable, because it may lead to obsolete inventory (i.e., expected time until obsolescence is 1.9 years).

**Recommendations**

Our analyses have shown that the risk of obsolescence is an important issue within the production environment of VDL ETG. Each item type may become obsolete in the subsequent period. Our analysis on demand process shows that VDL ETG faces both “sudden death” obsolescence and obsolescence due to gradual decrease in demand. However, currently the purchase parameters in BaaN are entered at the start of its life cycle, and not monitored or updated during an item’s life time. Therefore, we recommend VDL ETG to monitor these parameters. This helps them to better anticipate to decreases of demand and obsolescence. Additionally, we recommend to incorporate the risk of obsolescence within their purchase and inventory policy. Next, we recommend to avoid using EOQ policy within the MTO environment anymore. The demand in the MTO environment is not stable over time, compared to the ATO environment. Therefore, the EOQ policy within MTO results in higher obsolescence costs.

If VDL ETG decides to maintain their current definition regarding obsolescence, we recommend that they only classify an item as obsolete if it has not ‘moved’ for more than four months and it has not been reserved for production. This will provide a better estimation of the actual obsolescence costs.
Preface

This report is the result of my master’s thesis project, which I conducted at VDL Enabling Technologies Group Eindhoven between February 2016 and July 2016. The project is the final part of my master in Operations Management & Logistics at the Eindhoven University of Technology.

First, I would like to express my gratitude to dr. Willem van Jaarsveld, who served as my first supervisor from Eindhoven University of Technology. His enthusiasm about the subject, and support through the entire project made me enjoy this final phase of the master. Furthermore, he taught me how to convey scientific knowledge to companies. Thank you very much for your help. I also want to thank prof. Ton de Kok, my second supervisor from Eindhoven University of Technology, for the valuable feedback on my thesis. Thank you for the opportunity to work on the BTO project as well. It was a pleasure to be part of this interesting and challenging project.

Next, I would like to thank both company supervisors. I thank John Langenhuysen, my first supervisor from VDL ETG. Your operational knowledge related to production and inventory control within VDL ETG helped me a lot by identifying the actual problem, and to improve the quality of my thesis. I also would like to thank Jeroen Zwiep. Your questions and feedback have enabled me to look more critical to my own work. John and Jeroen, thank you for giving me full responsibility to work on this research project. You enabled me to shape my own research. Finally, I would like to thank all colleagues at VDL ETG for answering all my questions, providing me with input and suggestions. Also, thank you for letting me be part of your pleasant working atmosphere.

Last but not least, I would like to express my gratitude to my family, girlfriend and friends. I would like to thank my friends for the great years during my study in Delft and Eindhoven. Special thanks go to my parents Jan and Gerry, and my girlfriend Ivy. Thank you for supporting me throughout my study.

Jan Simons
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1. Introduction

This report presents the results of a master’s thesis project on obsolete inventory in the production environment of VDL Enabling Technologies Group Eindhoven (VDL ETG). An item is classified as obsolete if it cannot be used within production anymore. Therefore, obsolete inventory refers to obsolete items that are still kept in stock. VDL ETG belongs to the subcontracting division of the Van Der Leegte Group. VDL ETG is a tier-one (i.e., delivers directly) contract manufacturing partner of the Van Der Leegte Group. VDL ETG is a tier-one (i.e., delivers directly) contract manufacturing partner of multiple original equipment manufacturing companies. Therefore, VDL ETG produces highly complex and innovative mechatronic systems for customers worldwide (e.g., medical equipment, semiconductor devices; VDL ETG, 2013d).

Goyal & Giri (2001) and Ho & Li (1997) characterized these high-tech items as following; relatively high priced, long-life cycle, a high number of parts and rapid technological changes. These characteristics make it difficult to determine appropriate inventory levels. Too low inventory levels can lead to shutdown of production or assembly. In contrary, too high inventory levels lead to unnecessary high holding costs (i.e., total expenses to keep a certain level of inventory). Furthermore, high inventory levels may result in obsolete items. In 1996, Cobbaert and Van Oudheusden defined a clear difference between obsolescence, perishability and deterioration. Items which are subject to perishability have a fixed life time. After their life span, they perish completely and become useless (e.g., a photographic film). Deterioration refers to items that have a stochastic life time, which means that a certain proportion of stock will deteriorate per time unit (e.g., the breakage of glassware) (Cobbaert & Van Oudheusden, 1996, p. 240). Finally, they define obsolete items as items whose demand has decreased towards zero. This indicates that these items have entered the end of life phase (i.e., last phase of an item’s life cycle). Therefore, they become useless for usage in the future. This situation may occur when an item is replaced due to a design change.

This study aims to improve the inventory performance and ordering policy of VDL ETG. The inventories within VDL ETG are managed by the department Integral planning, who are physically located at the department Systems (see Figure 2). This department is responsible for the assembly of semi-finished items for several customers (e.g., ASML and FEI). Semi-finished items are transferred towards the Expedition department. The main research question addresses both practical value for the Systems and Integral planning department, and contributes to the scientific field of obsolete inventory:

How should VDL ETG incorporate the risk of obsolescence within their purchasing policy, to decrease obsolescence costs and to increase inventory performance?

In section 1.1, VDL ETG will be introduced. In section 1.2, the supply chain of VDL ETG and the characteristics of the department Systems will be described. Subsequently, section 1.3 will discuss the problem environment. In section 1.4, the main and sub research question will be introduced. Finally, in section 1.5 the scope of the project will be defined, and in 1.6 an outline of the master thesis will be presented.
1.1. Company background

In 1952, Pieter van der Leegte established the company ‘Metaalindustrie en Constructiewerkplaats P. van der Leegte’, and thereby he laid the foundation for VDL Group. In 1977, the company expanded after a first take over. Meanwhile, the VDL Group is an international industrial company that consists out of 85 companies in 19 different countries and has over 10,300 employees (VDL Group, 2014). In 2012, VDL Group took over Nedcar, and thereby became the only car assembler in the Netherlands (VDL Group, 2015). Since then, VDL Group focuses on the production and sales of semi-finished and finished items, busses and assembly of cars. Its headquarter is located in Eindhoven, and operating companies with their own specialisms are coordinated from here (VDL Group, 2014).

Originally, the ETG company was established as ‘Philips Machinefabriek’ in 1900. During the 80’s, the company developed strong relationships with original equipment manufacturing companies like ASML and FEI. Those companies both belonged to Philips at that time. During the 90’s, ‘Philips Machinefabriek’ grew and became a worldwide supplier of integrated solutions for Philips and other customers. In 2000, the company changed its name into Philips Enabling Technologies Group. After acquisition in 2006, the company became part of the VDL Group (see Appendix A.1). This resulted in VDL Enabling Technologies Group (VDL ETG, 2013a). An organizational chart of the VDL Group and VDL ETG are illustrated in Appendix A.1 and A.2, respectively (VDL Group, 2015).

VDL ETG is a worldwide operating tier-one contract manufacturing partner (i.e., direct supplier to original equipment manufacturers). Their customers are leading high-tech original equipment manufacturers, which operate in highly demanding markets (i.e., semicon & analytical, solar, medical, aerospace & defense, and production automation market; VDL ETG, 2013c). To support their customers worldwide, they have manufacturing facilities in China, the Netherlands, Singapore, Switzerland and USA (VDL ETG, 2013b). Unless stated otherwise, VDL ETG refers to VDL ETG Eindhoven.

The company supplies multiple customers worldwide. However, their customer base is relatively small. Hence, their business environment consists of only few businesses. VDL ETG’s turnover is mainly generated by sales towards companies within the semicon & analytical market. ASML, also a former company of Philips is a big customer of VDL ETG.

ASML manufactures lithography systems (i.e., scanners) to assist leading chip manufacturers (e.g., Intel and Samsung) in sustaining Moore’s law (ASML, 2016a). Moore’s law states that the number of transistors in an integrated circuit doubles approximately every two years (Moore, 2006). According to Qiu and Beaubois (2013), ASML is world’s leading provider of lithography systems, with a market share of 74%. Their market share will expand even more after the introduction of their new extreme ultraviolet lithography systems. In 2012, ASML started a ‘Customer Co-Investment Program’ to accelerate the development of the extreme ultraviolet technology to stay ahead of its competitors (ASML, 2016b). Thus, the management of VDL ETG expects a growth in demand from this customer (i.e., VDL ETG operates as tier-one supplier). Furthermore, they expect that the demand of other customers, who also supply to ASML, will increase as well (i.e., VDL ETG operates as a tier-two supplier).
1.2. VDL ETG’s supply chain

The internal supply chain and control structure of VDL ETG is depicted in Figure 2. Within this section, the production process and related departments will be discussed in general. In Appendix A.3, all functions related to the supply chain of VDL ETG are described. The specific organization of the supply chain differs per customer (e.g., FEI, ASML) or customer’s system. This will be further elaborated in section 2.2.

Integral planning is responsible for the goods flow control and is part of the Production office. The Production office creates master production schedules, which are based on the demand plan of their customers. This demand plan consists of forecasts and current booked orders. Based on this data, the enterprise resource planning of VDL ETG, which is called BaaN, suggests a material requirements planning. This planning is reviewed, and if necessary adjusted by the integral planner (i.e., employees at the department Integral planning). Finally, the customized planning is used by the integral planner to release production orders (i.e., requires Parts manufacturing to produce the required items) and procurement orders (i.e., requires Operational procurement to purchase the required items). Both, material requirements planning and master production schedules may be updated frequently, due to demand volatility of VDL ETG’s customers.

The second sub-department within Production office is Order management. They are responsible for direct contact with the customers and matching customer’s demand with supply. This department communicates with the customer about future orders and creates a demand plan, which serves as input for material production schedule. When the customer requires rescheduling, he communicates this with the order managers. Both, orders and rescheduling are communicated by order managers towards Integral planning.

Within the department Parts, Planning Parts is responsible for the planning of Parts manufacturing. Planning parts receives a planning advice from BaaN that has been approved by Integral planning. Based on this planning, Planning parts creates a production planning, which takes into account the released production orders from Integral planning to make sure that these are met. This planning is sent to Parts manufacturing. Zwartelé (2016) describes the Parts manufacturing as a job shop environment (i.e., a customer order driven manufacturing environment with small and unique batches). Besides production orders, Integral planning also releases procurement orders. These serve as input for Operational procurement. They are responsible for carrying out the released procurement orders. These activities take place parallel in time with activities of Parts.
Subsequent to *Operational procurement* and *Parts*, systems are assembled in the *Systems* department. Within this department, components are assembled to sub-assemblies or final items. Assembly can take place within a modern factory hall or within a cleanroom. If assembly takes place in a cleanroom, the required items need to be cleaned from dust and filth before they are allowed to enter. Production floor within *Systems* can be seen as a flow production line. *Systems’* production unit is characterized by high flexibility in terms of capacity, because the capacity is mainly dependent on operators who perform rather generic operations.

Input material control differs between *Parts* and *Systems*. Within *Systems*, a production assistant is responsible to release material from inventory. The assistant has insight in stock levels and item availability at the stock points. Hence, the stock point is included in *Systems* within Figure 2. *Integral planning* can also review the inventory levels, but they cannot directly release material from stock. For *Parts*, full material availability is assumed. Both stock points at *Parts* and *Systems* are managed by *Integral Planning*.

Items are kept at project inventory or anonymous inventory (visualized with triangles in Figure 2). The important difference between these inventory types is that items within project inventory are financially committed by VDL ETG’s customer, and items in anonymous inventory are not. Anonymous items may have only partially commitment, or even no commitment. Due to lack of commitment, VDL ETG needs to cope with the financial consequences if the anonymous items become obsolete. We will discuss these inventories in greater detail in section 2.1.

### 1.2.1. The customer order decoupling point

In their supply chain, VDL ETG applies two different production strategies, namely Assemble-to-Order (ATO) and Make-to-Order (MTO). Which strategy is used, depends on whether the production is forecast-driven (ATO) or order-driven (MTO). The main difference between these strategies is the
position at which a customer order is accepted (i.e., customer order decoupling point). These positions are visualized in Figure 3. In an ATO environment a customer order is accepted more downstream in the supply chain, in comparison to MTO. Within ATO, sub-assemblies are produced based on a forecast, and kept in stock before *Systems Assembly*. When an order is placed, these sub-assemblies are assembled into a final item within *Systems Assembly*. If a system is entirely produced within the ATO environment, the production of these items is forecast driven (e.g., wafer handler of ASML). Within the MTO environment, production and assembly starts after an order has been received. Therefore, the customer order decoupling point is located more upstream in the supply chain. These different locations of customer order decoupling points, result in different inventory types (see Table 1), and the location where inventory is kept within the supply chain (see Figure 3).

**Table 1: Inventory types per production strategy.**

<table>
<thead>
<tr>
<th>Supply Chain</th>
<th>Raw material</th>
<th>Work-in-Progress</th>
<th>Semi-finished item</th>
<th>Final item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assemble-to-Order</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Make-to-Order</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Arts (2015) concluded that VDL ETG faces demand uncertainty from their customers. This uncertainty is more related to the moment the customer will buy, rather than if they will actually buy. Due to the demand uncertainty, the exact future demand within the supply chain is unknown. This does not correspond with the terms as defined in the literature. Therefore, Arts (2015) has developed an alternative view of the customer order decoupling point within the supply chain of VDL ETG (see Figure 3). The different inventory types in the supply chain, and the ATO and MTO environment in relation to obsolescence costs will be discussed in chapter 2.

![Figure 2: Customer order decoupling points (CODP) in the supply chain of VDL ETG.](image)

### 1.3. Problem context

In this section, the complexity of VDL ETG’s supply chain (see Figure 2) is discussed. Their supply chain is characterized by high-tech items, demand and supply uncertainties. In 2014, Kamps
and Arts set up the document ‘A roadmap to the improvement of VDL ETG’s supply chain efficiency & control’. Their goal is to minimize costs while maintaining a certain service level. By interviewing several stakeholders and understanding all processes within the supply chain, they identified multiple key issues regarding the complexity of their supply chain (see Figure 3).

Figure 3: Key issues in supply chain of VDL ETG. Based on “A roadmap to improvement of VDL ETG's supply chain efficiency & control” by Kamps and Arts (2014). The grey circles are directly related to obsolescence.

These issues were used as input to set up a cause and effect diagram (see Figure 17 in Appendix A.4). This diagram enabled Kamps and Arts (2014) to identify the root causes of these problems. From this diagram we conclude that four main problems have a negative impact on the supply chain, namely; high inventory costs, high planning workload, low responsiveness and large investment in work in progress. During our project we focus on obsolete inventory with respect to the inventory performance (i.e., inventory costs). Obsolescence occurs when demand and supply are not equal. This is a result of multiple factors (e.g., uncertainties, design changes, high unit price). Figure 3 shows three major uncertainties which VDL ETG faces, and which may lead to obsolescence, namely demand date uncertainty, variance in supplier lead times and relevant yield issues. Furthermore, three external factors are directly related to obsolescence costs (grey circles in Figure 3). Highly technical items are subjected to many design changes. Therefore, items are replaced frequently (i.e., have a short life cycle; Goyal & Giri, 2001; Ho & Li, 1997). This results in obsolete items and obsolete inventory. The agreed lead time between VDL ETG and their customer is shorter compared to the actual time required for production. For that reason, VDL ETG is forced to purchase and procure several items in
advance. However, due to short life cycles these items may become useless. In general, the items on stock (i.e., required for production) are expensive. When these items become obsolete, the obsolescence costs (i.e., total value of obsolete items in stock) increase, which has a negative impact on the inventory performance.

Based on the cause and effect diagram, Kamps and Arts (2014) identified several master thesis projects that could improve the performance of VDL ETG’s supply chain (see section 1.3.1). The suggested projects are plotted against time in a swim lane diagram (see Appendix A.5). Within the next section we will describe which projects have been carried out already.

1.3.1. Roadmap towards improvements in the supply chain of VDL ETG

Project number 4 was the first project of the roadmap (see Figure 18 in Appendix A.5). This project focused on the improvement of rescheduling policies. This topic has been researched by Kamps (2015). Subsequently, Arts (2015) focused on project 6 and 10. At the beginning of 2016, Zwartelé finished project 7 and 9. These projects consider the control issues of Parts. Initially, this research would also include project 8 ‘an evaluation of minimal order quantity (MOQ), economic order quantity (EOQ) and economic production quantity (EPQ)’. Zwartelé (2016) mentioned that Integral planning is responsible for these calculations. Hence, there is a clear physical decoupling between Parts order release (‘project 8’, Integral planning) and Parts production control (‘Project 7 and 9’, Parts planning). This, in combination with the complexity of ‘project 8’, is why Zwartelé (2016) decided to keep project 8 out of the scope, and to focus on project 7 and 9.

To decide the project for this master thesis project, several interviews with multiple employees from different departments have been performed. During these interviews several employees mentioned that it is valuable to investigate the problems regarding obsolete inventory. Therefore, we decided to investigate the causes of obsolete inventory. In addition, the risk of obsolescence will be estimated, and we will investigate how this risk can be incorporated within the ordering policy of VDL ETG. This means that project 1 and 8 will be conducted during this master thesis project (see Appendix A.5). However, during our project we will not focus on EPQ. EPQ depends on the production capacity at the department Parts. This is behind our scope (see section 1.5).

1.3.2. Problem context VDL ETG Systems and Integral Planning

Obsolescence occurs both within anonymous and project inventory (see section 1.2; Langenhuysen, 2016a). During this project we held several interviews about the causes of obsolescence at VDL ETG. The information from these interviews has been used to create a cause and effect diagram related to obsolescence (see Figure 19 in Appendix A.6). The main effects of obsolete inventory are high obsolescence/inventory costs, and subsequently decrease of inventory performance. The five most important causes that came forward during the interviews are;

- Integral planning creates a planning, based on the demand plan of VDL ETG’s customers. VDL ETG cannot purchase the exact required number of items, as prescribed in this planning, because they are forced to order more than required. This is a result of minimal order quantity (MOQ) policy of its supplier. The required amount (stated in the planning) will be booked to project inventory. The surplus quantity needs to be kept in anonymous
inventory, and it is up to VDL ETG to decide whether these items can be used in another project or not.

- VDL ETG purchases more than stated in the planning of *Integral planning*. This policy is mainly used when VDL ETG estimates that all purchased items can be used within production (i.e., based on customer’s forecasts). The directly required items are used within production. The surplus items are kept in anonymous inventory, and used when they are required. In this case, VDL ETG purchases items according to the economic order quantity policy (EOQ) of Harris (1913). According to this policy, purchasing more than required leads to lower annual costs per item, compared to purchasing the exact required amount.

- Several items are categorized as long lead time items. The lead time to receive these items is longer than the agreed lead time between VDL ETG and its customer. To satisfy customer’s demand, these items are ordered in advance. In some cases, these items are purchased without, or with only partial commitment from the customer (Tjiptowidjojo, 2016).

- It is common for VDL ETG to start production if they have received an order from their customer. However, in some cases VDL ETG has not received an order yet, but they need to start production to keep pace with their customer’s forecast and to be able to deliver within the agreed lead time. In this situation, the managing board of VDL ETG commits towards production (i.e., an order from the management). It may occur that the actual order from a customer does not occur, which means that VDL ETG still has to cope with the financial consequences.

- Processes to deal with obsolete inventory are not followed correctly. Items that are redundant after a project has finished are not scrapped, but are transferred from project to anonymous inventory. Another possibility is that a project has never been stopped. According to the rules of VDL ETG a project needs to be ended after a fixed period of time. When items are not scrapped, but transferred to MRP inventory, they are not charged to the project. As a result, the project appears to have performed better than it actually did, and the obsolescence costs of anonymous inventory increase.

Within the first three situations, VDL ETG’s customer has only partially, or not committed to these products. Due to design and engineering changes these items can become obsolete, also indicated as a cause of obsolescence in Figure 19 (see Appendix A.6). The fourth situation occurs when the management of VDL ETG expects an order from their customer (i.e., production planning is based on a forecast). However, if the actual demand does not occur, these parts can become obsolete. In the latter case, the customer issued a commitment, but at the end of a project the processes regarding scrapping of redundant items are not followed up correctly. The first three major causes are within the scope of this master thesis project, which is discussed in greater detail in section 1.5. In the cause and effect diagram related to the obsolescence within VDL ETG (see Figure 19 in Appendix A.6), three sub-parts can be identified, namely *Engineering changes, Processes and Purchase policy/Inventory model*. During this master thesis project, we will focus on the latter sub-part. Greater details regarding the problem context can be found in the research proposal that corresponds to this project.

1.4. Project assignment

Based on the problem context and project selection (see section 1.3) the research project has been defined based on a research question, and several sub-questions. These will be discussed in this
section. The goal of this project is to discover and gain understanding of current problems regarding obsolete inventory, analyze the characteristics of the obsolete inventory, and quantification of the risk of obsolescence. We developed the main research question:

\[
\text{How should VDL ETG incorporate the risk of obsolescence within their purchasing policy, to decrease obsolescence costs and to increase inventory performance?}
\]

1.4.1. Sub-questions

To answer the main research question, five sub questions are formulated. Both, the main and sub research questions focus on the part Purchase policy/inventory model of the cause and effect diagram related to obsolescence within the production environment of VDL ETG (see Figure 19 in Appendix A.6).

- How is the quantity of items that become obsolete in the As-is situation within VDL ETG influenced by MOQ, EOQ and long lead time items?
- Is the risk of items becoming obsolete typical for a specific chain (i.e., customer)?
- How does the current definition regarding obsolescence perform at VDL ETG?
- Can VDL ETG foresee items becoming obsolete; does demand drop dead suddenly (i.e., “sudden death” obsolescence), or does demand decrease gradually?
- How could VDL ETG improve their ordering policy within the anonymous inventory when they incorporate the risk of obsolescence?

1.5. Scope

The inventories of VDL ETG are managed by the department Integral Planning, which are physically located at the department Systems. The goal of the master’s thesis project is to identify causes and the risk of obsolescence within the inventory of VDL ETG. Therefore, all inventories for which Integral Planning is responsible are within the scope.

There is a distinction between project and anonymous inventory (see section 1.2). Only the anonymous inventory will be within the scope of this project. In contrast to project inventory, items in anonymous inventory may have no or only partially commitment from their customer. Due to lack of commitment, VDL ETG has to cope with the financial consequences when these items are obsolete. Furthermore, only the taxable anonymous inventory is within the scope. It is possible that items are kept in stock explicitly, despite them being obsolete. In such case, the customer or VDL ETG has bought off the value of such item, and the value will not be on the balance sheet of VDL ETG anymore. Additionally, the finished goods inventory, items in consignment stock and repair spare parts & service inventory are beyond the scope of this project. The latter inventory is not managed by the department Systems.
1.6. Thesis outline

In chapter 2, we will discuss the as-is situation within VDL ETG regarding obsolete inventory. First, we will explain the difference between anonymous and project inventory in greater detail. Subsequently, we will describe the obsolescence costs within the anonymous inventory. Finally, we analyze the impact of VDL ETG’s ordering policies and long lead time items on the obsolescence costs. Within chapter 3, we propose a new definition to classify an item as obsolete. In addition, we will analyze the obsolete item’s demand process until they became obsolete (according to the new definition). We will analyze whether VDL ETG has to deal with obsolescence due to a suddenly drop, or gradually decrease in demand. In chapter 4, we estimate the risk of obsolescence within the production environment of VDL ETG according to the new definition. Subsequently, we will analyze the association between item characteristics and obsolescence. In chapter 5, we discuss the current inventory policy, and we will propose an improved inventory policy (i.e., incorporates the risk of obsolescence). Next, we perform a numerically evaluation of both inventory policies. At the end of this thesis, we provide a conclusion and recommendations in chapter 6.
2. Analysis of obsolescence costs in as-is situation

Within this chapter we will describe the as-is situation (i.e., current situation) at VDL ETG regarding obsolete inventory. First, we will describe the difference between project and anonymous inventory in greater detail. Additionally, we will describe the supply chain value of anonymous items. In section 2.2, we explain the current definition regarding obsolescence. Additionally, we will discuss the obsolescence costs within the anonymous inventory. Subsequently, we will assess obsolescence costs per customer and production strategy. In section 2.2.1, we describe the characteristics of obsolete items, stratified for obsolescence. Finally, in section 2.3 we discuss the ordering policies which are used within VDL ETG and their association with obsolescence costs.

2.1. Anonymous inventory

The department of Integral planning manages all inventories at VDL ETG. Inventory is kept to deliver the required materials and items to the departments Parts and Systems (see Figure 2). Within the latter department, several items are assembled in semi-finished items to be shipped towards the customers. The required items for assembly are either supplied by external suppliers (bottom black arrow in Figure 2), or by the Parts department within VDL ETG. On average, 30% of all items are internally produced by the Parts department (VDL ETG, 2016). Whether an item is produced by VDL ETG itself or not, depends on the type of item and (potential) capacity (restrictions) at the Parts department. In general, high complex items are only produced internally. The less complex items may be purchased, or produced internally (van Wandeloo, 2015). In order to meet the production plan, as delivered by BaaN, the integral planner orders the required items. In case the ordered items are produced internally, Parts is handled as an external supplier. Therefore, purchased items could be both internally and externally produced. To ensure continuity of the operations within both departments, a certain level of inventory must be kept. However, too high inventory levels lead to unnecessary high carrying costs and obsolescence costs. Hence, this should be avoided by determining optimal inventory levels. This cannot easily be determined, since high-tech items are subject to a high frequency of engineering changes during their development and production phase (Goyal & Giri, 2001; Ho & Li, 1997; Solomon, Sandborn, & Pecht, 2000). Due to these changes, items may become obsolete. Therefore, it is important for VDL ETG to incorporate the risk of obsolescence within their inventory policy (Masters, 1991).

All items are purchased according to the order policy “on order” or “anonymous” (see Table 2). “On order” means that the required items are purchased after VDL ETG received an actual order from their customer. Therefore, the customer is fully committed towards these items. In such case, the quantity of items purchased is exactly equal to the amount required for production. As an illustration, a customer orders five systems of which each requires two items of type A. In this case, a project will be set up to produce five systems. According to this policy 10 items of type A are ordered to be able to fulfill the customer’s demand. “On order” items are booked as project inventory (see section 1.2). Items can also be bought with only partially, or without customer commitment, which is called “anonymous” order policy. In this case, items are purchased based on forecasts. According to the planners of Integral planning, the “anonymous” policy is also used within the MTO environment (see section 1.2.1). VDL ETG may purchase more items than required to receive discount, which will increase their revenue, or due to MOQ policy of their supplier. The “anonymous” items are booked as anonymous inventory. The difference in customer commitment towards “on order” items and
“anonymous” items indicates that VDL ETG only has to cope with the financial consequences of obsolete “anonymous” items. Despite the anonymous items are purchased without customer commitment, VDL ETG uses them for assembly. When the moment has come for the items to be assembled, they are retrieved from anonymous inventory. In most cases, from that moment on the customer is committed to the items.

Table 2 shows the total number of order lines, total quantity ordered, and total value purchased per policy, based on the period March 2015 – March 2016. If multiple items are ordered at the same supplier at the same time, the corresponding order lines are consolidated before they are actually ordered. The table shows that the largest fraction of all items is purchased according to anonymous policy (Nas, 2016). These represent a value which is almost double the value of items purchased on order. As discussed in section 1.2.1, the wafer handler of ASML is completely produced within the ATO environment (i.e., forecast driven). This means that all required items are purchased anonymously.

<table>
<thead>
<tr>
<th>Order policy</th>
<th>Number of order lines per procedure</th>
<th>Total quantity ordered per procedure</th>
<th>Total value of purchased items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anonymous</td>
<td>41.8%</td>
<td>67.9%</td>
<td>63.8%</td>
</tr>
<tr>
<td>On order</td>
<td>58.2%</td>
<td>32.1%</td>
<td>36.2%</td>
</tr>
</tbody>
</table>

When an item is ordered for the first time, values are assigned to the purchase parameters in BaaN. Tjipuwidjojo (2015) mentions that these values are not monitored and adjusted during its life cycle. Currently, the inventory policy at VDL ETG is based upon the traditional EOQ policy (see section 1.3.2). Within this policy, the risk of obsolescence is not incorporated (Tjipuwidjojo, 2015; van Wandeloo, 2015). It has been shown that inventory control can be optimized if obsolescence is taken into account, and therefore this master’s thesis project focuses on incorporating the risk of obsolescence into the inventory policy of VDL ETG (Callioni, De Montgros, Slagmulder, Van Wassenhove, & Wright, 2005; Cobbaert & Van Oudheusden, 1996; David & Greenshtein, 1996). The monthly average value of anonymous inventory in VDL ETG’s supply chain is shown in Figure 4. Only the anonymous inventory is within the scope of this project, as we already mentioned in section 1.5. Unless stated otherwise, the term inventory refers to anonymous inventory.

Figure 4 shows that inventory represents around 50% of the total anonymous supply chain value. With inventory we mean raw materials, components and semi-finished assemblies in VDL ETG’s stock. Work in Progress represents the value of all items that are currently used for production or assembly (e.g., post-process of an item). Purchased refers to the items that are already purchased, but have not arrived at the warehouse yet.
2.2. Obsolescence costs of anonymous items

Obsolescence occurs in both anonymous and project inventory, but this problem is particularly relevant for anonymous inventory. The anonymous items are purchased with partially customer commitment, or without customer commitment. If these items become useless, VDL ETG has to cope with the financial consequences. Currently, VDL ETG classifies an item as obsolete if it has not ‘moved’ during the past four months (i.e., change of location or no decrease or increase of stock levels). This section focuses on the relationship between obsolescence costs, anonymous inventory and the production strategies within VDL ETG. In section 2.2.1, we evaluate the current definition to classify an item as obsolete. Figure 5 visualizes the ratio of obsolescence costs within VDL ETG’s inventory. For the period May 2014 – May 2016, the average total value of all obsolete items was 12% of total value anonymous inventory (see right axis of Figure 5).

An analysis of the item movements on the 29th of May showed that in total 28.9% of the total obsolescence costs have not ‘moved’ in the past two years (see Table 3). Employees suggest this is mainly due to the fact that scrapping obsolete items is very time consuming. Furthermore, these items are not scrapped because employees believe that the items will be functionally in the (near) future (Langenhuysen, 2016b). Note, the obsolescence costs have been accumulated in the past few years. The enumeration of obsolescence costs over the past two years is 71% of the total obsolescence costs.
The strategy and design of the supply chain can differ per customer as well as per system. The planners of *Integral planning* mention that anonymous items are purchased in both the ATO and MTO environment. In the ATO environment, purchases are driven by forecasts. VDL ETG decides the moment and the amount they buy, as long as they meet their customer’s forecast. The planners mention that only items with a steady demand over time are produced within the ATO environment. Within this environment, their customer is not fully committed towards these items. In general, a customer is only completely committed to an item for a certain period of time. During the remaining weeks, a customer is not, or only partially, committed to an item. For example, from week 12 until week 5 before delivery a customer is required to commit for 40% of the selling price, and 100% from week 5 until the actual delivery date. During the period prior to week 12, the customer is not committed to an item. In some cases, within the MTO environment items are also purchased without customer commitment. In this situation, VDL ETG is forced to purchase in advance. Otherwise, VDL ETG is not able to deliver within the agreed lead time (Nas & Zillig, 2016). Hence, these items are purchased without a customer’s order (i.e., no commitment). Therefore, VDL ETG has to cope with the financial consequences when these items become obsolete.

In Table 3 we place the obsolescence costs in perspective to the anonymous inventory value, and purchased value of the anonymous items. The latter two values are the average value per month based on the period March 2015 until March 2016. The majority of the obsolescence costs has accumulated during the past 2.5 years. A substantial part of the total obsolescence costs can be allocated to the customers that also represent the largest fraction of the anonymous inventory. The inventory value of customer 6 stands out because it is much higher compared to the average purchased value. In most cases, items for customer 6 are purchased on order. The redundant items within a project are transferred from project inventory to anonym inventory (see section 1.3.2). Nas and Zillig (2016) mention that this is done because customer 6 is developing a new system and has appointed VDL ETG for the production of some parts. Therefore, these materials are not scrapped yet. A similar conclusion holds for the customer 3 and customer 2. The systems of customer 3 are still in their prototype phase. Customer 3 has assigned the production of certain components to VDL ETG. Therefore, VDL ETG

![Figure 5: Obsolescence costs with respect to the anonymous inventory.](image-url)
has already invested to be able to build this system. However, when customer 3 production will start is unknown. For that reason, planners have transferred these items from project inventory to anonymous inventory (Langenhuyzen, 2016b). As a result, projects seem to generate more revenue than they actually have, because eventual scrap costs will be allocated to anonymous inventory. Within the supply chain of customer 7 - 9, the proportion of obsolescence costs is lowest. Harmsen (2016) mentions that this is due to the low frequency of engineering changes within the medical sector. Because of FDA regulations, engineering changes are scarcer in the medical sector. The entire obsolete stock is analyzed in detail in section 2.2.1.

Table 3: Average value per month of anonymous inventory per customer and average total value per month of all anonymous items purchased per customer (based on March 2015 – March 2016). Obsolescence costs (on 29th of May) divided per production strategy according to the current definition (percentage of total obsolescence costs).

<table>
<thead>
<tr>
<th>Customer</th>
<th>Anonymous inventory value</th>
<th>Value of purchased anonymous items</th>
<th>Obsolescence costs MTO</th>
<th>Obsolescence costs ATO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer 1</td>
<td>35%</td>
<td>63%</td>
<td></td>
<td>15%</td>
</tr>
<tr>
<td>Customer 2</td>
<td>2%</td>
<td>1%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>Customer 3</td>
<td>9%</td>
<td>2%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Customer 4</td>
<td>6%</td>
<td>6%</td>
<td>0.7%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Customer 5</td>
<td>19%</td>
<td>6%</td>
<td>14%</td>
<td>4%</td>
</tr>
<tr>
<td>Customer 6</td>
<td>7%</td>
<td>1%</td>
<td></td>
<td>19%</td>
</tr>
<tr>
<td>Customer 7</td>
<td></td>
<td></td>
<td></td>
<td>0.5%</td>
</tr>
<tr>
<td>Customer 8</td>
<td>5%</td>
<td>3%</td>
<td></td>
<td>0.1%</td>
</tr>
<tr>
<td>Customer 9</td>
<td></td>
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<td></td>
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<td>Customer 10</td>
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<td>Customer 11</td>
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<td>Customer 12</td>
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<td>Customer 13</td>
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<td>Customer 17</td>
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<td>Customer 18</td>
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<tr>
<td></td>
<td>10%</td>
<td>9%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>100%</td>
<td>80%</td>
<td>20%</td>
</tr>
</tbody>
</table>

2.2.1. Shortcomings of the current definition regarding obsolescence

The current definition of VDL ETG classifies an item as obsolete if it has not ‘moved’ for more than four months. According to this definition, an item has ‘moved’ when it changes from location (i.e., from inventory A to inventory B), or when its inventory level increases or decreases. This implies that an item is useful again (i.e., non-obsolete), if it only changes of location or its inventory level increases. Both movements are not preferable to classify an item as (non-)obsolete. However, the decrease of inventory level is a good representation whether an item is obsolete or not. Hence, this movement arises from an order. Unfortunately, the data does not allow us to check what kind of movement an item has undergone the last time.
In addition, the current definition is not sensitive to the fact that items may be reserved for production in the (near) future. This is a disadvantage, because in this situation these items increase the obsolescence costs incorrectly. These items are reserved for production or assembly, therefore, they have no negative impact on the inventory performance. Several planners and supply chain engineers of VDL ETG have confirmed this finding. Therefore, we were interested in the fraction of obsolete inventory that has been reserved for future production. We created a tool in Excel which analyzes whether an item is truly obsolete, or has been reserved for production or assembly (i.e., potentially obsolete). This analysis revealed that items with a total value of 25% of the total obsolescence costs have been labeled as obsolete, while there was still a demand for these items (see Figure 6).

![Obsolescence costs current rule at VDL ETG](image)

**Figure 6:** Obsolescence costs (left column) according to the current definition vs actual obsolescence costs (75%; right column) according to the current definition.

### 2.2.2. Analysis of item characteristics related to obsolescence

In this section we will briefly discuss the association between the item characteristics and obsolescence (according to the current definition). In total, we analyzed more than 5,500 items. Of these items, 38.4% were obsolete (see Table 4). To assess whether fractions differed significantly between obsolete and non-obsolete, we used the Chi-squared test for the categorical variables, and student’s T-test for continuous variables.

We analyzed the three largest customers, customer 1-4, customer 5 and customer 6 (i.e., correspond to 85% of the inventory value). The customers ASML and FEI have significantly lower proportion obsolete items (p<.001 and p=.001, respectively). The proportion of “customer 6 items” is significantly larger within the obsolete group (p<.001). This indicates that items that belong to customer 1-4 and customer 5 are less often obsolete, and items that belong to customer 6 are more often obsolete. VDL ETG also produces prototypes for their customers. Items used to create these prototypes are called new product introductions. These are often subject to many engineering changes, and are more expensive (e.g., because they are purchased in lower quantities without discounts; Tjiptowidjojo, 2016). These items should receive extra attention, since the proportion of them in the obsolete group is significantly higher compared to the non-obsolete group (p<.001). We also
investigated the differences between the purchasing policies (EOQ, MOQ and lot-for-lot) and the non-obsolete and obsolete group. These characteristics show that the fraction of items that are purchased according to the EOQ policy is significantly lower within the obsolete group (p<.001). The fraction of items purchased according to the MOQ policy is higher within the obsolete group. However, this difference is not significantly (p=.14). Purchasing policy lot-for-lot requires some additional attention, since these items are generally more expensive as they are ordered one by one. Fraction of items that are purchased lot-for-lot is significantly higher within the obsolete group (p<.001). However, the difference is small. Fraction of obsolete items within the MTO strategy is significantly higher, compared to non-obsolete items (p<.001). As mentioned in the previous section these items are mainly bought without customer commitment. Therefore, VDL ETG has to cope with the financial consequences when these items become obsolete. Finally, we assessed differences between the price per unit of obsolete and non-obsolete items. The mean unit price of obsolete items is lower compared to the non-obsolete parts. However, this difference is not significant (p=.71).

| Table 4: Relation between item characteristics and obsolescence. Characteristics are stratified for obsolescence (according to the current definition). |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | All items, N=5,500 (100%) | Non-obsolete items, 61.6% | Obsolete items, 38.4% | p-value |
| Customer 1-4, % | 44.1% | 49.4% | 35.6% | <.001* |
| Customer 5, %   | 20.0% | 21.4% | 17.7% | .001* |
| Customer 6, %   | 9.5% | 7.3% | 13.2% | <.001* |
| New Product Introduction, % | 10.7% | 7.9% | 15.2% | <.001* |
| EOQ, %          | 74.6% | 78.6% | 68.3% | <.001* |
| MOQ, %          | 6.6% | 6.2% | 7.3% | .14 |
| Lot-for-lot, %  | 18.7% | 15.2% | 24.5% | <.001* |
| MTO, %          | 56.2% | 42.1% | 78.7% | <.001* |
| Unit price (€), mean (±SD) | | | | .71 |

Obsolete; item has not ‘moved’ for the last four months, customer 1-4; item belongs to a system of customer 1-4, customer 5; item belongs to a system of customer 5, customer 6; item belongs to a system of customer 6, New Product Introduction; item is used for production of prototypes, EOQ; item is purchased according to the economic order quantity policy, MOQ; item is purchased according to the minimal order quantity policy, Lot-for-lot; item is purchased lot-for-lot, MTO; item is active in the MTO production strategy; Unit price; price per unit in Euros; *p<.05

### 2.3. Ordering policies within VDL ETG

All items are purchased according to the EOQ, MOQ or lot-for-lot ordering policies. In this section, we will describe the impact of MOQ and EOQ on the obsolete stock in greater detail. These purchase policies are used in both the ATO and MTO environment. Additionally, we will describe the impact of long lead time items on obsolete stock. The cause and effect diagram regarding obsolete inventory shows that purchase policies are an important reason for the occurrence of obsolescence (see Appendix A.6). As described in section 2.1, the anonymous items are purchased according to a forecast. Since, obsolete stock finds it origin in a discrepancy between demand and supply, this should
require some additional attention. The factors EOQ, MOQ and long lead time items are already defined in section 1.3.2.

2.3.1. Impact of EOQ and MOQ

VDL ETG produces highly complex systems for multiple customers. Goyal and Giri (2001) mention that it can be hazardous to purchase more than required within a highly complex environment, because of frequent engineering changes. This may result in useless stock. Therefore, we analyze the fraction of obsolete items in the as-is situation that are purchased according to EOQ and MOQ.

The left diagram in Figure 8 shows the proportion of obsolescence costs per purchase policy. 6% (€49,793) of the total obsolescence costs can be allocated to the MOQ policy. The EOQ policy represents a much larger fraction of the obsolescence costs, namely 81% (€695,935). Therefore, we analyze the quantities of these items (see right diagram in Figure 8). This diagram shows that in 63% of the EOQ purchased items, the total number of obsolete items is equal of higher than the purchased quantity. We analyzed whether this might be due to safety stock regulations. It appeared that only eight obsolete items have been assigned a safety stock, and that the quantity of obsolete stock is higher than its EOQ for two items only. These results have been discussed with several employees within VDL ETG. They mention that the parameters in BaaN (i.e., MOQ and EOQ) are entered at the start of its life cycle, and not monitored or updated during an item’s life time (Tjiptowidjojo, 2016). From this we can conclude that former purchase parameters are used while the demand for that item has been decreasing. Due to bad end of life management, this may result in the fact that the total quantity of obsolete items is equal or higher than EOQ.

2.3.2. Long lead time items

As discussed in section 2.2, VDL ETG is forced to purchase multiple expensive items in advance. Otherwise, they are not able to keep pace with the demand of customers. These items are called long lead time items. Currently, there is no definition for long lead time items. Therefore, we define these items as “items that have a lead time from supplier to VDL ETG, that is longer compared to the commitment period of VDL ETG’s customer”. The commitment periods are discussed in section 2.2. Within the ATO environment, all systems are produced in series. For example, VDL ETG produces 2 systems machines per week. The commitment pattern of a customer is 40% of the selling price from week 17 until week 9 before delivery, and 100% from week 9 until actual delivery. This can lead to

![Figure 7: Fraction of obsolescence costs (current definition) according to the purchase policies (left diagram). Quantity of obsolete items that are purchased according to the EOQ policy (right diagram).](image-url)
over commitment (i.e., value of 40% times selling price is higher than the actual value during production). This will compensate the not committed value of a long lead time item. Within the MTO environment, it may also occur that the long lead time items are purchased in advance, and without commitment. However, this does not occur very often (Nas & Zillig, 2016). Currently, a negligible part of the obsolescence costs is generated by these items (0.6% of the entire obsolescence costs). Therefore, we conclude that the impact of items with a long lead time on the obsolete stock is low.

2.4. Conclusion

Obsolete stock occurs both within anonymous and project inventory. At the moment, VDL ETG classifies an item as obsolete when it has not ‘moved’ (i.e., change of location or no decrease or increase of stock levels) during the past four months. It was shown that obsolescence costs represent 12.5% of the total inventory value of VDL ETG on average. The fraction of obsolete stock within the MTO environment (80%) is larger in comparison to the ATO environment (20%). This is caused by the level of inventory, which is required in order to be able to deliver items within the agreed lead times, and because redundant items are transferred from project to anonymous inventory (i.e., items of KLA and NXE). Our analysis shows that 64% of all purchased items are purchased according to the “anonymous” policy. Furthermore, we exposed the shortcomings of the current definition regarding obsolescence. Our analysis showed that in total 25% of the obsolescence costs have incorrectly been classified as obsolete. The stratification of item characteristics (for obsolescence) shows that the fraction of ‘MTO items’ is significantly higher within the obsolete group compared to the non-obsolete group. We conclude that a high fraction (81%) of the obsolescence costs is due to items that are purchased according to the EOQ policy. In most cases, the quantity of obsolete stock is equal or larger than the purchased quantity (i.e., EOQ). This showed us that the parameters regarding the purchase policies are not monitored during an item’s life cycle. Finally, we conclude that the impact of MOQ and long lead time items on the obsolescence costs is small, 5.6% and 0.6%, respectively.
3. Demand processes within VDL ETG’s supply chain

Obsolescence occurs if the demand for an item becomes zero, after a period with positive demand. In this chapter, we will discuss the demand process of all obsolete items prior to the moment they became obsolete. This may give insight in the question whether VDL ETG may foresee items becoming obsolete. First, we will discuss two types of inventory mentioned in literature (i.e., “sudden death” obsolescence and obsolescence due to gradual decrease in demand). Subsequently, we will analyze whether VDL ETG faces both types of obsolescence, or only one of them. In case our analysis shows that VDL ETG faces gradual decrease in demand, this may help VDL ETG to better anticipate to obsolescence in the future.

3.1. Different types of obsolescence

After a period of positive demand, the demand may drop to zero. This results in obsolescence. If this decrease to zero demand occurs gradually over time, a company can foresee items becoming obsolete. In this case, they should timely adapt their inventory policy to the actual number of orders. This enables them to reduce the amount of obsolete inventory, and therefore to minimize the negative impact on the inventory performance (Pinçe & Dekker, 2011). The demand may also drop to zero suddenly, called “sudden death” obsolescence (Cobbaert & Van Oudheusden, 1996). In this situation, a company cannot foresee an item becoming obsolete, which makes it more difficult to adjust the inventory policy. Multiple employees within VDL ETG have mentioned that purchase parameters in BaaN are entered only at the start of an item’s life cycle (i.e., the first time they are bought). After that, they are not monitored, and therefore they are not adjusted towards the actual demand (Tjiptowidjojo, 2016). To see whether VDL ETG has to cope with “sudden death” obsolescence or obsolescence due to gradual decrease in demand, we will analyze the demand process of all obsolete items before they became obsolete (see section 3.2).

As we have concluded in chapter 2, VDL ETG’s definition is not sufficient, since it classifies an item as obsolete if it has not ‘moved’ for only four months. Furthermore, it recognizes an item no longer as obsolete when it has been transferred to another location, or if the inventory level has increased. Especially the latter two cases are not appropriate. To be able to perform this analysis and all successive analyses, we have formulated a new definition of obsolescence. Analysis of the dataset and conversations with supply chain engineers and planners have led to the following definition: an item is classified as obsolete if no demand has occurred during the past two years. No demand for two years indicates that the item is in its end of life phase (i.e., item is phased out due to a replacement; see Figure 8). Hence, in this definition obsolescence does not refer to items that are still in stock. In case we talk about obsolete items that are still in stock, we will explicitly use the words obsolete inventory.

3.2. Gradual decrease or sudden drop of demand

Solomon et al. (2000) introduced the “zone of obsolescence” within the standard life cycle diagram of an item (see Figure 8). The maturity phase is characterized by high-volume demand. Generally, demand gradually increases prior to the maturity stage, and gradually decreases after the maturity stage. Finally, an item will enter the ‘zone of obsolescence’, in which its demand will become zero. The time until an item becomes obsolete differs per item type, and is influenced by external
factors (e.g., engineering changes; Solomon et al. 2000). However, as we already discussed in section 3.1, there is not always a period with gradual decrease of demand (i.e., “sudden death” obsolescence).

![Figure 8: Item life cycle with “zone of obsolescence”, based on Solomon et al. (2000).](image)

We have analyzed the demand process of the obsolete items according to the adjusted definition, based on the framework of Solomon et al. (2000). The order managers in the Production office department mention that the original equipment manufacturers (i.e., VDL ETG’s customers) announce timely when they start phasing out a system type to all other parties upstream in the supply chain. This enables VDL ETG to anticipate timely, and to decrease the production of final systems. However, this does not automatically imply that the total demand of the underlying items also decreases, since they can be used within multiple other systems. Therefore, we have analyzed the demand process of the underlying items, instead of the final systems.

In this analysis we have assessed the demand process (i.e., total demand plotted against time) of all items that had no demand in the period between January 2013 and December 2014 (see Figure 10). To make sure the items entered the zone of obsolescence within this period and not prior to this period, we excluded all items with no demand in 2012. In addition, we removed all item with an order between July 2008 and December 2008. This allowed us to assume that the items entered their maturity phase somewhere between January 2009 and December 2012 (see Figure 10). In total, 1,408 items were included in the dataset. All data was retrieved from BaaN, and transformed to a matrix with Visual Basic for Application. Again, we analyzed only anonymous items.

![Figure 9: Schematic illustration of requirements of the dataset. Only items with no demand (D) between July 2008 and December 2008, positive demand in 2012, and no demand between January 2013 and December 2014 (i.e., obsolete) are included in the dataset. Dataset consist of more than 1,000 items.](image)
3.2.1. Types of obsolescence within VDL ETG’s supply chain

Our analysis showed that VDL ETG has to deal with both gradual decrease in demand and “sudden death” obsolescence. From the dataset we concluded that 28% of all obsolete items have only been ordered once in period 1 (\(D(2012) = 1\)), see Figure 10. Hence, for these items it is very difficult, or even impossible, to foresee obsolescence. The rest of the obsolete items 72%, are ordered more than once between January 2009 and December 2012. The demand of these items may decrease gradually. This is analyzed in the next part of this section.

First, we tried to analyze the demand process by calculating the slope between the data points (time on x-axis, and total demand on y-axis). We observed a large diversity of the total demand per item, which made the interpretation of these slopes very difficult. Therefore, we concluded that this is not the appropriate method to analyze the demand process. Second, we tried to analyze the time between two consecutive orders (i.e., time interval). Our idea was that the time interval would increase, due to a lower demand volume. Unfortunately, we could not identify an increase in the length of the time interval when we got closer to period 2 (i.e., high variation in the length of an interval in period 1). Again, we concluded that this method was insufficient.

Finally, we analyzed the order frequency per month. Note, if a quantity larger than one is ordered simultaneously, this counts as one order frequency. Note, within this definition a quantity larger than one may ordered at once. We categorized items according to their order life time (OLT). OLT is specified as the time difference between the first month \((t = 1)\) and last month \((t = \{2,3,4,\ldots,48\})\) that demand occurred. For example, an item that received its first order in February 2010 \((t = 1)\) and its last order in March 2012 \((t = 26)\) has an OLT of 26. Therefore, this item has received demand in the active month 1 until 26 (see Figure 10). We distinguished three categories for OLT; OLT ranges from 13 to 24 months (active in 2011 - 2012), OLT ranges from 25 to 36 months (active in 2010 - 2012), and OLT ranges from 37 to 48 months (active in 2009 - 2012). Therefore, all columns, which represent the total order frequency per category, start in the origin of Figure 10. Items with an OLT lower than 12 months (only active in 2012) were not assigned to a category. These items are not active long enough within the supply chain to interpret the demand process sufficiently. Hence, Figure 10 shows the total order frequency per category per month of the OLT.

![Figure 10: Total order frequency of each order life time category. The grey columns visualize the total order frequency of items that are active within VDL ETG’s production strategy since 2009. The black columns visualize the total order frequency of items that are active since 2010. The light grey columns visualize the total order frequency of items that are active since 2011.](image-url)
The light grey column represents the total order frequency of all items that received demand during 2011 and 2012. The black columns represent the total order frequency of all items that received demand during 2010 – 2012. Finally, the grey columns show the total order frequency of the items that have been active since 2009. These items were active within the supply chain for the longest time (i.e., stable items). Note, that all these items have become obsolete during 2013 – 2014. Figure 10 shows that the order frequency decreases gradually within all three categories. For these items, VDL ETG can foresee obsolescence. Therefore, the parameters regarding the purchase policies (EOQ and MOQ) should be monitored during an item’s life cycle. At the moment this is not practiced within VDL ETG (Tjiptowidjojo, 2016). This may improve the balance between supply and demand, especially forwards the end of an item’s life cycle. The demand for the obsolete items that were active since 2009 decreased less, compared to the other two categories. After week 37, the demand was only slightly above zero. It is possible that the demand for regular production has dropped dead after week 37, but that there was still little demand due to production of spare parts. However, the data from BaaN did not allow us to distinguish between demand due to regular production, or production of spare parts (Kwanten, 2016).

Additionally, we categorized the items according to their unit price and performed the same analysis (see Appendix B.1). These graphs also showed a gradual decrease over time. However, we cannot interpret them correctly, because the graphs are based upon a small dataset. 34 items have a unit price higher than €1,000, but 13 of them received only one order (see Figure 20). In total, 71 items cost between €250 – €1,000. 19 items have only been demanded once (see Figure 21). Finally, Figure 22 is set up of all items with a unit price between €100 - €250 (95 items). 33 items only received one order. Due to the large fraction of items with only one order, we conclude that these graphs are not representable for all items within that category.

3.3. Conclusion

VDL ETG’s current definition regarding obsolescence has several shortcomings. Therefore, we proposed an adjusted definition: an item is classified as obsolete if no demand has occurred during the past two years. We used this new definition for the subsequent analyses. In this chapter we analyzed whether VDL ETG faces sudden drop in demand, gradual decrease in demand, or both. The analysis of the demand process showed that VDL ETG faces both “sudden death” obsolescence, and obsolescence due to gradual decrease in demand. Unfortunately, 28% of the analyzed items dropped dead suddenly. VDL ETG will not be able to timely adjust the parameters in BaaN for these items, and will not be able to anticipate for obsolescence. However, 72% of the items have been ordered more than once. Figure 10 showed that the demand of these items decreased gradually. The demand process of the obsolete items that were active since 2009, decreased less, compared to the items that were active since 2010 or 2011. Because VDL ETG also faces obsolescence due to gradual decrease in demand, we conclude that VDL ETG should monitor, and actively adjust the parameters concerning the purchase policies on a regular basis from now on. This enables them to better anticipate for obsolescence, and to minimize the amount of obsolete inventory in the future.
4. Obsolescence within VDL ETG’s supply chain

In this chapter, we focus on the occurrence of obsolescence within the supply chain of VDL ETG, according to the proposed alternative definition of obsolescence (an item is classified as obsolete if no demand has occurred during the past two years). In section 4.1, we introduce the framework of Jaarsveld and Dekker (2011) to quantify the risk of obsolescence. Subsequently, in section 4.1.1 we apply their model within the production environment of VDL ETG. Third, we will discuss a statistical model to analyze the association between item characteristics and obsolescence. The obsolescence costs associated with the new definition will be discussed in section 4.3. Here, we categorize items according to their purchase policy (i.e., EOQ, MOQ and lot-for-lot), to assess the total value of obsolescence costs per policy.

4.1. Quantification of the risk of obsolescence

In this section, we estimate the risk of obsolescence, based on the framework of Jaarsveld and Dekker (2011). They estimated the risk of obsolescence within a spare parts environment of a large original equipment manufacturer. We will perform the same analysis in the production environment of VDL ETG. We use the demand data of all anonymous items. The dataset consists out of more than 7,500 items with demand between January 2010 and December 2011 (see Figure 12).

We analyzed the order frequency (i.e., the number of times that demand occurred) during period 1. Period 2 serves as a buffer period, to avoid items being incorrectly classified as non-obsolete during period 3. In case an item’s demand is strongly decreasing during period 1, it is possible that this item receives its final order in period 2. Next, the item will not be ordered anymore. For this reason, we analyzed obsolescence of items during period 3 (see Table 5). Length of period 1 and 3 are equal, to make sure that the demand rates in both periods are equal.
Table 5: Outcomes of the analysis of the demand data. Values between parentheses show the results when the same analysis is performed one year earlier.

<table>
<thead>
<tr>
<th>Number of orders in period 1</th>
<th>Number of items</th>
<th>Expected fraction with zero demand (Poisson) (%)</th>
<th>Actual fraction of items with no demand in period 3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>834</td>
<td>36.79 ≈ e(^{-1})</td>
<td>70.3 (71.7)</td>
</tr>
<tr>
<td>2</td>
<td>544</td>
<td>13.53 ≈ e(^{-2})</td>
<td>65.8 (62.4)</td>
</tr>
<tr>
<td>3</td>
<td>412</td>
<td>4.98 ≈ e(^{-3})</td>
<td>61.2 (63.9)</td>
</tr>
<tr>
<td>4</td>
<td>322</td>
<td>1.83 ≈ e(^{-4})</td>
<td>49.4 (58.7)</td>
</tr>
<tr>
<td>5</td>
<td>237</td>
<td>0.67 ≈ e(^{-5})</td>
<td>52.7 (51.8)</td>
</tr>
<tr>
<td>6</td>
<td>310</td>
<td>0.25 ≈ e(^{-6})</td>
<td>66.5 (46.1)</td>
</tr>
<tr>
<td>7</td>
<td>188</td>
<td>0.09 ≈ e(^{-7})</td>
<td>51.6 (51.1)</td>
</tr>
<tr>
<td>8</td>
<td>190</td>
<td>0.03 ≈ e(^{-8})</td>
<td>55.8 (43.7)</td>
</tr>
<tr>
<td>9</td>
<td>197</td>
<td>0.01 ≈ e(^{-9})</td>
<td>42.1 (35.8)</td>
</tr>
<tr>
<td>10</td>
<td>192</td>
<td>0.00 ≈ e(^{-10})</td>
<td>37.5 (28.6)</td>
</tr>
<tr>
<td>11</td>
<td>134</td>
<td>0.00 ≈ e(^{-11})</td>
<td>44.8 (42.1)</td>
</tr>
<tr>
<td>12</td>
<td>126</td>
<td>0.00 ≈ e(^{-12})</td>
<td>43.7 (38.9)</td>
</tr>
<tr>
<td>13</td>
<td>131</td>
<td>0.00 ≈ e(^{-13})</td>
<td>33.6 (36.2)</td>
</tr>
<tr>
<td>14</td>
<td>98</td>
<td>0.00 ≈ e(^{-14})</td>
<td>37.8 (19.5)</td>
</tr>
<tr>
<td>15</td>
<td>106</td>
<td>0.00 ≈ e(^{-15})</td>
<td>24.5 (31.9)</td>
</tr>
<tr>
<td>≥16</td>
<td>&gt;3,000</td>
<td>≤0.00 ≈ ≤ e(^{-16})</td>
<td>42.1 (22.7)</td>
</tr>
</tbody>
</table>

Items are categorized according to their order frequency in period 1. For each category we assessed how many items did not have any demand in period 3 (see Table 5). In total, around 35% had no demand in period 3. The same analysis has been performed over the demand process during January 2009 – December 2013. The fraction of zero demand in period 2012 – 2013 is shown between parentheses. This analysis is attached to Appendix C.1. Contrary to Jaarsveld and Dekker (2011), we could not conclude that fraction of zero demand in period 3 is stable over time. In half of the cases the difference is larger than 5%. Furthermore, Jaarsveld and Dekker (2011) have also concluded that slow moving items become obsolete more often, compared to fast moving items. Again, our results were inconsistent with their findings.

If demand in period 3 is zero, items are not necessarily obsolete. It is important to distinguish between zero demand due to obsolescence, or due to statistical variation. If the demand is low, there is a large probability that the demand will be zero in the subsequent year. For example, if an item is ordered only once during period 1, the probability of no demand during period 3 is larger compared to an item that has been ordered multiple times during period 1. To obtain insight in the fraction of items with zero demand, we compared the actual fraction of zero demand with the fraction of zero demand according to a statistical distribution. For our analysis we assumed that demand is compound Poisson process distributed, function (1). We have analyzed the order frequency, therefore one order may consist out of quantities larger than 1 (i.e., compound Poisson process). By means of this analysis we attempted to distinguish between true obsolescence and statistical variation.

\[ P(X=k) = \frac{(\lambda t)^k}{k!} e^{-(\lambda t)} \]  

(1)
Table 5 shows that demand drops dead more often than expected, based on a Poisson process. To strengthen our conclusion that items with zero demand in period 3 are truly obsolete, we attached an additional fourth period (i.e., January 2015 until December 2015). We analyzed whether the obsolete items have received demand during this period. This indicated that around 3% of all obsolete items have received demand during period 4. Therefore, we can conclude nearly all items with zero demand in period 3 will also have zero demand in the future.

The expected fractions of zero demand in Table 5 do not give an estimate for the risk of obsolescence, but estimate the probability of zero demand during a period of two years according to a Poisson distribution. To estimate the risk of obsolescence ($\psi$), Jaarsveld and Dekker (2011) developed a two state model (see Figure 13). Demand process of the items is modelled with a sequential continuous-time stochastic process $\{X(t), t \geq 0\}$ with a finite state space $S = \{x_0, x_1\}$ and Markov property at each time $t \geq 0$ (i.e., a continuous time Markov chain). State $x_1$ indicates that demand is positive, and state $x_0$ represents the situation that demand is zero and the item is obsolete. In their model, Jaarsveld and Dekker (2011) did not use multiple states to model gradually decrease in demand, as proposed by Song and Zipkin (1993). According to Jaarsveld and Dekker (2011), it is not straightforward to estimate the corresponding parameters in such a model. The only method to estimate these parameters would be hidden Markov theory. The available dataset does not allow us to use hidden Markov theory, because the dataset is too small (Jaarsveld & Dekker, 2011).

![Figure 12: Continuous time Markov chain. State $x_1$ means that demand is positive, state $x_0$ means that demand is zero.](image)

In a continuous time Markov chain, we spend an exponential distributed time in a state before a transition to another state occurs. In general, a transition occurs with transition intensity $\lambda_{ij}$ and probability $p_{ij}$. In our case, we model a transition from state $x_1$ to $x_0$ (i.e., items become obsolete) with the parameter $\psi$ (i.e., risk of obsolescence). To actually apply the model, we need to estimate $\psi$ (section 4.1.1). Furthermore, we need to define $\lambda$ by using the actual demand data.

4.1.1. Estimating parameter $\psi$

To obtain the parameter $\psi$, the probability of no demand in period 3 needs to be calculated, given the demand in period 1. As with the model of Jaarsveld and Dekker (2011), the time origin is fixed at the end of period 1 ($t = 0$). We define period 2 as $(0, t)$, and period 3 as $(t, T)$. Therefore, were are interested in the demand during the interval $[t, t+T]$ (i.e., $D(t, t+T)$). Only items with demand during period 1 are included in this analysis. Furthermore, we assume that these items are still ‘moving’ at the end of period 1. Otherwise, it is possible that an item already transitioned to state $x_0$ during period 1. If we ignore this assumption, the probability of zero demand in period 3 would depend on the moment that the last order occurred. This also indicates that the probability will differ per item in the same category. This would complicate the estimation of $\psi$ (Jaarsveld & Dekker, 2011). The probability of
zero demand in period 3 can be calculated as shown below. These formulas are worked out in greater detail in Appendix C.2.

\[ P(C(t, t + T) = 0 \mid X(0) = x_1) = 1 - P(C(t, t + T) > 0 \mid X(0) = x_1) \]  
\[ = 1 - P(C(t, t + T) > 0; X(t) = x_1 \mid X(0) = x_1) \]  
\[ = 1 - P(C(t, t + T) > 0; X(t) = x_1 \cdot P(X(t) = x_1 \mid X(0) = x_1) \]  
\[ = 1 - P(C(0, T) > 0 \mid X(0) = x_1) \cdot e^{-\psi t} \]  
\[ = 1 - \frac{\lambda}{\lambda + \psi} \left(1 - e^{-(\lambda + \psi)T}\right) \cdot e^{-\psi t} \]

Finally, we retrieve the following function;

\[ P(C(t, t + T) = 0 \mid X(0) = x_1) = 1 - \frac{\lambda}{\lambda + \psi} \left(1 - e^{-(\lambda + \psi)T}\right) \cdot e^{-\psi t} \]

Table 5 shows that the actual fraction of items that are obsolete in period 3 is higher than expected, based on a compound Poisson process. To create a better fit between the fourth and third column, we adjust the parameter of the Poisson distribution with the parameter \( \psi \). Jaarsveld and Dekker (2011) showed that \( \psi \) can be calculated by taking the inverse of function (7). The fifth column of Table 6 shows the estimated value of \( \psi \) (i.e., the transition intensity to move from state \( x_1 \) to \( x_0 \)). Parameter \( p \) is the actual fraction of zero demand, \( t \) and \( T \) represent the length of period 2 and 3 respectively, and \( \lambda \) represents the order frequency in period 1. Again, the value between parentheses shows the value of \( \psi \) when the same analysis is performed on the dataset of January 2009 – December 2013. To be able to estimate \( \psi \), the number of items in period 1 per order frequency must be sufficient. Otherwise, we are not able to assess the actual fraction of zero demand (\( p \)). Therefore, we are only allowed to estimate \( \psi \) for the items with an order frequency of 1 - 15 in period 1. The size of the categories larger than 15 were too small to estimate \( \psi \) correctly (see Table 6).
Table 6: Estimation of obsolescence risk ($\psi$) within the production environment of VDL ETG.

<table>
<thead>
<tr>
<th>Order frequency in period 1</th>
<th>Number of items in period 1</th>
<th>Expected fraction with zero demand (Poisson) (%)</th>
<th>Fraction no demand period 3 (%)</th>
<th>$\int_{t,T,\lambda}^{-1} f(p) = \psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>834 (1407)</td>
<td>36.79</td>
<td>70.3 (71.7)</td>
<td>0.43/yr (0.45/yr)</td>
</tr>
<tr>
<td>2</td>
<td>544 (737)</td>
<td>13.53</td>
<td>65.8 (62.4)</td>
<td>0.58/yr (0.51/yr)</td>
</tr>
<tr>
<td>3</td>
<td>412 (565)</td>
<td>4.98</td>
<td>61.2 (63.9)</td>
<td>0.60/yr (0.65/yr)</td>
</tr>
<tr>
<td>4</td>
<td>322 (378)</td>
<td>1.83</td>
<td>49.4 (58.7)</td>
<td>0.46/yr (0.61/yr)</td>
</tr>
<tr>
<td>5</td>
<td>237 (336)</td>
<td>0.67</td>
<td>52.7 (51.8)</td>
<td>0.55/yr (0.53/yr)</td>
</tr>
<tr>
<td>6</td>
<td>310 (347)</td>
<td>0.25</td>
<td>66.5 (46.1)</td>
<td>0.84/yr (0.47/yr)</td>
</tr>
<tr>
<td>7</td>
<td>188 (268)</td>
<td>0.09</td>
<td>51.6 (51.1)</td>
<td>0.57/yr (0.57/yr)</td>
</tr>
<tr>
<td>8</td>
<td>190 (293)</td>
<td>0.03</td>
<td>55.8 (43.7)</td>
<td>0.66/yr (0.46/yr)</td>
</tr>
<tr>
<td>9</td>
<td>197 (201)</td>
<td>0.01</td>
<td>42.1 (35.8)</td>
<td>0.45/yr (0.37/yr)</td>
</tr>
<tr>
<td>10</td>
<td>192 (203)</td>
<td>0.00</td>
<td>37.5 (28.6)</td>
<td>0.39/yr (0.28/yr)</td>
</tr>
<tr>
<td>11</td>
<td>134 (133)</td>
<td>0.00</td>
<td>44.8 (42.1)</td>
<td>0.51/yr (0.47/yr)</td>
</tr>
<tr>
<td>12</td>
<td>126 (131)</td>
<td>0.00</td>
<td>43.7 (38.9)</td>
<td>0.49/yr (0.42/yr)</td>
</tr>
<tr>
<td>13</td>
<td>131 (105)</td>
<td>0.00</td>
<td>33.6 (36.2)</td>
<td>0.36/yr (0.39/yr)</td>
</tr>
<tr>
<td>14</td>
<td>98 (113)</td>
<td>0.00</td>
<td>37.8 (19.5)</td>
<td>0.42/yr (0.19/yr)</td>
</tr>
<tr>
<td>15</td>
<td>106 (91)</td>
<td>0.00</td>
<td>24.5 (31.9)</td>
<td>0.25/yr (0.34/yr)</td>
</tr>
</tbody>
</table>

Contrary to Jaarsveld and Dekker (2011), we are not able to assign a specific value of $\psi$ to each category. They saw a clear decrease in $\psi$, as a result of increase in $\lambda$. Our analyses did not show this; we noticed a large fluctuation in $\psi$ as $\lambda$ increases. This indicates that $\psi$ is not only related to just a few order frequency values. Therefore, we will calculate the weighted average (function (8)), and assign the same risk of obsolescence to each category. Weighted average over the periods 2010 – 2014 and 2009 – 2013 are 0.52/yr and 0.49/yr, respectively.

$$\bar{\psi} = \frac{\sum_{i=1}^{15} x_i \psi_i}{\sum_{i=1}^{15} x_i}$$

(8)

Note that $\psi$ must be interpreted as the transition intensity to move from a state in which demand is positive, to a state in which demand is zero (see Figure 13). Since we assumed that demand follows a Poisson process, the time until a next event occurs (i.e., demand occurs or an item becomes obsolete) is negative exponentially distributed, see formula (9).

$$F(t; \psi) = \begin{cases} 1 - e^{-\psi t} & t \geq 0 \\ 0 & t < 0 \end{cases}$$

(9)

This enables us to calculate the probability that an item will become obsolete in a specific period. For example, the probability that demand drops dead within half a year is equal to $F(t/2;0.52) = 1 - e^{-0.52(t/2)} = 0.23$. Note that $1 - e^{-\psi t} \approx \psi t$, if $t$ decreases. Therefore, we conclude that the probability of an item becoming obsolete within a small period (e.g., half a year, month or less), can be seen as $\psi t$. 

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4.2. Statistical model

Additionally, we analyzed item characteristics and their association with obsolescence (according to the new definition of obsolescence) using statistical analyses (i.e., logistic regression model). First, we describe the item characteristics stratified for obsolescence (see Table 7). Subsequently, we will discuss the logistic regression analysis. The dataset we used for this analysis differs from the dataset used for the estimation of the obsolescence risk. The dataset consists of more than 6,500 items, which received demand during 2009 and 2012. Items with no demand in 2012 are excluded from the dataset to make sure they become obsolete between January 2013 and December 2014.

4.2.1. Characteristics stratified for obsolescence

Of all items in the dataset, 28% had no demand during 2013-2014. Table 7 shows the fraction of each item characteristics within the non-obsolete and obsolete group. To assess whether fractions differed significantly between both groups, we used the Chi-squared test for the categorical variables, and student’s T-test for continuous variables.

A large fraction of all orders during 2009 – 2012 (77.4%) can be assigned to the three largest customers, namely customer 1-4, customer 5 and customer 6. The fraction of customer 1-4 items is significantly smaller within the obsolete items, compared to the non-obsolete items (p<.001). This indicates that items within the supply chain intended for customer 1-4 are less often obsolete. Items intended for systems of KLA and FEI are more often obsolete, however, these fractions do not differ significantly (p=.45 and p=.22, respectively). We can conclude the same for new product introduction items (p=.64). In addition, we studied the characteristics regarding procurement. 68% of all items in the dataset have been purchased according to EOQ. The fraction of obsolete items is significantly lower than non-obsolete items (p<.001). However, still 59.9% of the obsolete items is purchased according to EOQ. The problem of obsolete items is clearly present within the production environment of VDL ETG (see section 4.1.1). In case a large quantity is purchased, this may result in a large quantity of obsolete items that cannot be used anymore. Furthermore, these items may be purchased without commitment, or only with partial commitment from their customer, whereby VDL ETG needs to cope with the financial consequences. The percentage of items purchased according to MOQ policy is significantly larger (p<.001) within the obsolete group, compared to the nonObsolete group. Because these items do have lower unit prices, and the financial consequences for VDL ETG may be lower compared to EOQ, this does not necessarily require additional attention. Finally, fraction of obsolete items purchased lot-for-lot is significantly larger compared to the non-obsolete group (p<.001). Several items with no demand during period 2013 - 2014 are still kept in stock, which is discussed in section 4.3. In that section, we categorized items according to their purchasing policy, to assess total values of obsolescence costs per policy. Internally produced items (build) are generally more expensive and have a highly complex nature (high complex item; van Wandeloo, 2016). Demand for these items drops dead more often significantly, p<.001 and p<.001, respectively. If production batches are large, this may result in obsolete items and high obsolescence costs (similar to EOQ and MOQ). Again, VDL ETG has to cope with these financial consequences. Contrary to high complex items, no/low complex items are cheaper and are purchased from external suppliers (van Wandeloo, 2016). Fraction of non-obsolete low complex items is significantly higher than obsolete items (p<.001). The relative proportion of obsolete medium complex items does not differ significantly from the fraction within the non-obsolete group (p=.83). The majority (87.0%) is kept in stock within central inventory. Therefore, it is obvious that a large fraction of the items with no demand during the
period 2013 – 2014 is stocked in central inventory. The fraction of obsolete items located in central inventory is significantly smaller compared to non-obsolete items (p<.001). 10% of the items in the dataset are located in pre-expended stock (e.g., two-bin inventory). In total, 42% of these items are obsolete between 2013 and 2014. The fraction of items located in pre-expended is significantly larger within the obsolete group (p<.001). However, these items are generally cheaper compared to other items. Therefore, these items will probably have a lower impact on the obsolescence costs (van Wandeloo, 2016). According to our analysis in section 4.1.1, we are not able to assign a certain risk of obsolescence to each individual order frequency. However, the stratified data indicates that the fraction of items with low demand (below 130 during 2009 – 2012) is significantly larger within the obsolete group (p<.001). We dichotomized the total demand to two categories (both represent ±50% of the items), namely into items with low demand during 2009 - 2012 (ranges from [1-130]) and items with high demand (ranges from [131-∞]). Furthermore, the mean order frequency of obsolete items is significantly lower, compared to the mean of non-obsolete items (p<.001). This indicates that items that are ordered less frequently are more often obsolete in a subsequent period. Furthermore, obsolete items are significantly less active compared to the non-obsolete items (i.e., used in production for shorter time; p<.001). Finally, the unit price of obsolete items is significantly higher. Again, this may have a negative impact on the financial and inventory performances of VDL ETG (p=.001).
Table 7: Relation between item characteristics and obsolescence. Characteristics are stratified for obsolescence (according to the new proposed definition).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>All items, N&gt;6,500 (100%)</th>
<th>Non-obsolete items, 71.9%</th>
<th>Obsolete items, 28.1%</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer 1-4, %</td>
<td>35.5%</td>
<td>37.9%</td>
<td>29.4%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Customer 5, %</td>
<td>31.2%</td>
<td>21.4%</td>
<td>31.9%</td>
<td>.45</td>
</tr>
<tr>
<td>Customer 6, %</td>
<td>10.7%</td>
<td>10.4%</td>
<td>11.4%</td>
<td>.22</td>
</tr>
<tr>
<td>New Product Introduction, %</td>
<td>3.2%</td>
<td>3.1%</td>
<td>3.4%</td>
<td>.64</td>
</tr>
<tr>
<td>EOQ, %</td>
<td>68.0%</td>
<td>71.1%</td>
<td>59.9%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>MOQ, %</td>
<td>18.2%</td>
<td>17.0%</td>
<td>21.1%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Lot-for-lot, %</td>
<td>13.8%</td>
<td>11.9%</td>
<td>19.0%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Build, %</td>
<td>18.2%</td>
<td>17.1%</td>
<td>20.9%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>No/low complex item, %</td>
<td>69.1%</td>
<td>70.6%</td>
<td>65.4%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Medium complex item, %</td>
<td>11.1%</td>
<td>11.0%</td>
<td>11.2%</td>
<td>.83</td>
</tr>
<tr>
<td>High complex item, %</td>
<td>19.8%</td>
<td>18.4%</td>
<td>23.4%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Central inventory, %</td>
<td>87.0%</td>
<td>89.0%</td>
<td>81.8%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Pre-expended stock, %</td>
<td>10.0%</td>
<td>8.0</td>
<td>15.1%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Total demand &lt;130, %</td>
<td>49.7%</td>
<td>42.6%</td>
<td>67.7%</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Order frequency, mean (±SD)</td>
<td></td>
<td></td>
<td></td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Number of years with demand (mean±SD)</td>
<td></td>
<td></td>
<td></td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Unit price (€), mean (±SD)</td>
<td></td>
<td></td>
<td></td>
<td>.001*</td>
</tr>
</tbody>
</table>

Obsolete; no demand occurred during 2013 – 2014, customer 1-4; item belongs to a system of customer 1-4, Customer 5; item belongs to a system of customer 5, customer 6; item belongs to a system of customer 6, New Product Introduction; item is used for production of prototypes, EOQ; item is purchased according to the economic order quantity policy, Lot-for-lot; item is purchased lot-for-lot, Build; item is built internally at the Parts department, No/low complex item; (very) low level of complexity, generally purchased from an external supplier, Medium complex item; medium level of complexity, purchased from external supplier or produced internally at the department Parts, High complex item; high level of complexity, only produced internally at department Parts, Central inventory; item is kept at the central inventory, Pre-expended stock; item is kept in stock in pre-expended stock (i.e., two-bin), Total demand <130; total demand during 2009 – 2012, Order frequency; total times an order is placed during 2009 – 2012, Unit price; price per unit in Euros, Number of years with demand; amount of years an item has been ‘active’ during 2009 - 2012; *p<.05
4.2.2. Logistic regression analysis

The association between the item characteristics and obsolescence can be investigated by means of a logistic regression analysis. This statistical method allows to test models to predict categorical outcomes (Pallant, 2005). As shown in Table 7, we use both categorical and continuous variables (i.e., independent variables) to predict obsolescence (i.e., dependent variable). Initially, only the characteristics of which the fraction of non-obsolete and obsolete items differed significantly (see Table 7) are included, see Figure 14.

![Figure 13: Predicting variables and dependent variable (non-obsolete or obsolete) within logistic model. Variables with bold border were retained in the logistic regression analysis.](image)

Logistic regression assumes no multicollinearity between two predicting variables. Multicollinearity exists if the predicting variables are highly correlated \( (r \geq .8) \) (Pallant, 2005). Predicting variables that correlate higher than .8 do not contribute to a good logistic regression model. Therefore, we need to check for multicollinearity (multicollinearity matrix is attached in Appendix C.3). We removed the variable Pre-expended stock. This variable correlated -.862 with Central inventory \( (p<.001) \). We have chosen to retain the Central inventory, because these items are generally more expensive. Therefore, we are more interested in the association between these items and obsolescence. We also removed the variable Build, because of its high correlation with the variables High complex item and No/Low complex item, .76 \( (p<.001) \) and -.70 \( (p<.001) \). Despite these correlations are not above .8, they are relatively high, and there may exists a large overlap between high complex items and items that are produced internally at VDL ETG. Furthermore, we were required to remove one of the three variables relating the purchase policy to solve redundancies. We
decided to remove the variable MOQ, because the items that are purchased according to this policy are cheaper. Therefore, this characteristic is less interesting, compared to the other two. Finally, we performed the logistic regression analysis with nine dependent variables (see Figure 14). Table 8 shows the summarized output of the logistic regression, the entire output is attached to Appendix C.4.

| Table 8: Logistic regression predicting likelihood of reporting obsolescence (i.e., obsolete or non-obsolete). |
|-----------------------------------------------|-----------------------------------------------|
| Item characteristic          | B     | p-value | OR (\(\text{e}^B\)) | 95% CI for OR |
| Customer 1-4                  | -.104 | .12     | .901 | .789       | 1.029 |
| EOQ                           | -.130 | .15     | .878 | .734       | 1.050 |
| Lot-for-lot                   | .347  | .001    | 1.414 | 1.145      | 1.748 |
| No/low complex item           | -.356 | <.001   | .701 | .582       | .843  |
| High complex item             | .082  | .44     | 1.085 | .882       | 1.335 |
| Central inventory             | -.727 | <.001   | .483 | .399       | .585  |
| Total Demand (<13)            | .611  | <.001   | 1.843 | 1.605      | 2.117 |
| Unit price (£)                | .000  | .03     | 1.000 | 1.000      | 1.000 |
| Order frequency               | -.004 | <.001   | .996 | .996       | .997  |
| Number of years with demand   | -.011 | .67     | .989 | .939       | 1.041 |

OR: odds ratio, CI: confidence interval

The full model was statistically significant (\(\chi^2 = 688.48; p<.001\)), which indicates that this model was able to distinguish between obsolete and non-obsolete items. The model as a whole explained between 10% and 14% of total variance in obsolescence, and correctly classified 9.6% of all items. We will only discuss the column odds ratio (OR), because these values represent the strength and direction of association between the predicting and dependent variable. As shown in Table 8, lot-for-lot, no/low complex items, central inventory items, total demand (below 130) and items with a higher order frequency made unique significant contribution to the model. The confidence interval (CI) of these characteristics does not contain the value 1, which means that the null hypothesis (i.e., there is no association) is not supported. We identify total demand <130 as strongest predictor, with an OR of 1.6. This indicates that items with a total demand below 130 were 1.6 times more likely to receive no demand in the subsequent two years, than items that have a total demand larger than 130, controlling for all other factors in the model (\(p<.001\)). Additionally, the OR of .995 for order frequency indicates that for every additional order an item was .005 less likely to become obsolete (less than 1), controlling for other factors (\(p<.001\)). The OR of 1.4 for lot-for-lot, indicates that items which are purchased lot-for-lot were 1.4 times more likely to be obsolete in the next two years, than items that are purchased according to EOQ and MOQ, controlling for all other factors in the model (\(p=.001\)). No/low complex items have an OR of .73 (\(p<.001\)). This indicates that low complex items were .27 less likely to become obsolete, controlling for all other factors in the model. The OR for items stored at the central inventory is .48, indicating that items stored at this location were .52 less likely to become obsolete than those stored in another location (\(p<.001\)), controlling for other factors in the model.

Unfortunately, the results shown in the Hosmer and Lemeshow Test table in Appendix C.4, shows that the model is not supported. The Hosmer and Lemeshow Goodness of Fit Test (i.e., most reliable test of model fit available in SPSS) is significant, which indicates our model has a poor fit. The item characteristics and their associations are not sufficient to predict whether an item is obsolete or non-obsolete. The Chi-square value is 161.916 with a significance level of <.001. This value is smaller than .05, therefore we can conclude that there is no support for the model. To try to improve
the Goodness of Fit, we tightened the rules regarding multicollinearity. We removed predicting variables which correlated above .7. However, this did not improve the Goodness of Fit, since the Hosmer and Lemeshow test remained significant.

We performed the same logistic regression analysis on a different dataset, which consists of items with demand during the period 2009-2012. We noticed that the ORs from this analysis were different from the ORs as shown in Table 8. This indicates that the associations between the item characteristics and obsolescence are not constant over time. This makes it difficult to conclude which characteristics are associated with obsolescence, and to predict which item types have a higher change of becoming obsolete.

### 4.3. Inventory value of items with no demand in the past two years

In chapter 3, we proposed an alternative definition for obsolescence (i.e., an item is obsolete if no demand has occurred during the past two years). However, obsolete items can only harm the inventory performance if these items are still kept in stock while they cannot be used anymore. We applied this definition to the current inventory of VDL ETG (i.e., June 2016, see Table 9). We analyzed how these costs originated. First, we analyzed whether the items with zero demand between 2013 and 2014 are still in stock (as estimated during the analysis in section 4.1.1). These items represent a fraction of 55.5% of the total obsolescence costs. We checked whether the items had demand between January 2015 and May 2016. If this was the case, the item was excluded from obsolescence costs. A large fraction (20%) of the obsolescence costs was represented by items that received their last order between January 2009 and December 2010. Our dataset did not allow us to analyze the demand process prior to 2009. The percentage 24.3% stands out. This value represents all items with a last order before January 2009, or items that have been transferred from project inventory to anonymous inventory before June 2014. We are unable to analyze which of the two causes the highest fraction of these costs. Therefore, we discussed this finding with several employees from VDL ETG. They mentioned that a transfer from project to anonymous inventory is the most obvious reason (discussed in section 1.3.2).

### Table 9: Derivation of the obsolescence costs according to the new definition of obsolescence.

<table>
<thead>
<tr>
<th>Order frequency during 2011 - 2012</th>
<th>Obsolescence costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20.1%</td>
</tr>
<tr>
<td>1-5</td>
<td>24.2%</td>
</tr>
<tr>
<td>6-10</td>
<td>4.7%</td>
</tr>
<tr>
<td>11-15</td>
<td>8.0%</td>
</tr>
<tr>
<td>≥16</td>
<td>18.7%</td>
</tr>
<tr>
<td>Rest</td>
<td>24.3%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

Additionally, we investigated how the obsolescence costs, as defined in Table 9, are related to the purchase policy. Table 7 shows that 19% of obsolete items have been purchased as lot-for-lot. We concluded that this policy represents a total value of €102,113. This is remarkable, because these items should be purchased solely as a reaction to customer orders. After analyzing these items in greater
detail, we see that 45% of the items have been replaced by another item due to an engineering change. These are useless for production, but are still kept in stock. Besides that, in some cases (12% of €102,113) the Operational procurement department has deviated from the lot-for-lot policy. For the remaining value, no reason can be found in the available data. We analyzed whether this was due to safety stock regulations. However, this was not the case for the remaining items. It may be the case that these items were redundant in a project, and transferred to anonymous inventory. Subsequently, these items have not received any demand, and became obsolete (see section 1.3.2). The rest of the obsolescence costs can be allocated to items which are purchased according to a MOQ or EOQ policy. This is not surprising, because within these policies VDL ETG purchases more than required.

4.4. Conclusion

The quantification of obsolescence did show that this risk is explicitly present within VDL ETG’s supply chain (see Table 6). Furthermore, we concluded that the risk of obsolescence is not typical for items that are ordered less frequently. This implies that items with a larger demand volume also have a large probability of becoming obsolete in a subsequent period. Our analysis of associations between item characteristics and obsolescence did not show any characteristics that were strong and independent predictors of obsolescence. Both analyses made us conclude that obsolescence is a severe issue within the production environment of VDL ETG. Therefore, it is hard to anticipate with the aim to avoid obsoleteness. In section 4.3, we discussed the obsolescence costs if we apply the proposed definition of obsolescence (see Table 9). This is lower compared to the obsolescence costs according to the current definition of obsolescence (see section 2.2). However, we did not study which period length of no demand would be the best rule to classify an item as obsolete.
5. Risk of obsolescence incorporated within inventory control

At the moment, the risk of obsolescence is not incorporated within the inventory policy of VDL ETG (Langenhuysen & Tjiptowidjojo, 2015; Tjiptowidjojo, 2015). In this section we show how the risk of obsolescence can be implemented in the current inventory policy. First, we will briefly discuss the VDL ETG’s current inventory model. Second, we will discuss an improved inventory model (Cobbaert & Van Oudheusden, 1996). Finally, in section 5.3 we will perform a numerical analysis to compare both models.

5.1. Current inventory policy

The ordering policies are discussed in section 2.3. We will propose an improved inventory model for the items that are purchased following the EOQ policy. VDL ETG is only able to change the purchase quantity of these items, therefore, we will only propose an improved purchase model for these items. Within the MOQ policy, VDL ETG is forced to purchase a minimum quantity from their supplier. However, the stratified data showed that one third of the MOQ items became obsolete during 2013-2014 (see Table 7). Therefore, purchasing these items also requires additional attention, which will be discussed in greater detail in the recommendations (see chapter 6.2).

VDL ETG’s inventory policy is a continuous review (s, Q) inventory model. This means that VDL ETG purchases a reorder quantity (Q) each time the inventory level has dropped to the reorder level (s) (Melchiors, Dekker, & Kleijn, 2000). The value of s may differ per item, but is constant over time. In general, the reorder level of expensive items is equal to zero (i.e., s=0). However, the reorder level of cheaper items (e.g., items in pre-expended stock) is positive (VDL ETG, 2016). Currently, VDL ETG calculates Q according to Harris’ (1913) framework. Harris (1913) composed a total cost function per year, function (10). The first part of the function represents the ordering costs per year (i.e., fixed ordering costs times the number of reorders (λ/Q)), and the second part represents the holding costs per year (i.e., costs of carrying inventory during one year). λ is defined as demand per year. Note that we neglect the total value of all items purchased during a year, because this is a constant factor.

\[ \text{TC}(Q) = \frac{A\lambda}{Q} + \frac{Qvr}{2} \]

\[ A: \text{fixed ordering costs [€]} \]
\[ \lambda: \text{demand rate [unit/time]} \]
\[ Q: \text{order quantity [unit]} \]
\[ v: \text{unit price [€/unit]} \]
\[ r: \text{holding rate [€/€/unit]} \]

The ordering costs decrease if Q increases, and the carrying costs increase linearly if Q increases (see Figure 14). The black line represents the total costs. The value of EOQ will be calculated to set the derivative of TC(Q) equal to 0, \[ \frac{d\text{TC}(Q)}{dQ} = 0 \]. This means we can calculate EOQ as following:
VDL ETG’s inventory model assumes that demand is deterministic and constant over time, that unit price is independent of reorder quantity (i.e., no discount), and that relevant cost factors are constant over time as well. Furthermore, this model assumes that lead time is deterministic and constant over time, that no shortages are allowed, and that the total reorder quantity is delivered at once. Due to these assumptions, the model is a simplification of the real world. However, the model is able to provide a good overall idea of the inventory performance.

As discussed in chapter 2, this purchase policy is used both within the MTO and ATO environment. Both environments are prone to rapid technological developments and engineering changes. This may lead to items becoming obsolete. The current inventory policy may have a negative impact on the inventory performance, especially when the unit price is high and/or the demand rate is low. This is particularly the case within the MTO environment. This environment is less static compared, to the ATO environment (i.e., ATO environment is forecast driven).

5.2. Improved inventory policy

In this section we introduce an inventory model that incorporates the risk of obsolescence. Several researchers have investigated how the inventory policies could be improved by incorporating the risk of obsolescence. To the best of our knowledge, only Masters (1991) and Cobbaert and Van Oudheusden (1996) have generated an extension on the EOQ model of Harris (1913). In this section we will discuss the model of Cobbaert and Van Oudheusden (1996).

5.2.1. Model of Cobbaert and Van Oudheusden (1996)

Cobbaert and Van Oudheusden (1996) proposed two extensions of the original EOQ model. Within their first extension they assume that the risk of obsolescence is constant over time. Their

\[
EOQ = \sqrt{\frac{2A\lambda}{vr}}
\]
second model is a more sophisticated model, because it assumes that the risk of obsolescence varies over time. However, this makes implementation more difficult. Together with several experts from VDL ETG we decided to propose the first model of Cobbaert and Van Oudheusden (1996) as a substitution of the current policy. Due to the assumption of a constant probability over time, it can be easily implemented. Despite this model being simpler than other inventory models discussed in literature, it is able to give a good overall indication of inventory performance.

Cobbaert and Van Oudheusden (1996) added obsolescence costs to the total costs function, see function (12). The researchers assume that the time until a next event (i.e., either demand occurs again or item becomes obsolete is negative exponentially distributed). This is similar to our approach. In section 4.1.1, we discussed that in our situation the expected time \( E(T) \) until an item becomes obsolete is equal to \( 1/\psi \). The first part in function (12) represents the costs while demand is still positive. The latter part represents the costs if an item has become obsolete. The definition of the variables \( A, Q, v, r \) and \( \lambda \) is equal as in function (11). Variable \( \psi \) represents the risk of obsolescence per year, equal to 0.52/year (see section 4.1.1). Variable \( c_o \) represents the obsolescence costs per unit. We assume that these costs are equal to the unit price plus the carrying costs during one year (i.e., \( Qc_o/2 \)), and that an item has no salvage value. Because \( \psi \) is constant, function (12) can be rewritten to function (13).

\[
TC(Q) = \left( \frac{A\lambda}{Q} + \frac{Qvr}{2} \right) \frac{1}{\psi} + \frac{Qc_o}{2}
\]

(12)

\[
\psi: \text{risk of obsolescence [time]}
\]
\[
c_o: \text{obsolescence costs [€/unit]}
\]

\[
TC(Q) = \frac{A\lambda}{Q} + \frac{Qvr}{2} + \frac{Q\psi c_o}{2}
\]

(13)

Function (13) is visualized in Figure 15. The obsolescence costs are visualized with a linear grey dotted line. By adding the obsolescence costs, the minimum of the total costs shifts to the left compared to Figure 14.

![Figure 15: Total costs per year against the reorder quantity according to Cobbaert and Van Oudheusden’s model (1996).](image-url)
Again, the value of EOQ will be calculated to set the derivative of \( TC(Q) \) equal to 0, \( \frac{dTC(Q)}{dQ} = 0 \). This results in an EOQ function which incorporates the risk of obsolescence (EOQ\(^{\psi}\));

\[
EOQ^{\psi} = \sqrt{\frac{2A\lambda}{vr + c_o\psi}}
\]  \( (14) \)

The assumptions of this model are similar to the assumptions of Harris’ (1913) model. Additionally, Cobbaert and Van Oudheusden (1996) assumed that half of the stock is scrapped. However, this assumption becomes reasonable when \( \lambda \) (i.e., demand rate) increases. If \( \lambda \) increases, and all other variables remain constant, the reorder quantity (i.e., EOQ) increases. Furthermore, the number of reorder cycles per year (\( \lambda / EOQ \)) increases (visualized with dotted line in Figure 17). As a result, the cycle length decreases and becomes smaller and smaller compared to the expected time until obsolescence occurs (i.e., \( EOQ/\lambda < 1/\psi \)).

![Figure 16: Visualization of two different cycle lengths. Dotted line represents shorter cycle length due to a higher value of \( \lambda \).](image)
5.3. Numerical analysis

In this section, we will illustrate the advantages of incorporating the risk of obsolescence within the inventory policy of VDL ETG. In the master’s thesis report handed in at VDL ETG, we calculated both EOQ and EOQ\(^v\) based on real demand data of items that are currently purchased according to the EOQ policy. Within this document we use hypothetical, but realistic values for items. To illustrate the advantages regarding total costs per year, we enter both EOQ’s in function (13). For the variables \(A\) and \(r\) we choose two hypothetical values within a production environment, €30 and 0.1/year, respectively. \(v\) represents the unit price of an item, which is hypothetical. For \(\psi\), we will use the weighted average value of 0.52, as discussed in section 4.1.1. Furthermore, the actual costs of obsolescence (e.g., scrapping an item) are unknown. Therefore, we assume that these costs \((c_o)\) are equal to the unit price of an item plus the costs of keeping an item on inventory for one year. We do not assume salvage value of obsolete items. The advantages of incorporating the risk of obsolescence within the inventory policy is shown in Table 10.

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>EOQ</th>
<th>EOQ(^v)</th>
<th>Unit price</th>
<th>Total costs estimation of EOQ</th>
<th>Total costs estimation of EOQ(^v)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ordering</td>
<td>Holding</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>2</td>
<td>€ 125</td>
<td>€ 37.50</td>
<td>€ 25.00</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>2</td>
<td>€ 250</td>
<td>€ 75.00</td>
<td>€ 75.00</td>
</tr>
<tr>
<td>65</td>
<td>4</td>
<td>2</td>
<td>€ 2,250</td>
<td>€ 487.50</td>
<td>€ 450.00</td>
</tr>
<tr>
<td>185</td>
<td>7</td>
<td>3</td>
<td>€ 2,000</td>
<td>€ 792.86</td>
<td>€ 700.00</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>6</td>
<td>€ 25.00</td>
<td>€ 20.00</td>
<td>€ 18.75</td>
</tr>
<tr>
<td>24</td>
<td>42</td>
<td>16</td>
<td>€ 8.00</td>
<td>€ 17.14</td>
<td>€ 16.80</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>4</td>
<td>€ 25</td>
<td>€ 13.33</td>
<td>€ 11.25</td>
</tr>
<tr>
<td>12</td>
<td>37</td>
<td>15</td>
<td>€ 5</td>
<td>€ 9.73</td>
<td>€ 9.25</td>
</tr>
</tbody>
</table>

In Table 10, we have simulated four different scenarios. The first scenario simulates the situation in which demand is lower than 15 (equal to analysis in Table 6). The second scenario simulates the situation in which the total demand is larger than 15. We were not able to assign a specific value of \(\psi\) to each category of order frequency (see section 4.1.1), and therefore we assume that we can incorporate the value of 0.52 for items with a demand larger than 15 as well. To simulate this scenario, we derived demand data from the ATO environment. Within this environment, purchases are forecast driven. Therefore, VDL ETG also purchases expensive items according to the EOQ policy (VDL ETG, 2016). However, these items have a large probability of becoming obsolete. In the third scenario, we simulate the situation in which the unit price is lower than the fixed purchase cost (€25). However, the fixed purchase costs are relatively low compared to the other cost factors. Therefore, in this situation the inventory model of Cobbaert and Van Oudheusden (1996) results in lower costs, compared to the current inventory model of VDL ETG. In the last scenario we see that EOQ and EOQ\(^v\) is larger than the annual demand. The value of EOQ is even larger than the total demand during two years. However, a situation in which the time until the entire purchased quantity (EOQ) is
consumed \( \left( \frac{Q}{\lambda} \right) \) is larger than the expected time until obsolescence occurs \( E(T) = \frac{1}{\psi} = \frac{1}{0.52} = 1.9 \text{ year} \) is not preferable. In this situation, obsolete stock is unavoidable.

Table 10 clearly shows the effect of implementing the risk of obsolescence within the inventory model. Because we incorporate this risk, the reorder quantity decreases, whereby the cycle length decreases (see Figure 17). As a result, the average inventory (EOQ/2) per cycle decreases. This leads to lower carrying costs and obsolescence costs. However, due to a shorter cycle length the total ordering costs increase. However, the extra ordering costs are lower compared to the savings in carrying and obsolescence costs.

5.4. Conclusion

The current \((s, Q)\) inventory model of VDL ETG can be improved by incorporating the risk of obsolescence. Within our numerical analysis we analyzed several scenarios. We conclude that the improved model of Cobbaert and Van Oudheusden (1996) results in cost savings in all scenarios. The numerical analyses, based on real demand data, showed that in some cases VDL ETG purchases more than the total annual demand, or even during two subsequent years. We concluded that the expected time for an item to become obsolete is 1.9 years. Therefore, VDL ETG should not purchase more than 1.9 years in advance.
6. Conclusion and recommendations

This final chapter presents the conclusion and recommendations from our master thesis project. First, we will describe the conclusion per research question. Subsequently, we will discuss recommendations for VDL ETG to handle obsolescence.

6.1. Conclusion

The objective of this research project was to analyze the causes of obsolescence within the production environment of VDL ETG, and to improve the ordering policy within the anonymous inventory. We will discuss the conclusion per research question.

Research question 1. How is the quantity of items that become obsolete in the As-is situation within VDL ETG influenced by MOQ, EOQ and long lead time items?

On average, the obsolescence costs represent 12.5% of the total anonymous inventory value. Our analyses showed that the items that are purchased according to the EOQ policy represent a large fraction of the obsolescence costs (81%). Additionally, we saw that in most cases (63%) the quantity obsolete items is equal or higher than EOQ. This is due to the lack of monitoring the parameters in BaaN during an item’s life cycle. Our analysis allowed us to conclude that the impact of MOQ and long lead time items on the obsolescence costs is low, 6% and 0.5% respectively.

Research question 2. Is the risk of items becoming obsolete typical for a specific chain (i.e., customer)?

Our analysis on the derivation of the obsolescence costs regarding the current definition shows that a large fraction (66%) of the obsolescence costs can be assigned to the two largest customers (i.e., customer 1-4 and customer 5). However, the stratified data showed that items that belong to these two customers are significantly less often obsolete, compared to the items of other customers (see Table 4). Additionally, we analyzed the obsolescence costs per MTO and ATO supply chain. The obsolescence costs within these supply chains were 80% and 20%, respectively. This is because the ATO environment is forecast driven, and the demand is more stable over time.

Research question 3. How does the current definition regarding obsolescence perform at VDL ETG?

The current definition of VDL ETG classifies an item as obsolete if it has not ‘moved’ during the past four months (i.e., change of location or no decrease or increase of stock levels). However, a movement due to change of inventory location or increase in inventory level means that an item will be classified as non-obsolete. This is not preferable. Another shortcoming of the current definition related to obsolescence is that items are incorrectly classified as obsolete. Our analysis showed that 75% of the entire obsolescence costs is actually obsolete (i.e., a total value of 25% has been incorrectly classified as obsolete). Applying the new definition regarding obsolescence on the anonymous inventory resulted in lower obsolescence costs. Because we did not investigate in detail which period length is the optimal one to classify an item as obsolete, we cannot conclude that the current definition will actually lead to lower obsolescence costs.
**Research question 4.** *Can VDL ETG foresee items becoming obsolete; does demand drop dead suddenly (i.e., “sudden death” obsolescence), or does demand decrease gradually?*

The current definition regarding obsolescence had several shortcomings. Therefore, we proposed another definition: an item is classified as obsolete if no demand has occurred during the past two years. Our analysis showed that VDL ETG faces both “sudden death” obsolescence and obsolescence due to gradual decrease in demand. In case of sudden drop of demand (28% of the analyzed items), VDL ETG cannot anticipate to obsolescence timely. However, Figure 10 showed that the demand of the remaining items (72%) decreased gradually. Therefore, we conclude that VDL ETG should monitor, and actively adjust the parameters concerning the purchase policies on a regular basis from now on. This enables them to better anticipate to items that become obsolete, and to decrease the amount of obsolete inventory in the future.

**Research question 5.** *How could VDL ETG improve their ordering policy within the anonymous inventory when they incorporate the risk of obsolescence?*

In section 4.1.1, we estimated the risk of obsolescence within VDL ETG’s production environment. This analysis showed that the risk of obsolescence is not higher for items which are ordered less frequently. This implies that items with higher demand are at risk for becoming obsolete as well. In addition, we analyzed the association between item characteristics and obsolescence. This analysis did not show any characteristics that were strong independent predictors of obsolescence. From this, we concluded that obsolescence cannot be predicted using item characteristics. Both analyses have indicated that obsolescence is a severe issue within the production environment of VDL ETG (see sections 4.1.1 and 4.2.2). Therefore, it is hard to anticipate for obsolescence within the supply chain.

In chapter 5, we discussed the model of Cobbaert and Van Oudheusden (1996) as an improvement of VDL ETG’s current inventory and purchase policy. From our numerical analysis, based on actual demand data, we conclude that the proposed model results in cost savings in all different scenarios. In some cases, VDL ETG purchases more than 2 years in advance. However, the expected time until an item becomes obsolete is 1.9 years. Purchasing over 1.9 years in advance may thus lead to obsolete inventory.

**6.2. Recommendations**

In the cause and effect diagram related to obsolescence (see Appendix A.6), we identified three sub-parts, namely *purchase policy/inventory policy, engineering changes, and processes*. In this section we will discuss the recommendations that came forward during our research. We will assign these recommendations to one of these parts.

6.2.1. Purchase policy/Inventory model

Within their current inventory model, VDL ETG classifies an item as obsolete if it has not ‘moved’ for more than four months (i.e., change of location or no decrease or increase of stock level; section 2.2). In case VDL ETG wants to maintain this definition, we recommend that they only classify an item as obsolete if it has not ‘moved’ for more than four months and it has not been reserved for assembly or production. This gives a better view of the items that are truly obsolete, and
therefore it is a better estimation of actual obsolescence costs (see Figure 6). Therefore, we advise to use the designed tool in Excel (see section 4.3)

VDL ETG has to cope with both “sudden death” obsolescence and obsolescence due to gradual decrease in demand (see chapter 3). In most cases, the purchase parameters in BaaN are not monitored during the life cycle of an item. We recommend to monitor, and if necessary, to adjust these parameters (i.e., on an annual basis). This enables VDL ETG to anticipate changes in demand, which may lower the obsolescence costs, and improve their inventory performance (see Table 10).

Items may be purchased according to lot-for-lot, MOQ or EOQ policy. As discussed in section 4.1.1, the risk of obsolescence is clearly present in the supply chain. Concerning lot-for-lot, we recommend to strictly follow the policy. There are reasonable arguments to purchase items according to this policy (i.e., highly priced items). However, our research showed that in some cases there has been deviated from this policy. These deviations may lead to obsolescence costs. With respect to MOQ, we recommend that VDL ETG negotiates with their suppliers to lower their MOQ policy. In case of EOQ, we recommend to implement the proposed EOQ model (EOQ*; see section 5.2.1). This will lower the number of obsolete items.

In section 2.3, we discussed that the EOQ policy is used within the MTO environment. This implies that items are not only purchased after a customer order, but they are also purchased in advance. This results in high obsolescence costs within the MTO environment, compared to the ATO environment (see Table 3). The demand in the ATO environment is more stable over time, compared to the MTO environment. Therefore, we advise VDL ETG to not use the EOQ policy within the MTO environment, or only use this policy in case their customers are fully committed to these orders (i.e., VDL ETG has not to cope with the financial consequences).

During our research we noticed that the costs of scrapping processes are currently unknown. At the moment, a large fraction of all obsolete items are not scrapped, but are kept in stock, because it may be possible that demand occurs in the future. To make a better decision whether an item must be scrapped, or should be kept in stock for a longer period of time, we recommend to calculate all costs concerning the scrapping process. This enables VDL ETG to make better decisions with regard to their inventory, and obsolete items.

The proposed improvement of VDL ETG’s inventory model is simpler than other models in literature. VDL ETG should see this improved model as a starting point towards the implementation of more complicated models. The proposed model assumes that demand is deterministic. However, this is never the case in a real world. A more complicated model (i.e., demand is stochastic) could enable VDL ETG to approach reality more precisely.

Our research showed that the expected time until an item becomes obsolete is equal to 1.9 years. To anticipate on the risk of obsolescence, and therefore, to lower the quantity of obsolete items, VDL ETG should never purchase more than the total demand over a period of 1.9 years. We recommend to maximum purchase 1.5 years in advance.

The logistic regression analysis did not show any item characteristics that were strong and independent predictors of obsolescence. This shows us that none of the current characteristics were able to predict obsolescence. We only analyzed item characteristics which are typical for the internal supply chain of VDL ETG (see Figure 2). We recommend to perform the same statistical analysis.
based on factors that are representative of the external supply chain (e.g., price fluctuations or increased lead time upstream in the supply chain).

6.2.2. Engineering changes

All processes regarding engineering changes were out of our scope. However, engineering changes are a major cause of items becoming obsolete. For that reason, we advise VDL ETG to analyze the impact of engineering changes on VDL ETG’s supply chain and obsolescence costs. Furthermore, we advise to analyze the processes to handle these changes in greater detail, and to evaluate the transparency of these changes throughout the supply chain.

We recommend to physically distinguish between the production for regular items and the production for spare parts. This will improve the visibility of the demand process. An item may still be required for regular production or assembly (i.e., non-obsolete), or an item is only produced occasionally to serve as a spare part (i.e., the item itself has become obsolete). At this moment, if one spare part is required, the planned production quantity is increased by one. This may lead to an incorrect interpretation of the demand process.

6.2.3. Processes

The third set of causes is related to the processes regarding scrapping of obsolete stock. Several planners have mentioned that it requires a lot of work to obtain approval to scrap an item (i.e., high workload). These bureaucratic procedures are equal for all item types (e.g., both cheap and expensive items). Due to this multiple, items are not scrapped, but are kept in stock. Despite, the first intention was to scrap them. Even though these processes were outside of our scope, we recommend to revise processes to make it easier to scrap of obsolete stock.

We noticed that redundant items within project inventory are transferred to anonymous inventory, which incorrectly improves the revenue of a project and decreases the performance of anonymous inventory (see section 1.3.2). The risk of obsolescence is clearly present within VDL ETG’s supply chain (see section 4.1.1). Therefore, we recommend not to transfer redundant items from project to anonymous inventory, and to take the losses on the project instead of on anonymous inventory.

Despite we did not investigate in detail which period length is optimal to analyze whether an item has become obsolete, we recommend to change the definition regarding obsolescence. Together with several employees within VDL ETG, we adjusted the definition into: an item is classified as obsolete if no demand has occurred during the past two years. No demand for two years indicates that the item is in its end of life phase. This definition only takes into account the demand for items, and does not account for increases of the inventory level or a change of inventory locations, which is the case according to the current definition (see section 2.2.1). We think this new definition will provide a better view regarding the obsolescence costs and the inventory performance. However, we did not study which exact duration of no demand would be best to classify an item as obsolete. Therefore, we advise to analyze this (e.g., shorter or longer than two years).
References


Tjiptowidjojo, F. (2016). Factors that have impact on items becoming obsolete (29-2-216) by Simons, J (interviewer).


VDL ETG. (2016). ITM Stuklijst retrieved from BaaN.


Appendix

A.1 Organizational chart of VDL Group
A.2 Organizational chart of VDL ETG
A.3 Functions within the VDL ETG supply chain

In section 1.2, we introduced the internal supply chain of VDL ETG. Some employees are assigned to a specific section within the supply chain, while others have no specific functions. A chain refers to a specific customer (e.g., Philips, KLA) or a specific item of a customer (e.g., Twinscan or Cymer from ASML). The chain specific functions are:

- Account Manager: is responsible for the (long-term) relationship with customers and plays an important role in the sales process
- Integral Planner: is responsible for the integral planning of the chain (e.g. order, material release and rescheduling)
- Order Manager: is responsible for direct communication with customers about the order details (e.g. order lead times and demand plans)
- Operational Buyer: is responsible for fulfilling the purchase orders, which are released by Integral planning
- Production Assistant (Systems): is responsible for the material coordination, ensures the availability of material in the stock of Systems and releases materials for the assembly of sub- and final assemblies

The non-chain specific functions are:

- Parts planner: is responsible for the planning of production orders and manages the capacity constraints
- Production Assistant (Parts): is responsible for correct and timely flow of input material
A.4 Cause and effect diagram – key issues VDL ETG’s supply chain

Figure 17: Cause and effect diagram supply chain VDL ETG (Kamps & Arts, 2014)
A.5 Roadmap towards improvement of VDL ETG’s supply chain

Figure 18: Roadmap to the improvement of VDL ETG’s supply chain efficiency and control (Kamps & Arts, 2014)
A.6 Cause and effect diagram – obsolete inventory

Figure 19: Cause and effect diagram regarding obsolescence of inventory
B.1 Order frequency per category unit price

Figure 20: Total order frequency of all items with a unit price between €100 - €250 against the order life time

Figure 21: Total order frequency of all items with a unit price between €250 - €1,000 against the order life time

Figure 22: Total order frequency of all items with a unit price higher than €1,000 against the order life time
### C.1 Fraction of no demand in period 2012 – 2013

<table>
<thead>
<tr>
<th>Order frequency in period 1</th>
<th>Number of items in period 1</th>
<th>Expected fraction with zero demand (Poisson) (%)</th>
<th>Fraction no demand period 3 (%)</th>
<th>$f_{T,t}^{-1}(p) = \psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1407</td>
<td>36.79</td>
<td>71.7</td>
<td>0.45/yr</td>
</tr>
<tr>
<td>2</td>
<td>737</td>
<td>13.53</td>
<td>62.4</td>
<td>0.51/yr</td>
</tr>
<tr>
<td>3</td>
<td>565</td>
<td>4.98</td>
<td>63.9</td>
<td>0.65/yr</td>
</tr>
<tr>
<td>4</td>
<td>378</td>
<td>1.83</td>
<td>58.7</td>
<td>0.61/yr</td>
</tr>
<tr>
<td>5</td>
<td>336</td>
<td>0.67</td>
<td>51.8</td>
<td>0.53/yr</td>
</tr>
<tr>
<td>6</td>
<td>347</td>
<td>0.25</td>
<td>46.1</td>
<td>0.47/yr</td>
</tr>
<tr>
<td>7</td>
<td>268</td>
<td>0.09</td>
<td>51.1</td>
<td>0.57/yr</td>
</tr>
<tr>
<td>8</td>
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<td>0.01</td>
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</tr>
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<td>0.00</td>
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<td>0.28/yr</td>
</tr>
<tr>
<td>11</td>
<td>133</td>
<td>0.00</td>
<td>42.1</td>
<td>0.47/yr</td>
</tr>
<tr>
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<td>0.00</td>
<td>38.9</td>
<td>0.42/yr</td>
</tr>
<tr>
<td>13</td>
<td>105</td>
<td>0.00</td>
<td>36.2</td>
<td>0.39/yr</td>
</tr>
<tr>
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<td>113</td>
<td>0.00</td>
<td>19.5</td>
<td>0.19/yr</td>
</tr>
<tr>
<td>15</td>
<td>91</td>
<td>0.00</td>
<td>31.9</td>
<td>0.34/yr</td>
</tr>
</tbody>
</table>

Overall fraction of items with zero demand in period 3, and positive demand in period 4: 3.06%  
The weighted average value of $\psi = 0.49$

### C.2 Explanation of the probability function

Demand during interval $(t, t+T)$ is $C(t,t+T)$. The probability of no demand during $(t, t+T)$ can be calculated as follows

$$P(C(t,t+T) = 0 | X(0) = x_i) =$$

$$1 - P(C(t,t+T) > 0 | X(0) = x_i) =$$

$$1 - \sum_{k \in S} P(C(t,t+T) > 0; X(t) = k | X(0) = x_i) =$$

$$1 - P(C(t,t+T) > 0; X(t) = x_i | X(0) = x_i) + P(C(t,t+T) > 0; X(t) = x_0 | X(0) = x_i) =$$

$$1 - P(C(t,t+T) > 0; X(t) = x_i | X(0) = x_i) =$$

$$1 - P(C(t,t+T) > 0 | X(t) = x_i) \cdot P(X(t) = x_i | X(0) = x_i)$$  \(15\)

$$1 - P(C(t,t+T) > 0; X(t) = x_i | X(0) = x_i) =$$

$$1 - P(C(t,t+T) > 0 | X(t) = x_i) \cdot P(X(t) = x_i | X(0) = x_i)$$  \(16\)

In function (16) holds $P(C(t,t+T) > 0; X(t) = x_0 | X(0) = x_i) = 0$. When the system enters state $x_0$ at or before $t$, $C(t,t+T) > 0$ cannot hold anymore because $x_0$ is an absorption state. Function (3) is rewritten to function (4) by using the characteristics of conditional probability: $P(A \cap B | C) = \frac{P(A; B; C)}{P(C)}$. The required steps are shown below.
$$1 - P(C(t, t + T) > 0; X(t) = x_i | X(0) = x_i) =$$

$$1 - P(C(t, t + T) > 0; X(t) = x_i; X(0) = x_i) =$$

$$1 - \frac{P(C(t, t + T) > 0; X(t) = x_i; X(0) = x_i)}{P(X(t) = x_i; X(0) = x_i)} =$$

$$1 - P(C(t, t + T) > 0 | X(t) = x_i) \cdot P(X(t) = x_i | X(0) = x_i) \quad (19)$$

Function (19) still differs from function (4), but function (19) can be obtained by using the Markov property. This property says that the future state \((X(s+t))\) only depends on the current state \((X(s))\), and not on the past \((X(u), 0 \leq u < s)\) (Kulkarni, 2011).

$$1 - P(C(t, t + T) > 0 | X(t) = x_i; X(0) = x_i) \cdot e^{-\psi t} \quad (20)$$

Function (20) is obtained by substituting the latter part of (19) with \(e^{-\psi t}\). This is proofed below. Take \(T_{obs}\) as the time the transition from state \(x_i\) to \(x_0\) occurs, and \(F(t)\) and \(F(0)\) as cumulative distribution function of exponential distribution with parameter \(\psi\). This also indicates the memoryless property of an exponential distribution.

$$P(T_{obs} > t | T_{obs} > 0) =$$

$$\frac{P(T_{obs} > t; T_{obs} > 0)}{P(T_{obs} > 0)} = \frac{P(T_{obs} > t)}{P(T_{obs} > 0)} =$$

$$= \frac{1 - F(t)}{1 - F(0)}$$

$$= \frac{1 - (1 - e^{-\psi t})}{1 - (1 - e^{-\psi 0})} = e^{-\psi t} \quad (21)$$

Using expression (21) in (19) we get function (20). Using property time homogenous we obtain formula (22).

$$1 - P(C(0, T) > 0 | X(0) = x_i) \cdot e^{-\psi t} \quad (22)$$

We still need an expression for \(P(C(0, T) > 0 | X(0) = x_i)\). This can be obtained by conditioning on the type of the first event occurs after 0. The first event occurs at \(\min(T > 0, T = 0)\). A transition to \(x_1\) takes place if \(\min(T > 0, T = 0) = T > 0\), otherwise a transition to \(x_0\) occurs. Hence, the time until entering \(x_1\) or \(x_0\) is exponential distributed with parameter \(\lambda + \psi\) (i.e. \(\text{Exp}(\lambda + \psi)\)). The probability that \(\min(T > 0, T = 0) = T > 0\) (i.e. enter \(x_1\)) is \(\frac{\lambda}{\lambda + \psi}\). A transition to \(x_0\) occurs with probability \(\frac{\psi}{\lambda + \psi}\). This is due to the following property of the exponential distribution: Let \(T_1, \ldots, T_k\) be independent random variables with \(T_i\) having an exponential(\(\lambda_i\)) distribution with \(i = \{1, 2, \ldots, k\}\). Then the distribution of \(\min(T_1, \ldots, T_k)\) is \(\text{Exponential}(\lambda_1, \lambda_2, \ldots, \lambda_k)\). The probability that \(\min(T_1, T_2, \ldots, T_k) = T_i\) is \(\frac{\lambda_i}{\lambda_1 + \lambda_2 + \ldots + \lambda_k}\) (Kulkarni, 2011; Queen’s University, 2012).
Figure 24 shows a potential sequence of transitions of the CTMC. In this graph the first event is a transition to from $x_1$ to $x_1^+$. Because at $t=0$ the system already is in a state with positive demand, we introduce here state $x_1^+$. State $x_1^+$ is equal to $x_1$, but it is introduced here to clearly indicate that the system stays in a state with positive demand. The model stays in $x_1$ until the part becomes obsolete and moves to $x_0$. So, the time in $x_1$ is exponential distributed with parameter $\psi$. If the model leaves $x_1$, it moves with probability 1 to $x_0$, because there is no other state to go to (see Figure 24). Hence, transition from $i$ to $i$ within a CTMC is not allowed (in contrast with a discrete time Markov chain). $x_0$ is an absorption state which means that the system stays in state $x_0$ forever once it gets there.

![Figure 23: Possible transition path of continuous time markov chain](image)

Now we know the probability of a transition to $x_1$, we can fill in function (16). We get:

$$P(C(0,T) > 0 | X(0) = x_1) = \frac{\lambda}{\lambda + \psi} x_1 + \frac{\psi}{\lambda + \psi} x_0$$

In state $x_1$ demand occurs before $T$ with probability $1 - e^{-(\lambda + \psi)T}$. Within state $x_0$ no demand will occur. This leads to function (23).

$$P(C(0,T) > 0 | X(0) = x_1) = \frac{\lambda}{\lambda + \psi} \left( 1 - e^{-(\lambda + \psi)T} \right)$$

(23)

Using this expression in (2) we get the final expression (24).

$$P(C(t,t+T) = 0 | X(0) = x_1) = 1 - \frac{\lambda}{\lambda + \psi} \left( 1 - e^{-(\lambda + \psi)T} \right) e^{-\psi t}$$

(24)

$\psi$ will be estimated by the inverse of function (24). These values are shown in Table 6 of section 4.1.1.
C.3 Multicollinearity matrix for logistic regression analysis

<table>
<thead>
<tr>
<th></th>
<th>ASML</th>
<th>EOQ</th>
<th>MOQ</th>
<th>Lot-for-lot</th>
<th>Build</th>
<th>No/low complexity</th>
<th>High complexity</th>
<th>Central inventory</th>
<th>Pre-expended stock</th>
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** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)
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C.4 Output of logistic regression analysis

Case Processing Summary

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<sup>a</sup> If weight is in effect, see classification table for the total number of cases.

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Block 0: Beginning Block

Classification Table<sup>ab</sup>

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a. Constant is included in the model.

b. The cut value is .500

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Block 1: Method = Enter

Omnibus Tests of Model Coefficients

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Model Summary

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a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

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Contingency Table for Hosmer and Lemeshow Test

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a. The cut value is .500
### Variables in the Equation

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<tr>
<th>Step 1</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
<th>95% C.I for EXP(B)</th>
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<td>.124</td>
<td>.901</td>
<td>.789 on 1.029</td>
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<td>.734 on 1.050</td>
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<td>.001</td>
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<td>.701</td>
<td>.582 on .843</td>
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<tr>
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<td>.882 on 1.335</td>
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</tbody>
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a. Variable(s) entered on step 1: ASML, EOQ, LFL, ComplexLowNo, ComplexHigh, CentraalInventory, UnitPrice, OrderFrequency, NumYearsUsed.