MASTER

Component commonality and the effect on inventory efficiency and cash positions in a high growth environment

van Miert, G.

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Component commonality and the effect on inventory efficiency and cash positions in a high growth environment.

by
Gijs van Miert

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Student identity number TU: 521462

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Supervisors:
prof. dr. B. Melenberg, Tilburg University
dr. M.J. Reindorp, Eindhoven University of Technology
M.F. van Sloun, Applied Micro Electronics "AME" B.V.
M. Theelen MSc, Applied Micro Electronics "AME" B.V.

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I   Abstract

This study focuses on the use of component commonality to increase control over both the inventory level and cash position at Applied Micro Electronics "AME" BV. The firm operates according to the principles of an original design manufacturer in the market for products with integrated electronics. It develops and produces products for its customers but does not brand or market its products with its own name. The firm is classified as a high-growth firm, increasing its revenues by 15-30% per year. This revenue growth is mainly caused by the introduction of new products. Due to the high growth of AME, the number of products and number of components used increases significantly.

The use of component commonality (i.e., using a component for multiple products) is believed to be important for increasing control over the inventory level and cash position. Therefore, the current situation at AME has been investigated and compared to the current findings in literature. This analysis shows that improvements can be made in terms of component commonality. I extended a classic inventory model, used for calculations and simulations, to examine the effects of component commonality on both the inventory level and the cash position.

The simulations show that component commonality in fact is advantageous, i.e. the inventory level is lowered and the cash position becomes more stable.

II   Executive summary

Applied Micro Electronics "AME" B.V. is a company providing complete product solutions with integrated electronics to its customers in a business-to-business environment. The firm operates according to the principles of an original design manufacturer: products are developed and produced by the firm but are marked or branded by its customers. AME has experienced very rapid growth of revenues (15-30% per year) due to the introduction of newly developed products. The strong growth of the number of products resulted in a similar growth in components. Since the firm is believed to continue its current growth, it has been looking for possibilities to reduce the increase in the number of components. At the moment, AME likes to gather insights in the effects of component commonality on the inventory holdings and the cash position. Therefore, that is the main goal of this research, along with determining whether this method is a possible basis for future improvements. Given this objective, the aim of the analyses is to answer the following research question:

> *What possible benefits in inventory can be achieved if component commonality becomes a more dominant requirement in product development, and if so, what is the impact on the cash position?*

To investigate whether component commonality can be a possible solution for the challenges provided, I examine the current situation of inventory holdings at AME. At the same time, I study the current literature to identify possible effects of component commonality. The study of the current inventory situation shows that components account for almost 60% of total inventory investments. The total active inventory holdings of AME (corrected for obsolete inventories) are valued at €1.8 million (almost 25% of its assets). Besides, the level of component commonality has been determined using two measures: the degree of commonality index and the percentage of component commonality. The degree of commonality index is used to calculate the average number of products for which a component is used. The percentage of component commonality shows the relative number of components that is common (i.e., a component is being used in at least two products). The current level of components show commonality of 52% on average, but a low level of degree of commonality index of 3. This means that on average, components at AME are used in 3 products on a total of 235 products under investigation. The average use of components is shown in Figure 1. The level of component inventory combined with the percentage of component commonality and low degree of commonality index, show that improvements can be made regarding the current situation of component commonality.
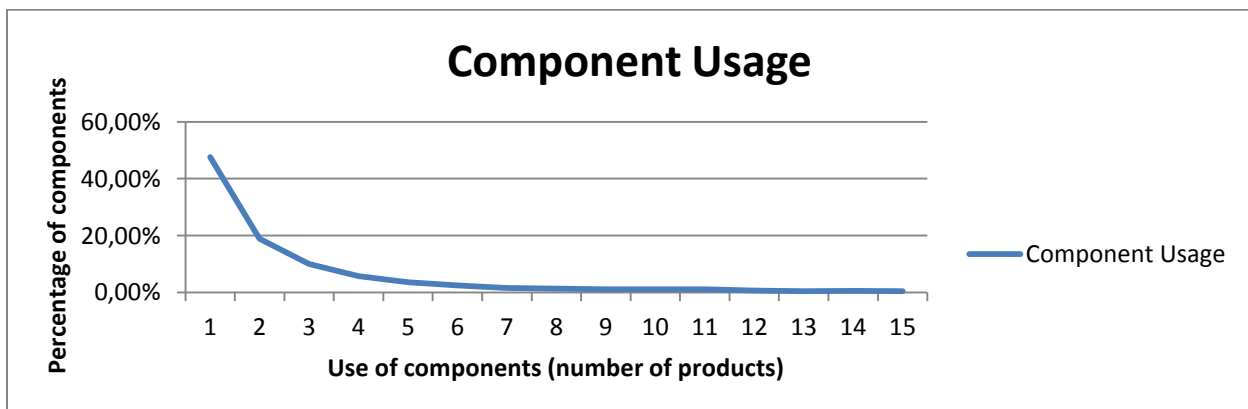

Figure 1: Component usage (shortened range) based on degree of commonality index

Besides the analysis of the current situation, I studied the literature to determine whether component commonality can provide a solution for the challenges presented. It shows that advantages of component

commonality arise from benefits in operations (e.g. shorter time to market, reduced operational costs), whereas most disadvantages arise from reduced revenues due to a lower customer preference for standardized products. Since AME operates as an original design manufacturer in a business-to-business environment, product composition is not visible to the final customer in most cases, the disadvantages of component commonality exert only a minor influence on the situation under investigation. The advantages to internal operations, especially inventory holdings, are of significant value. Both the inventory situation of AME and the literature provide opportunities for improvement at AME.

To investigate the possible effects of component commonality more thorough, an inventory model is extended to assess the impact of increased component commonality on both inventory levels and cash position. Although the literature describes a myriad of models extensions, none of them allow for any number of products and any number of components under service level constraint for multiple periods. Therefore, the model used is based on a classical inventory model (de Kok, 2005). The model has been chosen for allowing multiple periods of inventory simulation and relative simple addition of new products and components. The model extension, as will be described, allows for derived demand of any number of products and any number of components in a two-level BOM structure, given service level constraints. However, allowing for multiple products and components given various component commonality settings requires the development and integration of a matrix notation for product structures.

The model assumes an (R, s, Q)-replenishment policy for all components in a make-to-order production situation: component levels are checked regularly with a specified interval R and an amount Q is ordered when the inventory level reaches the safety stock level s. Manufacturing of products is assumed to be under full control and can take place when components are available. To ensure components are available for production, all components are set to a P_1-service level of 95%, meaning that in 95% of the order arrivals the inventory level of a component is still positive.

To provide insights in the financial consequences of component commonality, as is part of the dual research question formulated, the model is extended to facilitate cash flows. Cash inflows are based on demand, whereas cash outflows are based on shipping moments. The cash flows in combination with an initial cash position provide the possibility to investigate the effects of increased component commonality on the cash position.

The model shows that increased component commonality reduces the overall level of safety stocks. The optimal situation proves to be an increase in the degree of commonality index and the percentage of component commonality. The resulting effect of decreasing safety stock levels can be explained by the pooling of demand variation of common components. However, the analysis showed that the degree of commonality index exerts a more significant effect than the percentage of component commonality. These results are similar to the effects of increased component commonality on overall inventory levels. That is, increases in component commonality result in lower levels of inventory. Again, most reductions in inventory could be achieved when both component commonality measures are increased. The result proved to be robust under various demand variation and order quantity settings. The sensitivity analyses additionally showed that component commonality is beneficial mainly when using components with large demand variability and high order quantities.

Finally, the model provides insights into the effects of component commonality on the firm's cash position. The simulation results show a more stable cash position (Figure 2). A stable cash position is characterized by less volatility: less high peaks and less deep dips. However, the average cash position stays equal when component commonality becomes more dominant.
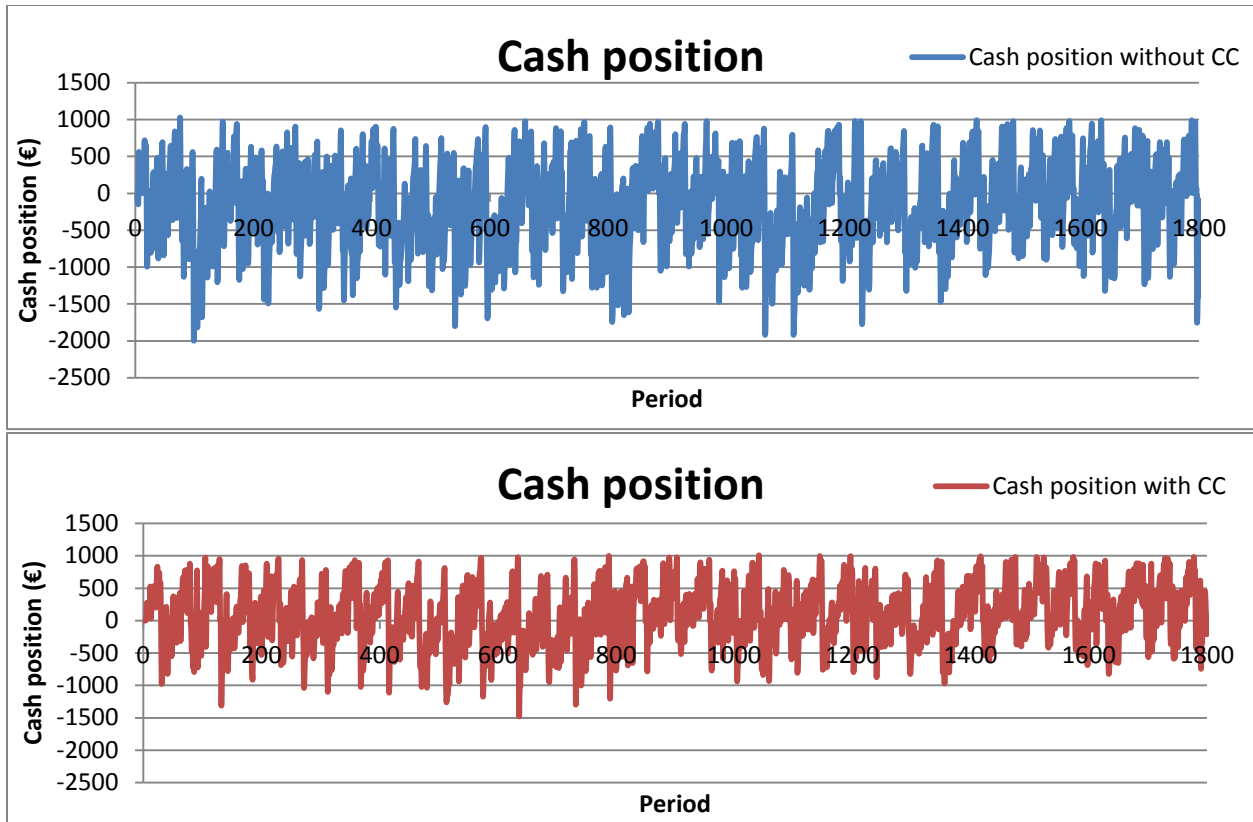
Figure 2: Cash position stability

The simulation setup and the variable setting have been chosen to reduce firm blindness. However, the model output strongly depends on the model input. The recommendations provided can be combined into three directions for future improvements:

- Parameterization of firm variables to determine the numerical costs and revenues of increased component commonality implementation.
- Model improvements to facilitate the use of operational costs (e.g. holding, handling, and ordering costs) to obtain a better estimation of the component commonality effects.
- Create a clear distinction of products and components, and analyze the effects of component commonality per product category in order to assess the best possible direction for implementation.

Concluding, increasing component commonality reduces not only safety stock levels under equal service-level conditions, but also reduces the total inventory holdings. Besides, increased component commonality has a dampening effect on the volatility of the cash position but does have a very small effect on the average cash position. Therefore, the investments freed by decreasing overall inventory levels can be reinvested elsewhere and do not have to be reinvested in the cash position.

III   Preface

This report is the result of my master thesis project, in partial fulfilment for the degree of Master in Operations Management at Eindhoven University of Technology and in partial fulfilment for the degree of Master in Finance of Tilburg University.

This master thesis marks the end of my study period in which I have been given many opportunities both within and outside the curriculum. I have enjoyed the numerous challenges presented in the group work and individual assignments that presented me all the various aspect of Industrial Engineering and Finance. I am grateful that I had the opportunity to enjoy a great year in the board on the International Research Project, in which I have come to know many new and exciting cultures. With writing this thesis I started to realize that this special period, my student life, is ending and a new phase begins; my working life. I would like to thank several people who gave me the opportunity to work on this master thesis and who supported me during the project and during my time as student.

First, I would like to thank my supervisors from university. Bertrand Melenberg, thank you for the confidence in the project and always being critical and open towards my academic and personal attitude. Matthew J. Reindorp, thank you for the support and feedback during this research project. In particular, I appreciated the discussions I had with you regarding the direction and content of the project.

Furthermore, I would like to thank my company supervisors at AME. Marlies Theelen, thank you for your guidance and reflection during my project. You were always there for me, whether it was providing advice, just having a small talk, or arranging practicalities. Marc van Sloun, thank you for the special opportunity to execute this project at AME and your helpful and quick feedback.

Finally, I would like to thank my family and friends for their continuous support and interest, for distracting me at the right moments and putting everything in perspective. Special thanks go to my parents and brother for giving me the opportunity to finish these studies successfully.

Gijs van Miert

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IV   List of definitions

Abbreviation	Definition
AME	Applied Micro Electronics "AME" B.V.
B2B	Business-to-business
BOM	Bill of material
CC	Component commonality
CCM	Coordinate measuring machine
CoLT	Component lead time
COGS	Cost of goods sold
CuLT	Customer lead time
DCI	Degree of commonality index
EDM	Electrical discharge machine
ERP	Enterprise resource planning
FIFO	First-in-first-out
FTE	Full time equivalent
MPS	Master production schedule
MRP	Material requirement planning
MTO	Make to order
ODM	Original design manufacturer
OSG	Operations support group
PCB	Printed circuit board
PAO	Plan and offer
POCC	Percentage of component commonality
PT	Production time
PTH	Plated through hole
RD&D	Research design and development
SKU	Stock keeping unit
SMD	Surface mounted device
TCCI	Total component commonality index
WACC	Weighted average cost of capital

V   List of parameter definitions

Parameter	Definition
α	Value of the inverse normal distribution
a	Payment term for customers
$a_{i,j}$	Number of components i required to produce a single item j
$A_{i,j}$	Matrix containing product and component structure
b	Percentage borrowing costs
$B_{i,k}$	Backorders
β	Sum of all immediate parents all components have in a complete set of finished products or major subassemblies
C_i	Component i
$C(t)$	Cash position
$\bar{C}$	Average cash position over all periods
$CI(t)$	Cash inflow of the firm in period t.
$CO(t)$	Cash inflow of the firm in period t
$CV(\ )$	Coefficient of variation
d	Total number of distinct components in the set of end items
$D_j(t)$	Independent demand for product j in period t
e_i	One vector
$E(\ )$	Expected value
ϕ_i	Number of immediate parent component i has over a set of finished products or major subassemblies.
ϕ^{-1}	Inverse normal distribution
$G_i(t)$	Dependent demand for component i in period t (i.e. demand derived from products j).
$G_i(t, t+x)$	Dependent demand for component i in between period t and $t+x$
$H_i(t)$	Shipment of product i in period t
$I(\ )$	Indicator function
k	Order moment number after t=0
l_i	Delivery lead time, the time between the order and the physical receipt of items (i.e. component i ordered at p_{ik} are available for usage at $p_{ik} + L_i$).
M	Margin on products
o	Unit opportunity costs
$p_{i,k}$	The kth replenishment order moment of item i after time $t=0$
P_j	Product j
$Q_i(t)$	Quantity ordered of item i in period t
r	Discounting percentage for borrowing costs
R	Review period
σ	Standard deviation
s_i	Reorder level for component i
t	Period indicator
t_i	Payment term for orders of component i
T	Model time span
$U_{i,k}$	Undershoot of component i in replenishment cycle k, Undershoot is defined as the amount of units the inventory position drops below the safety stock level at the moment of customer orders.
$Var(\ )$	Variance
v_i	Value of component i when ordered
$WACC$	Weighted average cost of capital
x^+	Represents the maximum of 0 and x; max(0,x)

$X(t^-)$	Net stock just before replenishment
$X_i(t)$	Physical inventory of item i at the start of period t, just before the receipt of $p_{ik}(t)$.
$Y_i(t)$	Net inventory of item i at the start of period t, just before the receipt of $p_{ik}(t)$.
z_i	Calculation variable for lead times (number of periods)

VI   List of figures

VII   List of tables

1   Introduction

This report is the result of my master thesis project executed at Applied Micro Electronics "AME" B.V. (AME) in Eindhoven, the Netherlands. The firm is considered a high growth firm with increasing revenues between 15-30% per year, by developing and manufacturing many new products which can be designed by AME or externally. AME operates as an original design manufacturer: developing and producing new products for customers that market and sell the products under their own brand name. By developing and producing many new products each year, AME experiences a significant growth of components inventory. The firm would like to investigate whether the use of common components on various products can reduce the inventory growth and if so, its impact will be on the company's financial figures. In this report, the current situation of common components at AME will be discussed and insights will be provided in the effects of component commonality. The findings of the current situation lead to the development of an inventory model which facilitates the modeling of common components. Since the problem involves possible financial implications as well, the model will be expanded to show the component commonality effects to the firm's operational cash position.

The research has been conducted at a medium sized company started in 1996 that operates in accordance to the principles of and original design manufacturer (ODM). The firm develops and produces products for its customers without branding or marketing them. The firm expanded its activities towards the production of electronics in the early 2000's and in recent years moved to an integral product approach of complete customer solutions including the development, design and production of products with electronics and mechanics.

Product developed by AME starts in the research, design and development (RD&D). In this stage of the products lifetime all components are selected. These can already be used in existing designs or can be new to the firm. Since the number of developed products grows rapidly, the number of new components used grows as well. Therefore, inventory holdings increase significantly. The firm has identified common components as a possible solution for this growth problem.

In this report the current situation at the firm will be extensively discussed. For the analysis, the total inventory investments at the end of the accounting year 2013 have been considered. To gain more insight in the total inventory holdings, various cross section analyses were made, including cross section analyses based on component prices and functional inventory categories. The inventory holdings at the firm can be divided in two distinct categories, based on component prices: a relative large number of cheap components resulting in almost 60% of inventory investments, and a relative small number of more expensive components or sub-assemblies.

In addition to the analysis of the current inventory holdings, the current level of component commonality has been considered. In the analysis of component commonality two measures have been used: the degree of commonality index (DCI) and percentage of common components (POCC). The DCI measures the average number of products for which a component is used. The percentage of common components shows the relative number of components that are at least used for two products. AME's DCI is 3.37, although it must be said that it includes extreme cases of commonality as well (the top 2% values). When excluding these extreme cases, the DCI measure drops from 3.37 to 2.83 in a product portfolio consisting of 235 products. When considering the POCC, it shows that 52.4% of components are used for more than one product. The analyses combined show that a significant part of components is common. However, the number of products for which a component is used is limited given the large product portfolio.

To provide additional insights in the current situation, cross section analyses have been performed to find the cause of the relative low component commonality. First, components were categorized in functional component categories as already exist within the firm. The analysis showed that certain component categories exhibit considerably more component commonality. Thereafter, components were categorized per price category and it

turned out cheap components at the firm show more component commonality than more expensive components, with respect to both DCI and POCC.

Furthermore, the literature has been studied to determine whether component commonality can provide a solution to the challenges presented. Studies show that advantages of component commonality arise from benefits in operations (e.g. shorter time to market, reduced operational costs), whereas most disadvantages arise from reduced revenues due to a lower customer preference for standardized products. Since AME operates as an original design manufacturer in a business-to-business environment and product composition is in most cases not visible to the final customer, the disadvantages of component commonality exert only a minor influence on the investigated situation. The advantages to the internal operations, especially inventory holdings, are of interest to the challenges presented. Both the inventory situation of AME and the literature provide opportunities for improvement at AME.

To investigate the effects of component commonality more thorough, a model is developed to assess the impact of increased component commonality on both inventory levels and cash position. The model is based on a classical inventory model (de Kok, 2005). It allows for the control of a single item under service level constraints. The current literature describes various model extensions but none of the models described allows for any number of products and any number of components under service level constraint concerning multiple periods. The extended model builds on a classical inventory model of De Kok (2005) for stock control for one location with one product. The model has been chosen for allowing multiple periods of inventory simulation and relative simple addition of new products and components. The model extension, as will be described, allows for derived demand of any number of products and any number of components in a two-level BOM structure, given service level constraints. However, allowing for multiple products and components given various component commonality settings requires the development and integration of a matrix notation for product structures.

The model assumes an (R, s, Q)-replenishment policy for all components in a make-to-order production situation. Components levels are checked periodically with a specified interval R and an amount Q is ordered when the inventory level reaches the safety stock level s. In this model the assumption has been made that customer lead times are longer than production lead times, but shorter than the sum of production lead time and component lead time by a single period. This assumption facilitates the 'make to order' (MTO) policy and requires the firm to hold component stock. From the demand for products, the demand for components was derived. To ensure components are available for production, all components are set to a P_1-service level of 95%, meaning that in 95% of the order arrivals the inventory level of a component is still positive.

To provide insights in the financial consequences of component commonality, the model is extended to facilitate cash flows as well. Cash inflows are based on demand, whereas cash outflows are based on order moments. The cash flows in combination with an initial cash position provide the possibility to investigate the effects of increased component commonality on the cash position. These will be measured by the coefficient of variation of the cash position.

To investigate the effects of component commonality, a set of calculations and simulation experiments will be described. The calculations and simulations will be described by means of an empirical model. The model consists of four quadrants: (1) low DCI and low POCC, (2) high DCI and low POCC, (3) low DCI and high POCC, and (4) high DCI and high POCC. Based on the empirical method, the results of various component commonality settings and the effects on inventory holdings and the cash position have been considered if the effects on inventory are significant.

The analysis of the effects of component commonality is split into the effect on safety stock levels and the effect on overall inventory holdings. The model simulations show that increased component commonality reduces the overall safety stocks. The optimal situation proves to be an increase in DCI and POCC. The effect of decreases in safety stock is explained by the pooling of demand variation of common components. However, the analysis shows that DCI has a more significant effect Than the POCC. The effect of increased component commonality is similar with respect to overall inventory levels. That is, increased component commonality results in lower inventory levels. Again, most reductions can be achieved when both component commonality measures are increased. The results prove to be robust under various demand variability and order quantity setting. The sensitivity analyses also show that component commonality is most beneficiary to components with large demand variability and high order quantities.

Finally, the model provides insights in the effects of component commonality on the firm's cash position. The simulations show a more stable cash position, characterized by less volatility (less high peaks and less deep dips). Although, the average cash position stays equal when component commonality becomes more dominant, the more stable cash position reduces the dependency on external (short term) financing since the probability of a negative cash position decreases.

 To improve the implementation at AME and increase the robustness of the model, several directions for further research are provided.

The thesis report will proceed as follows. Section 2 will outline the company and the context in which the master thesis was executed and provides an introduction of component commonality. Section 3 will elaborate on the research design, including the problem definition, problem statement, research question and scope of the project. Section 4 describes the findings in the literature regarding component commonality, inventory models, and cash positions. Chapter 5 elaborates on the current inventory situation based on the inventory investments, current level of component commonality, customer specific stock, and dead stock figures. Section 6 presents an inventory model that allows for different component commonality settings and includes the operational cash flows related to the inventory investments. Section 7 reports the simulation results of the model described in the previous section. Finally, section 8 presents the conclusions, limitations, recommendations, and implementations.

2   Research Context

This chapter describes the research context in which the master thesis has been executed. A broad company overview is provided and the firm's departments will be discussed in more detail according to the life cycle of a product of AME.

2.1   Applied Micro Electronics "AME" B.V.

Applied Micro Electronics "AME" B.V. is a medium sized company located in Eindhoven, the Netherlands. It has two locations. AME provides integrated product solutions, combining knowledge in the fields of electrical and mechanical engineering, applied mathematics and physics in developing and manufacturing products with integrated electronics. Products of AME typically consist of a printed circuit board (PCB) on which electronic components are placed. These components can be surface mounted devices (SMD) or plated through hole (PTH). Examples of AME's products are smart energy tracking units, control panels for coffee machines, motor controls for refrigeration units, and many more.

AME operates in accordance to the principles of an original design manufacturer (ODM): development and manufacturing of products is done by AME but products are branded and marketed by its customers. Therefore, AME mostly operates in a business-to-business (B2B) environment. AME strives for more vertical integration for two reasons, namely, lower costs and more control over quality and lead times.

In day-to-day operations, the firm consists of three main departments: research design and development (RD&D), Operations and Business development. These main departments are supported by the operations support group (OSG), including human resource management, finance, IT and other staff positions. The RD&D department is concerned with the development of integrated solutions (electronics and mechanics). Subsequently, the Operations department is responsible for the manufacturing (including procurement, servicing and logistics) of the developed products. In this department this master thesis project was executed. The third department, the Business development department, is concerned with attracting new customers and exploring new market opportunities. The organization diagram is depicted in Figure 3.

At the end of 2013, AME employs 146 people (103 Fte[1]), of which 58 work (45 Fte) in the RD&D department, 71 (46 Fte) in the Operations department, 1 (1 Fte) in the Business development department and 16 (11 Fte) in the operations support group. This representation of AME is quickly dated since the firm has realized a steady average revenue growth between 15-30% each year for the past 10 years, and is expected to do so for years to come. The revenue growth forecast for the coming years is well above 20% on an annual basis, mainly caused by the introduction of new products.

The process of a new product starts with an offer from the Business development, in which the costs and planning of a new product generally have been defined. In most offers, the functions of the product to be supplied are listed instead of providing specific designs or components. Decisions about specific components are made by the project team of the RD&D department.

In some cases, AME produces externally developed products. These products are not designed at AME and for that reason, designs and related components cannot be changed unless investments are made for redesign.

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[1] Fte stands for full time equivalent which in the Netherlands covers a forty hour workweek.
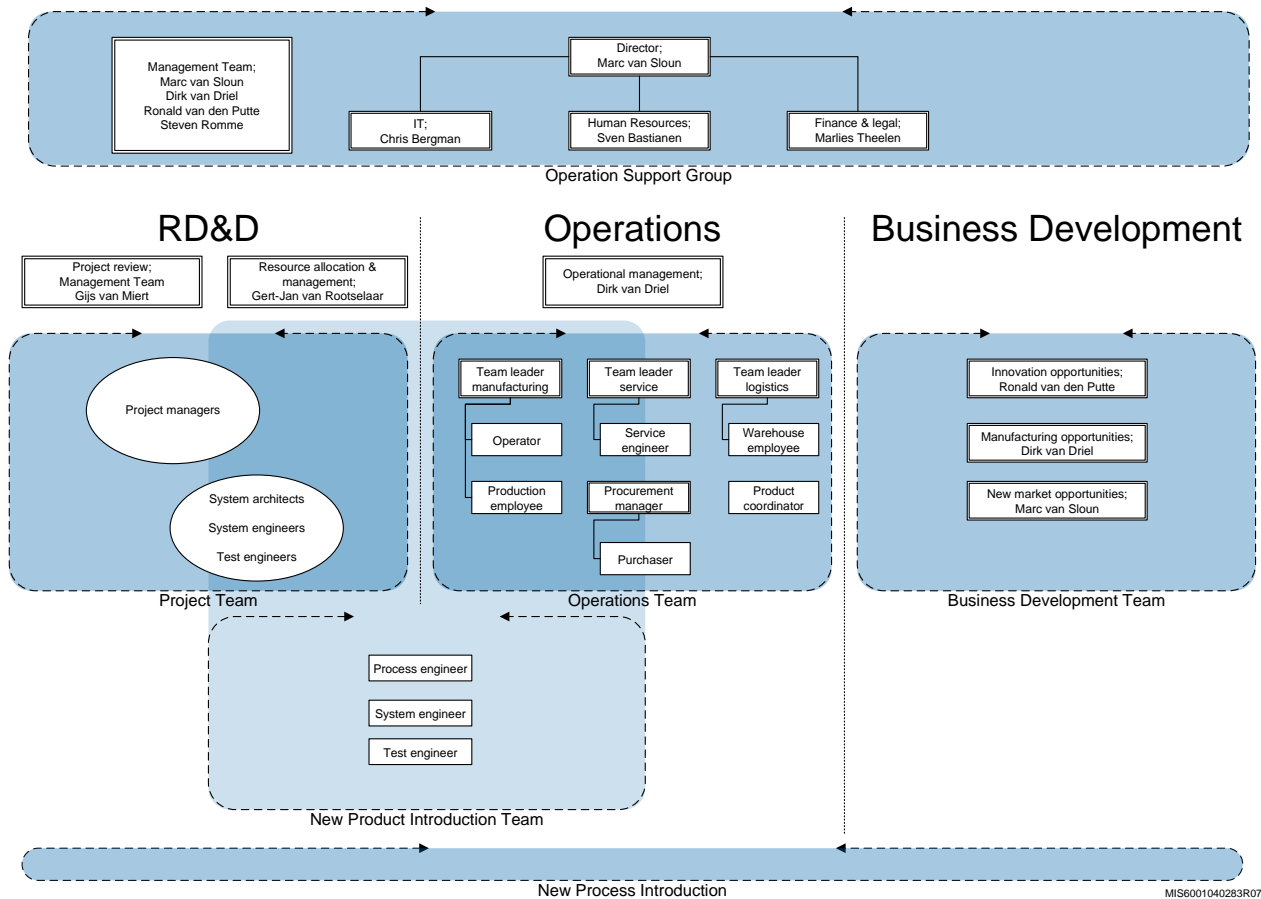
Figure 3: Organization diagram AME

2.2   New product development (RD&D)

Products designed at AME start their life at the RD&D department, where the design, development and industrialization of new products takes place. The development of a new product (e.g. a coffee machine control panel) is done on a project basis. In the early phase of the development project, the critical components of a product design are decided upon. In case of the coffee machine control panel, the glass front cover and LED-touch pad are critical components due to technical challenges related to steam and vapor. In this state of the project, all components can be investigated for use (e.g. components that suit the technical challenges best, or components that are cheap). When the architecture of the product has been clearly defined and critical components are known from the project definition phase, the actual development phase starts. In this phase, the design of the product is developed in more detail and the complete bill of material (BOM) becomes clear. At this moment in the project, the project manager can decide to change the composition of the product. When the product is approved, all parts of the architecture are integrated into a complete product design. Based on this design, a prototype will be produced which will be tested extensively. If the products passes all tests and all required documents are in order, the project manager releases the developed product for production. Then, a first batch (pre-series) is produced which is again tested. After approval of the pre-series batch, production can begin. This complete process is depicted in Appendix A.

2.3   Operations

The Operations department is concerned with the production of products and all associated task, such as procurement, delivery and maintenance of the various products. When a product reaches its final phase of development, the procurement of components is already initiated for the first production series. This shows the importance of a clear bill of material early in the project. When the product is completely finished, it will be produced in relative large quantities. The processes required to produce the products at AME is discussed in the sections below.

2.3.1   Procurement

Based on the sales orders from customers, a material requirement planning (MRP) is made on which the schedule of procurement is based. Inventory at AME is controlled according to a (s, nQ) stock policy. It is monitored by the ERP-system: when the level of inventory drops below the safety stock level an order is placed for 'n' times the order quantity 'Q'. The integer 'n' is determined based on the inventory needs for the coming period, which is based on the production schedule. AME orders approximately 80% of its components automatically due to supply agreements (supplier forecasting). These agreements include the automated ordering of goods based on the inventory needs. The other part (approximately 20%) of procurement is done manually using purchase orders. New components are first ordered manually and are added to the supplier forecasting later.

The reception of goods consists of two parts: the reception of the physical goods and the reception of the accompanying invoice. Most incoming goods are moved to the automated warehouse. An overview of the warehouse structure and storage locations at AME is provided in Figure 4. After an agreed number of periods after the receipt, the invoice is due.
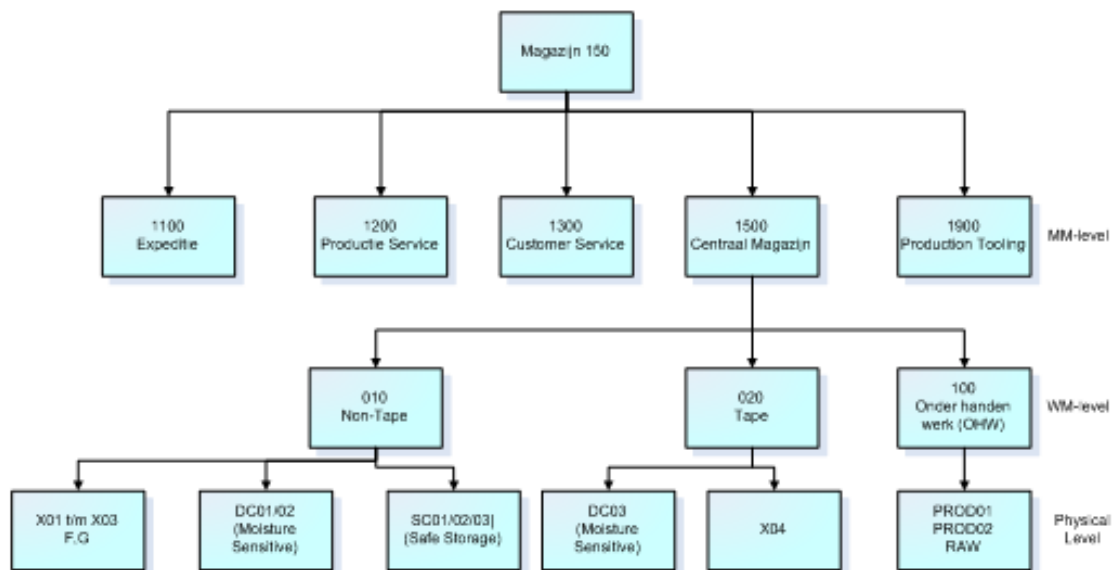
Figure 4: Warehouse structure of AME

As is clear from the procurement section, AME orders most components automatically. However, a significant part of goods is ordered manually. New components are added to the automated order policy if the component usage is expected to be high. If possible, low volume components are added to the automated ordering process periodically. When the number of components significantly increases the number of procured components,

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especially manual procured components, increase the workload. Decreasing the workload and with that costs is one of the possible operational benefits of increased component commonality.

2.3.2 Warehouse management

The previous section briefly described the incoming components being stored in warehouses of AME. The components at AME can be classified simply as 'tapes' and 'non-tapes' (central warehouse). The other warehouses shown in Figure 4 will not be considered in this master thesis project. Tapes can contain up to several thousand components. However, a disadvantage that these can only be used on a single production line (AME has two production lines) at each moment in time. The functional separation between tapes and non-tapes is made since tapes (regardless the number of components) need to be picked as a whole and cannot be separated in single items. All other items (non-tapes) are picked to order in the exact amount.

The components in the warehouse can be picked for production or moved for multiple reasons. The most common component movements are specified below:

- Production: the picking and returning materials for production and the report of finished goods.
- Sales: prepare for delivery.
- Raw: components with incidental need
- Inventory counting: two times a year the correctness of inventory levels is checked.

An overview of the component movement in and out of the central warehouse is shown in Figure 5.

Since the technical lifespan of components is limited, AME enforces a first-in-first-out (FIFO) warehouse management. The incoming date is based on the date the goods are entered in the ERP-system. It is paramount that tapes returned to the central warehouse from the production floor retain their initial entry date for FIFO to be facilitated properly.
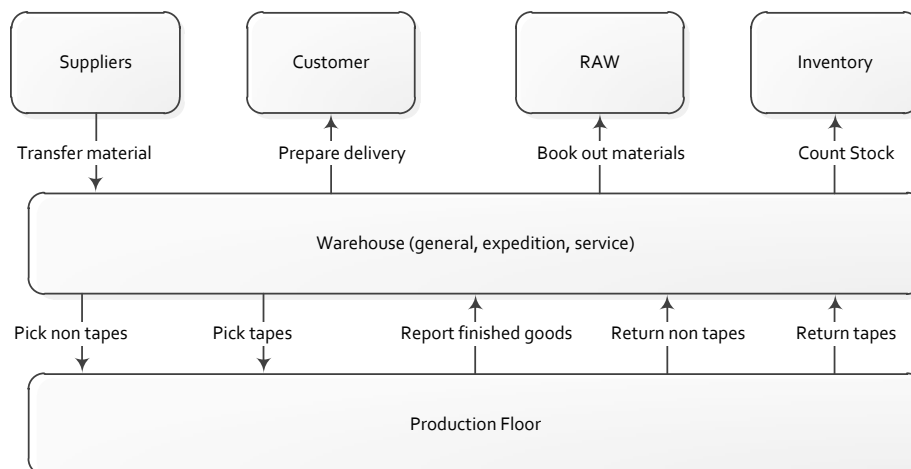
Figure 5: Stock movements to and from the warehouse

2.3.3 Manufacturing

Manufacturing planning is based on the sales order and forecasts. A high level planning is proposed by the ERP-system, from which a more detailed production schedule is derived by the operations manager. The high level plan is checked for availability of materials, production floor capacity and approval of necessary production orders. This results in a Master Production Schedule (MPS) which prioritizes orders. Since AME currently has two production lines, a cross check needs to be performed to make sure a single tape is not planned on both lines at the same

time, or at least two tapes need to be available. After all checks have been performed on materials and capacity the production orders are released.

All non-tape components are picked in exact numbers for each production order. However, tapes are picked as a whole and need to be prepared. Before tapes can be used on the production floor they need to be prepared by placing them on so called 'feeders'. For high volume components, the tapes stay on the feeders to ensure short set-up times. However, low volume component tapes are placed on feeders every time these are required for production. Production consists of the placing of all components on the PCB and soldering all components to the PCB. When required, the product is sealed to protect it from weather influences. Part of all PCB's is shipped to the customer; others are used for system-assembly, i.e., integration of mechanics and electronics. Finally, all tapes are removed from the production lines and are returned to the automated warehouse or feeder-locations. Only tapes required for the next production series remain on the production line.

The increase in new products and components increases the complexity and effort required to prepare a production order. When components are used in high volumes the components are more likely to stay on the feeders and decrease the set-up effort. Also, reduction in the number of components for various production orders will reduce the complexity of production preparation.

The division of components in tapes and non-tapes is functional in operations. However, in the analysis into component commonality the functional division is not relevant since the type of storage does not determine whether a component is common. For this reason the difference in component storage (tapes and non-tapes) will not be included in the analyses. The difference in component storage and the effect on operations will be briefly considered in chapter 8.

2.3.4 Service and maintenance

Service and maintenance are a result of products that fail during production tests (e.g. optical, functional or in-circuit tests) or products that are returned by customers in case of malfunction after delivery. When the product is repaired it is returned to the warehouse. From there, it can continue as an ordinary product. If the product cannot be repaired, the components are scrapped and booked from the service warehouse.

3 Project design

In this chapter the design of the project will be presented. First, the problem definition will be described in section 3.1. Secondly, the problem statement will be presented in section 3.2. The scope and data of the project will be defined in section 3.3. Both problem description and problem statement lead to the formulation of the research question, together with five sub-questions which will be stated in section 3.4.

3.1 Problem definition

In 2013, the inventory efficiency at AME was investigated (Berkien, 2013). From this, the management of AME concluded that inventory turnover (ITR) was too low. The inventory turnover rate represents the frequency in which the inventory is used annually. The ITR of AME is currently around 3; indicating that inventory is used 3 times every year, i.e., four months of inventory is held at AME. According to the study into inventory efficiency, the inventory turnover can be increased to a possible 5 or 6. A recommendation from the previous examination involved the limiting of stock increase while the output of finished products increases. Reducing or limiting the growth of inventory holdings can improve the inventory turnover. The problem defined at AME and as presented in this section is based on interviews with relevant employees within the company and information provided by the ERP- and data-management system. Based on this qualitative and quantitative information the main problem encountered is identified as:

AME has high inventory levels in relation to its sales (reduced inventory efficiency) and expects the ratio to increase due to high firm growth.

Measures relating to the high inventory levels will be presented in section 5.1. As a possible solution to the problem and due to the nature of the business (possibility of designing the product including the component choice), AME would like to investigate the effects of component commonality on both inventory holdings and the firm's cash position. AME would like to know whether component commonality is a feasible solution to the problem described.

The goal of AME is translated in the project objective to identify the possibilities to reduce inventory levels and investigate the effects on the firm's cash position based on component commonality.

3.2 Problem statement

All identified causes, based on the interviews and data, where combined in the cause- and-effect diagram (see Figure 6) on which the definition of the problem statement, relative high inventory levels, was based. The decision concerning the problem statement was made together with the supervisors at AME.

The following possible causes for the high inventory levels require further investigation in this study:

- **High customer specific stocks:** AME holds many different and customer specific components, as a result of the characteristics of the original design manufacturer (ODM) in combination with a large base of customers requesting specific and unique products.
- **Relatively low inventory turnover:** based on the inventory turnover rate, the efficiency of AMEs inventory is low. To increase this number the inventory should preferably be decreased.
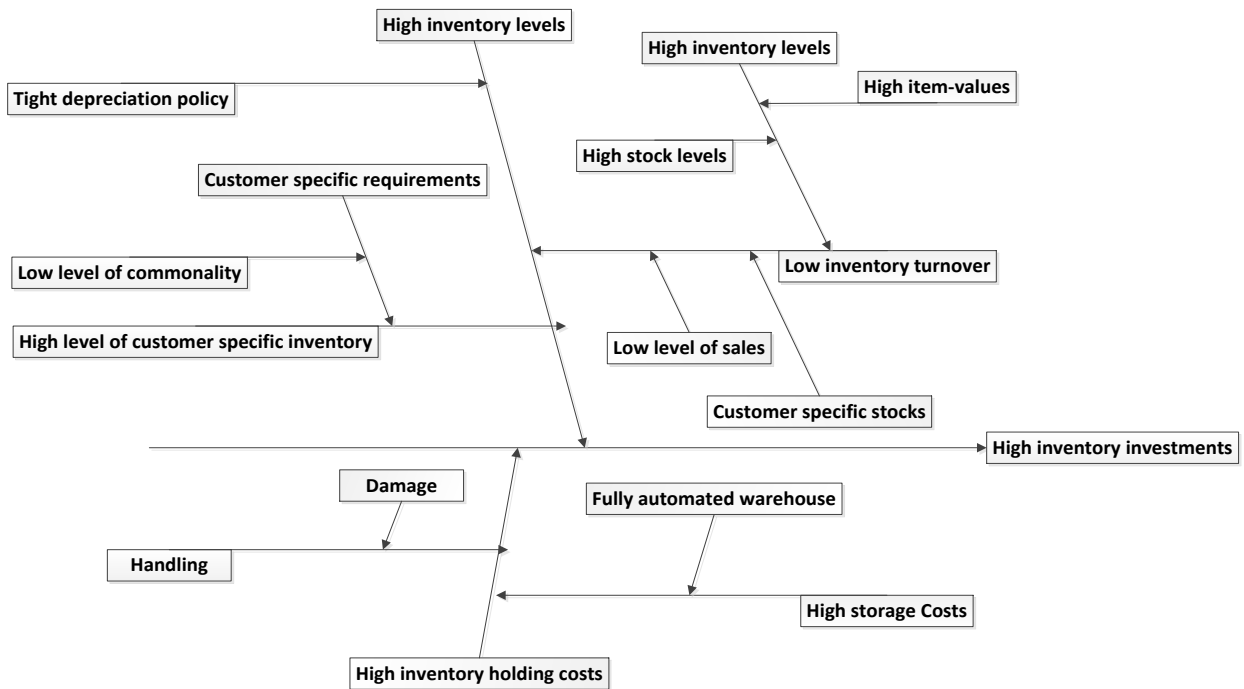
Figure 6: Cause and effect analysis (Ishikawa diagram)

The first problem statement indicates large inventory holdings per customer that can be used for a specific customer only. For each of these customers' specific components, sufficient inventory should be present, which raises the total inventory level. Component commonality, presented as possible solution, likely decreases customer specific stock and lowers inventory levels. Based on the problem outlined in the first section and the problem statements as presented above, a research question has been formulated. Besides the main research question, five sub-questions will be described in section 3.4. From the answers to these questions directions for implementation will be derived for the problem at AME.

3.3   Scope and data

In this section, an overview is provided on the scope of the project. It is based on the selection and information given above and indicates the main focus and delineation of the project.

Inventory
In the component commonality analysis only the component inventory (central warehouse) is considered. All other inventories (service, production tooling, and expedition) will be out of the scope of this project. The main focus is on component inventory. Only components that have a positive inventory will be included in the analysis to prevent pollution of the data.

Products
Some products within the portfolio of AME are not produced anymore. Therefore, a selection needs to be made to include only products that are actively produced. In manufacturing products, both production lines are considered since both are similar.

3.4   Research questions

Based on the objective the following research question has been defined:

What possible benefits in inventory can be achieved if component commonality becomes a more dominant requirement in product development, and if so, what is the impact on the cash position?

The main research question shows the dual problem, including both the inventory holdings and the financial effects of component commonality. Based on the dual problem question, five sub-questions have been formulated:

- Given the current level of inventory and the indicated inventory categories, what are the characteristics of inventory at AME (value distribution and functional inventories)?
- What is the current level of component commonality of the inventory?
- Based on the possible effects of component commonality, determine the inventory effects of component commonality on safety stocks and overall inventory holdings when increasing the use of commonality?
- Based on the possible effects of component commonality on inventory investments, what is the impact on the cash position?
- What is the impact on short term financing needs (cash position) of implementing increased component commonality?

As can be seen from the sub-questions, a focus is placed on understanding the current situation, which will serve as a benchmark in this master thesis project. To answer the questions above, the effects of component commonality on inventory holdings (i.e. total inventory holdings and inventory efficiency) and the effects of component commonality to financials (i.e. the cash position) will be considered.

To provide a neat and structured overview of the master thesis project a research framework (Figure 7) shows an overview of the methods used to answer the research question and sub-questions. This includes the extension of an inventory model to determine the possible benefits of component commonality and a financial extension to analyze the effects of component commonality on the cash position. These different scenarios are then compared to one another to determine the possible benefits, which will result in answers to the research question.
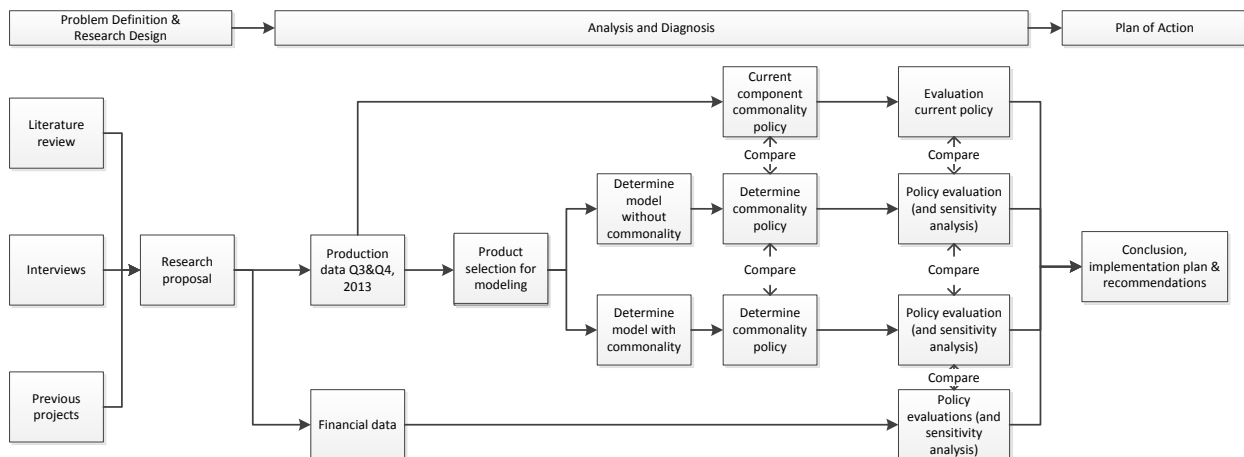
Figure 7: Research framework

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The different steps within the analysis and diagnosis of the research framework are set out below.

Step 1: **Selection of data** for analyzing the current situation and the possible benefits of increased component commonality.

Step 2: **Assess the current situation**. To set a benchmark for comparison of the model (step 3), the current situation is analyzed in detail. The production data selection is verified and calculations regarding inventory levels including component commonality will be performed.

Step 3: **Determine production subset and modeling approach**. A review of the literature, in which a wide variety of modeling approaches concerning component commonality will be discussed, each with specific assumptions and limitations (see section 4.2).

Step 4: **Determine the financial impact.** Based on the preceding steps the financial impact of component commonality is determined (i.e. cash position).

In a previous analysis of the inventory efficiency at AME (Berkien, 2013) it was shown that the firm's inventory can be used more efficiently. A direct recommendation involved the limiting of stock increase while increasing the output of finished products. Given the continuous growth of products and components, the limiting of inventory levels is important to increase inventory efficiency. From interviews with employees, the large amount of customer specific stock and inefficient use of component inventory are indicated as causes of reduced inventory efficiency. Furthermore, component commonality is put forward as a possible solution.

4   Literature

In this chapter three concepts are considered; component commonality, inventory models including component commonality and the cash position effects of component commonality. First, the current literature on component commonality is discussed in section 4.1. In section 4.2, the current literature on inventory models is presented. Finally, in section 4.3, the cash position effects are considered. The current literature will act as a guide for the analysis into the three concepts.

4.1   Component commonality

To provide a good theoretical basis on component commonality, the findings in literature will be presented. Generally, commonality is an approach in manufacturing and inventory management to simplify the control of resources and to increase possibilities for analysis of existing products to optimize costs. This definition includes many possibilities for component commonality. To create focus and to narrow the definition several additional indices of component commonality have been found. Some of the indices found are considered:

- Commonality is a group of related products that share common characteristics, which can be features, components and/or subsystems. It is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently be developed and produced. (Meyer and Lehnerd, 1997),
- Component commonality generally refers to an approach in manufacturing in which two or more different components for different end products are replaced by a common component that performs the function of those it replaces. (Ma et al., 2002),
- Component commonality refers to a manufacturing environment where two or more products use the same components in their assembly. Commonality is an integral element of the increasingly popular assemble-to-order strategy that investigates certain critical components -typically, with long lead time and expensive- in a generic form. (Mirchandani & Mishra, 2002),
- Commonality is defined as the number of parts/components that are used by more than one end product and is determined for all product families. (Ashayeri & Selen, 2005),
- Commonality is the use of the same version of a component across multiple products. It is a cost decreasing strategy in a stochastic demand environment because by pooling risks the total volume of common components can be forecasted more accurately. (Labro, 2004).

From these additional definitions of component commonality, it is clear that the use of a component for multiple products is of significant importance to the definition. This definition will be used in a wide range of research directions and will be used for this project. Based on the company description of chapter 2 this definition will be tailored to the specific company context. To determine whether this type of component commonality can be a solution to the master thesis problem, as was presented in chapter 3, the advantages and disadvantages of component commonality found in the current literature will be discussed. The most important findings are presented below:

Advantages of component commonality:

- Commonality substantially lowers the costs of proliferated product lines and mitigates product and process complexity (Heese and Swaminathan, 2006).
- Commonality reduces the cost of safety stock, shortens the time for reaching the market, decreases set-up times, increases productivity and improves flexibility (Zhou and Grubstrom, 2004).

- A design configuration with commonality can lower manufacturing cost and design savings are obtained as a result of common design effort (Desai et al., 2001).
- Commonality provides a way to offer high variety while retaining low variety in operations and thus lower costs (Labro, 2004)
- Commonality reduces the total inventory required to meet a specified service level. The optimal stock of common components is lower than the combined optimal stock it replaces (Gerchak et al., 1988).

From these advantages it is clear that benefits of component commonality are widely disseminated but are all of an operational nature. Component commonality can affect the time to market, reduces product and process complexity, and reduces operational costs. The disadvantages presented in the current literature are:

- Commonality reduces product differentiation and with that revenues; component commonality can reduce revenues due to a reduced fit to customer preferences (Heese and Swaminathan, 2006),
- The combined optimal stocks of product specific components are higher with commonality than without (Gerchak et al., 1988).
- A design with commonality may hinder the ability to extract price premiums through product differentiation (Desai et al., 2001).

The disadvantages of component commonality show that most disadvantages arise from difficulties in product differentiation. Customer preferences can't be always met, which reduces revenues.

Conclusively, from the current literature I observe that advantages in component commonality arise from benefits in operations (e.g. shorter time to market, reduced operational costs) whereas most disadvantages arise from reductions in revenues due to a lower customer preference. Since AME operates as an original design manufacturer in a business-to-business environment and product composition is not visible to the final customer in most cases, the disadvantages of component commonality have a reduced impact on the components and products at AME. The advantages to the internal operations however, especially inventory holdings, are of value to this master thesis.

To assess possible inventory holding optimizations, multiple inventory models have been considered. These are discussed in the following section.

4.2   Inventory model including component commonality

To investigate the possible effects of component commonality on inventory levels, a model should be considered. To gain insight in the models already available, the literature was studied for a suitable model. An overview of the models currently described in the literature is listed below.

- The model described by Baker et al. (1986) which considers two products with one common component in a single period service constraint and uniformly distributed demand.
- Gerchak et al. (1988) describe a model with a single common component but any number of products and a general distributed demand.
- Nonas (2009) describes a model for three products sharing multiple common components under a general demand pattern.

As can be concluded from the list above, various models are already available. The model described by Baker et al. (1986) analyses the effect of component commonality on safety stocks, using analytical expressions in a single period. The paper of Gerchak et al. (1988) examines the effects further by allowing for multiple products. However, Gerchak et al. are using only one common component in a single period analytical analysis to examine the effect of component commonality on safety stocks. Last, Nonas (2009) examines the effects of component

commonality on general inventory levels in an analytical analysis using an algorithm for a limited number of periods.

The models described, allow for various product structures with multiple components but only a limited number of products. Furthermore, the models only allow for a confined number of periods based on analytical models. This restricts an easy comparison of various component commonality settings and the effects on both safety stocks and inventory holdings. To allow for an easy comparison between various component commonality settings, and examine the effects on safety stock levels and average inventory holdings, a multi-period model should be considered, that also allows for simple entry of a product structure with any number of (common) components and any number of products under service level constraints. Service level constraints are required to determine accurate levels of safety stocks. A model including these requirements will be presented in chapter 6.

4.3   Cash position

According to Labro (2004), three research streams have been developed since the first papers on component commonality were published around 1970. First, the effects of component commonality on inventory levels were considered (see section 4.2). A second stream arose in the early 1990's and investigated the effect of component commonality on a variety of other costs. Thirdly, a research stream emerges which anchors in the marketing literature and tries to find a potential for demand substitution and customer preferences. However, it is argued that component commonality is only relevant in the debate on demand substitution when it concerns external component commonality (noticeable by the customer) instead of internal component commonality (e.g. cable harness of a car). In section 4.1 it is concluded that demand substitution and customer preferences are not included in the scope of this project since the composition of products is mostly invisible to the customer.

From the first research stream we learn that fewer investments in inventories are required to meet service levels. The accuracy of demand forecasts increases since demand fluctuations are decreased through risk pooling, lowering inventory costs. Besides inventory costs, it can be seen from the second research stream that general ('complexity') costs will decrease. A wide range of costs has been examined: production set-up costs will decrease, costs for component testing will be lower since less components need to be tested (Thonemann and Brandeau (2000)) , but also the number of suppliers can be decreased (and with that supplier managing costs (Perera et al. (1999)). Most costs in addition to the inventory costs are discussed during the last two decades.

However, in the vast literature on component commonality, and its effects on inventory holdings including a wide variety of costs and revenues, the effect of component commonality on a firm's liquidity (e.g. cash flow management and cash positions) is still open for study.

In conclusion, based on the findings in the current literature, component commonality seems to be a good possibility to reduce the growth of inventories. Component commonality reduces operational complexity and lowers the inventory investments. However, component commonality can be disadvantageous if the customer can note the standardization of components. Since AME operates in a business-to-business environment the disadvantages apply to a lesser extent to AME. Secondly, to test the effects of component commonality on inventory levels, a model needs to be extended to include multiple products and components under service level constraints. Finally, the effect of component commonality on liquidity of the firm is a still open subject in the current literature.

Conclusively, component commonality is a possibility to reduce the increase of inventory levels. In the next section, the current situation of component commonality will be discussed in accordance with the research framework presented in section 3.4.

5 Data selection and current situation

This chapter describes the inventory data collected and focuses on the analysis of the current inventory situation at AME. First, the current inventory position is described in section 5.1. Second, the current situation regarding component commonality is discussed in section 5.2 and cross section component commonality analyses will be considered in section 5.3. Finally, customer-specific stock is considered in paragraph 5.4. The analysis here will serve as a benchmark for the model simulations shown in chapter 7.

5.1 Inventory position

To gain insight in the current inventory level of AME, the inventory at the end of the accounting year 2013 (December 31st, 2013) has been examined. As can be seen in Table 1 the gross inventories (inventories including obsolete inventories) at AME tie up almost 33.6% of total assets, a significant percentage. Net inventories (inventory corrected for obsolete inventories), the inventories under investigation, still account for almost a quarter of total asset value. These values are similar for the accounting years 2012 and 2013.

Table 1: Inventory figures AME (2012-2013)

	2013, December 31st		2012, December 31st	
Gross inventory	€ 2,484,000	33.6%	€ 2,142,000	33.5%
Net inventory	€ 1,814,000	24.6%	€ 1,448,000	22.6%
Total assets	€ 7,382,000	100%	€ 6,396,000	100%

The scope of the project only includes those components in the central warehouse of AME that have a positive number of units available. When excluding all other warehouses from the analysis, the gross inventory value (only central warehouse) is €2,344,000, at the end of the accounting year 2013. The total inventory held at other warehouses is small (about 5% of total inventory). This small percentage of inventory held at other warehouses emphasizes the delineation to the central warehouse.

To provide more insight in the inventory holdings of AME, two cross sections of the inventory holdings have been considered. First, the inventory is split into different price categories to show the value decomposition. Total inventory values are presented per price category in Table 2. This table shows that most stock keeping units (SKUs) contain components that are relatively inexpensive (less than €2). Combined, these cheap components (75.3%) account for a significant amount of inventory value (59.8%). The graphical distribution of inventory categories based on price as are shown in Table 2, is depicted in Appendix B.

Second, the inventory has been decomposed based on functional inventory categories. These categories are used in the Operations department to classify product classes. These categories are shown in Table 3.

Table 3 shows that most value (77%) is tied up in components (passive, discrete, analog, digital and electromechanical), which account for almost 80% of all stock keeping units. Components account for a considerable amount of inventory at AME. The remainder of inventory consists of (purchased) sub-assemblies (16% of inventory value) and additional supporting supplies (7% of total inventory value) in various functional inventory categories. As can be seen from

Table 3 the inventory of finished goods is zero, which confirms the scope, since all finished products are transferred to the expedition warehouse, which is considered out of scope.

Table 2: Inventory categorized by price (value of components)

Value range [from-till]			Number of SKUs	Percentage SKU	Cum. Percentage SKU	Value of SKUs	
€	-	€ 0,10	2061	35,5%	35,5%	€	268.000
€ 0,10	€	0,50	1324	22,8%	58,4%	€	548.000
€ 0,50	€	1,00	523	9,0%	67,4%	€	219.000
€ 1,00	€	2,00	462	8,0%	75,3%	€	365.000
€ 2,00	€	5,00	468	8,1%	83,4%	€	335.000
€ 5,00	€	10,00	260	4,5%	87,9%	€	197.000
€ 10,00	€	25,00	297	5,1%	93,0%	€	218.000
€ 25,00	€	50,00	163	2,8%	95,8%	€	55.000
€ 50,00	€	100,00	97	1,7%	97,5%	€	60.000
€ 100,00	€	250,00	117	2,0%	99,5%	€	59.000
€ 250,00	€	500,00	22	0,4%	99,9%	€	12.000
€ 500,00	€	1.000,00	6	0,1%	100,0%	€	8.000
€ 1.000,00	€ 100.000,00		0	0,0%	100,0%	€	-

Table 3: Inventory categorized by functional category

Product Group	Number of dedicated SKUs	Percentage of SKUs	Cum. Percentage SKU	Value of SKUs	
Passive	1482	25,6%	25,6%	€	360.000
Discrete	370	6,4%	31,9%	€	145.000
Analog	355	6,1%	38,1%	€	301.000
Digital	315	5,4%	43,5%	€	388.000
Electromechanical	2042	35,2%	78,7%	€	608.000
Sub-Assemblies	432	7,4%	86,1%	€	380.000
Purchased sub-assemblies	2	0,0%	86,2%	€	-
Finished Products	0	0,0%	86,2%	€	-
Packaging Materials	39	0,7%	86,8%	€	18.000
Computer and Accessory	33	0,6%	87,4%	€	10.000
Consumable Goods	730	12,6%	100,0%	€	134.000
Office Supplies	0	0,0%	100,0%	€	-
Assembly Tools	0	0,0%	100,0%	€	-
Remaining	0	0,0%	100,0%	€	-

The cross section analyses above show that most value of inventory holdings is tied up in SKUs and/or components with low item values. To investigate the overlap of both cross section analyses, the functional inventory categories are split into different price categories. The value distribution of each category (passive, discrete, analog, digital and electromechanical) is depicted in Appendix C.

The figures in Appendix C show that the functional inventories indicated by 'Passive' and 'Discrete' consist mainly of relative low-value items (less than €1). The functional inventories indicated by 'Analog', 'Digital' and 'Electromechanical' show slightly more expensive components, mostly ranging from €0.1 to €5. The inventory of the category 'Sub-assemblies' consists of relative expensive parts: most item values range from €5 to €250. These analyses show that the inventory of the central warehouse at AME consists mostly of cheap components.

It also shows that component inventories tie up a significant percentage of assets, which shows the potential for component commonality at the firm. Most inventories at AME consist of low-value components (less than €2). The accumulated low-value components account for a significant part of stock keeping units and total inventory investments. The total value of low-value components equals almost 60% of total inventory value under consideration. In the next section the current situation concerning component commonality will be discussed.

5.2 Component commonality

In this section the current level of component commonality at AME will be described. First, a selection of products is made that will be included in the analysis. Second, the current level of component commonality will be calculated.

5.2.1 Product selection and product structure

To consider the current situation of component commonality, the product portfolio (the range of product produced at AME) needs to be investigated. However, to obtain a good understanding of the current component commonality situation, only relevant products need to be included. All products of AME are indicated by a unique number (product number). However, some products in the current product portfolio of AME were considered obsolete or new versions had been released for different reasons. To ensure that only relevant products were included in the analysis, only products with a production order between June and December 2013 were included. The delineation of products is in line with the scope as is discussed in chapter 3. This selection led to a total number of unique bills of material (BOMs) of 263 and a total of 3350 unique components.

To control for new versions of products during the timeframe under consideration (June-December 2013), an analysis was performed on the different versions of products. In this analysis, a total of 26 products have been found for which multiple versions have been produced. For these 26 products, the components of different versions were examined. The products showed an average component overlap between versions of 80%. Some product releases did show 100% commonality with its predecessor (a product with only new software). To ensure an unambiguous analysis of component commonality, only the latest versions of products were included in the analysis. After confining the product sample, the analysis includes 235 products (based on the bills of material) and 3317 components.

The sample of products included in the analysis has been selected and includes recently produced products, corrected for old or obsolete versions. To provide insight in the structure of the various products the bills of material are considered. The structure of products (including the customer) is presented in Figure 8. In the analysis into component commonality and the structure of the bills of material, it is assumed that increasing component commonality is technically feasible.
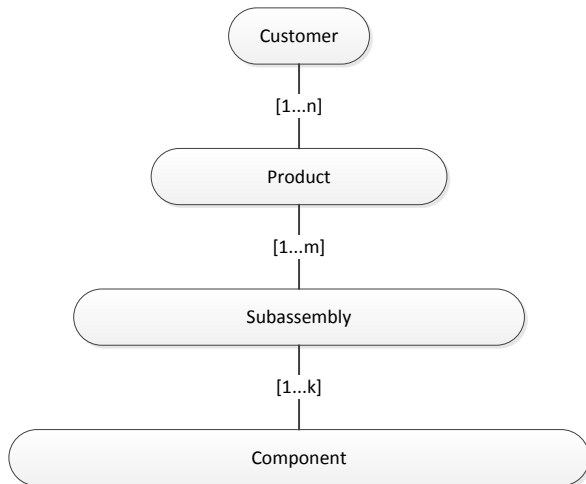
Figure 8: Customer and product structure at AME

Figure 8 shows that a subassembly consists of a specific number of components, whereas products consist of one or multiple subassemblies. Also, although a product is made for a specific customer, a specific customer can have multiple products. In the BOM structure the final product is indicated as level 0 with all components defined as level n depending on the number of intermediate sub-assemblies.

The structures of products produced by AME have been examined by evaluating the bills of material of all 235 products (excluding the customer level). Bills of material were assessed, based on the number of components required and the number of levels in the bill of material. The simplest products consist of a two-level BOM (level 0 for the final product and level 1 for all the components). This shows a product consisting of only components without any subassemblies. The most complex product found at AME in terms of BOM levels consisted of 5 levels, including multiple sub-assemblies. An example of two BOM-structures is presented in Figure 9, a two-layer BOM (left) and a four-layer BOM (right).
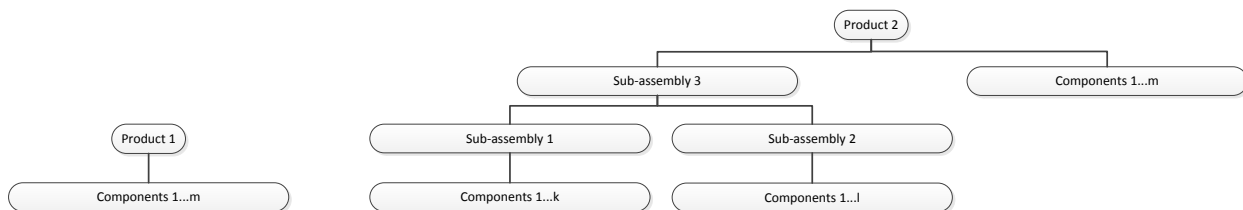
Figure 9: Example of BOM-structures

This analysis shows that AME creates new versions of products relatively frequently. These new versions can cause biased results and need to be removed from the data since the overlap in components in different versions is considerable. The remaining products under consideration show structured bills of material varying between 2 and 5 levels. Most products, however, have a relative simple two-level BOM structure.

5.2.2   Calculating component commonality

In this section the current level of component commonality is determined. As is described in section 4.1, various definitions of component commonality exist. The definition used for component commonality in this report is the use of a component for multiple products. Besides the many definitions of component commonality, also many options for component commonality calculations have been described. In this project, three component commonality measures have been used to calculate component commonality and assess the current situation

regarding component commonality. First, the 'degree of commonality index' (DCI) has been used as initial measure to determine the current level of component commonality. Besides the DCI, the total constant commonality index (TCCI) and the percentage of commonality (POCC) have been used. According to the literature (Collier, 1981; Wacker and Treleven, 1986), these measures combined give a representation on the level of component commonality. The mathematical representation of both DCI and TCCI is given in below (Wazed et al., 2009):

$$DCI = \frac{\sum_{i=1}^{d} \phi_i}{d}$$

$$TCCI = 1 - \frac{d-1}{\sum_{i=1}^{d} \phi_i - 1}$$

In these equations the characters stand for:

ϕ_i Number of immediate parents component i has over a set of finished products or major subassemblies
d Total number of distinct components in the set of end items

The degree of commonality index is calculated by summing all parenting products for all components per component and dividing it by the number of distinct components. The DCI represents the average number of products for which a component is used. In comparison to the DCI, the TCCI is a relative measure with absolute boundaries ranging from 0 to 1, where the DCI ranges from 1 to β in which $\beta = \sum_{i=1}^{d} \phi_i$. To illustrate the calculation of both measures and gain more insight in them, simple example calculations are shown in Figure 10. A parenting product can consist of multiple components or subassemblies. For example, in Case III in Figure 10, items 5-9 are considered components, item 3 is a sub-assembly and parenting product for components 5-7, item 4 is a sub-assembly and parenting product for components 5, 7, and 8 and item 1 and 2 are the parenting product for sub-assemblies 3 and 4 and respectively sub-assembly 3 and component 9.

The third component commonality measure, the percentage of component commonality measures the number of components that have been used in multiple sub-assemblies of products. This number divided by the total number of component results in the percentage of common components.
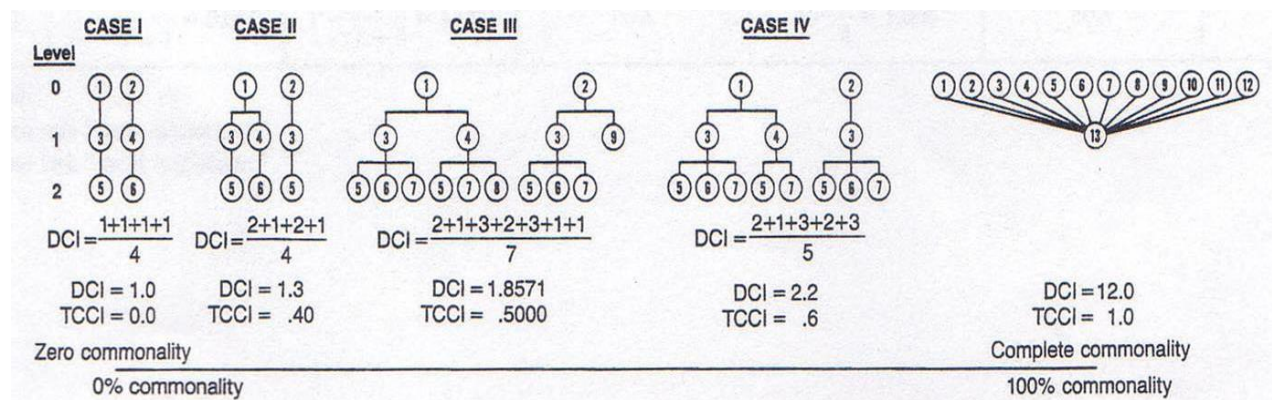

Figure 10: Component Part Standardization (Wacker & Treleven, 1986)

The following sections describe the initial calculations of component commonality.

5.2.2.1   Degree of commonality index

The degree of commonality index (DCI) is a commonly used measure to assess component commonality. It measures the average component usage (the average number of products for which a component is used). The calculation method for degree of commonality index is shown in the previous section.

This method of calculation has been applied to the 235 products under consideration. The overall degree of commonality at AME is 3.37. This figures shows that components at AME are used in 3.37 parent items on average, out of the 235 products available. Since this DCI measure seems relatively small, a close look was taken at the whole range of components and for each component the level of commonality (the number of products for which a component has been used (ϕ_i)), was calculated. The most common levels of commonality are depicted in Figure 11. This range of component usage (1-15) accounts for 96.2% of components. A graph for the whole commonality range can be found in Appendix D. The average component commonality of 3.37 stems from a positively skewed distribution. Almost fifty percent (47.6%) of all components is used only once, 19 percent twice and 10 percent is used by three parenting products. Component commonality ranging from one to three already accounts for more than seventy-five percent (76.6%) of all components. The DCI exceeding 3 (3.37) is caused by several extreme cases; 59 components (less than 2% of all components) have been used in more than 20 parenting products, of which 9 components have a commonality that is even larger than 50 and the most extreme case involved a component with 104 parenting products. These extreme cases involved cheap components, the most extreme case (ϕ_i=104) involves a ceramic capacitor.
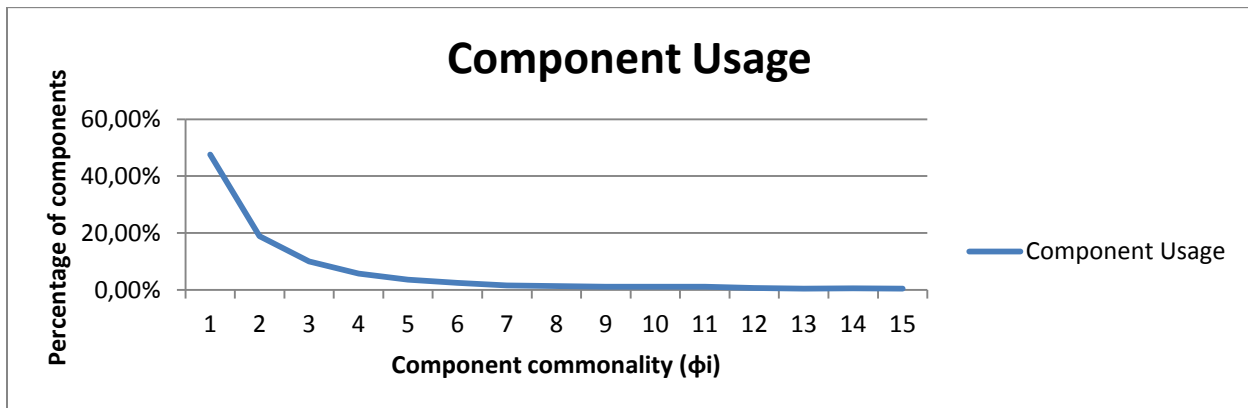
Figure 11: Component usage (shortened range)

However, excluding these most extreme cases of component commonality (2% most extreme cases) the DCI measure drops by 16% (from 3.37 to 2.83). Here it shows that the impact of extreme commonality cases on the degree of commonality index is significant. The analysis of the degree of commonality index shows limited component commonality in the product portfolio of AME. The major part of components is used in less than three products.

5.2.2.2   Total constant commonality index

A second measure to assess the current component commonality situation at AME is the total constant commonality index. The total constant commonality index (TCCI) is used to complement the view on component commonality provided by the calculation of DCI. The TCCI ranges from 0 to 1 in absolute values in which a TCCI value of zero indicates no component commonality and a TCCI figure of 1 indicates full component commonality (see also Figure 10).

The calculation method of the TCCI measure is discussed above. The calculation method has been applied to the 235 products under investigation. The TCCI calculations returned a value of 0.7033, which is relatively high and indicating a high level of component commonality. This seems to be in contrast to the low component commonality based on the DCI measure. However, the DCI calculations showed large influence of components with extreme commonality. Again, if the top 2% is removed from the component commonality analysis, the TCCI value drops from 0.7 to 0.65 (a decrease of 8.2%). Still the TCCI measure is high.

To explain the difference in component commonality a close look was taken into the definition of both measures. The degree of commonality index calculates the average number of products for which a component has been used. The total constant commonality index sums number of parenting items for all components that are used in multiple products. The TCCI shows the relative number of common components. The TCCI measures the relative number of common components, but does not completely fit the data of AME. This can be shown below:

$$TCCI = 1 - \frac{d-1}{\sum_{j=1}^{d} \phi_i - 1} = 1 - \frac{d-1}{\beta - 1} = \frac{\beta - 1}{\beta - 1} - \frac{d-1}{\beta - 1} = \frac{\beta - d}{\beta - 1}$$

This equation for the TCCI calculation represents an approximation of the percentage of components that have more than a single parent, under the implicit assumption that no component is an extreme case of component commonality. Since multiple components have extreme cases of commonality, the TCCI does not have the desired effect of showing an approximation for the relative number of components. Besides, the measures β and d of DCI are also the inputs for TCCI. This means TCCI is another representation of DCI, and does not provide additional explanatory value. Therefore, the TCCI measure will be excluded from following analyses.

5.2.2.3   Percentage of component commonality

A third measure used in the analysis of component commonality is the percentage of component commonality (POCC). The POCC measures the percentage of components that has been used in at least two products of major sub-assemblies. The POCC measure complements the DCI measure. Applying the calculation method to the product selection resulted in a percentage of component commonality of 52.4% (1737 out of 3317 components).

This still is a relative high number of common components. In comparison to the TCCI, the percentage of component commonality gives a better insight into common components due to the reduced sensitivity for outliers. The mathematical representation of POCC is given below. In the equation, $I(\phi_i > 1)$ represents the indicator function. The indicator function returns a value of one when the condition is true and a value when the condition is not met.

$$POCC = \sum_{i=1}^{d} \frac{I(\phi_i > 1)}{d}$$

As can be observed from the component commonality calculations, 52.4% of the components are used for multiple products. This is clearly shown by the calculations on the percentage of component commonality. However, common components are used for a limited number of parenting products. The DCI measure shows an average of about 3 parenting products per component. Considering only common components, the average number of products for which a component has been used is about 5. The percentage of component commonality shows the potential for common components and the degree of commonality index shows the real use of common components. The potential at AME is still large, since almost half of the components are not yet common. The components that are common have a large number of products to which they can still be applied.

In the next section, the component commonality is further examined by looking at specific cross-sections of the product portfolio. This is done to provide more insight in the characteristics of component commonality at AME and to identify possible directions in which changes to the policy will have most impact.

5.3 Component commonality cross section analyses

In the previous sections, an overall view of component commonality at AME is presented based on the three measures described; DCI, TCCI and POCC. It was decided to continue the analysis with two measures; DCI and POCC. In this section, several cross-sectional analyses will be made in order to better characterize the component commonality at AME. First, component commonality is discussed per price category. Thereafter, component commonality will be discussed based on the functional product categories. Finally, component commonality will be analyzed per customer.

5.3.1 Component commonality per component price

In this section, a cross section analysis of component commonality is made based on component prices. The price categories used in this analysis are equal to the categories used in section 5.1. In the table below (Table 4), component commonality is shown for all components in each price category, based on the subset of 235 products and 3317 components. Table 4 shows more component commonality for cheaper components. Both the DCI and POCC are higher for cheaper components. This means that cheaper components are used more often in multiple final products or major sub-assemblies. The category of most inexpensive components (€0.00-€0.10) has the most component commonality, based on both the DCI measure as well as the POCC. The average use of components is significantly higher than other categories. Other component price categories show average component usage (DCI) between 2.03 and 2.66. These components show potential for increased use based on the POCC of almost 50%. In these analyses it is assumed that increasing component commonality is technically feasible.

Table 4: Component commonality (DCI and (POCC) per price category

Component commonality per price category (Price range [from-to])				DCI	POCC
€	0,00	€	0,10	4,74	59%
€	0,10	€	0,50	2,66	56%
€	0,50	€	1,00	2,14	48%
€	1,00	€	2,00	2,03	47%
€	2,00	€	5,00	1,71	35%
€	5,00	€	10,00	1,41	29%
€	10,00	€	25,00	1,29	22%
€	25,00	€	50,00	1,27	19%
€	50,00	€	100,00	1,44	31%
€	100,00	€	250,00	1,08	8%
€	250,00	€	500,00	1,00	0%
€	500,00	€	1.000,00	1,00	0%
€	1.000,00	€	100.000,00	1,00	0%

The analysis shows that cheaper components show more component commonality when compared to more expensive components in terms of DCI and POCC. The cheapest components have a significantly higher DCI measure than all other component price categories. In section 5.1, the analysis showed that the inventory of AME consists mostly of relative cheap components and these components show most commonality, but still relatively low values for the degree of commonality index.

5.3.2   Component commonality per product category

This section provides an overview of the component commonality per functional inventory category. In Table 5, an overview is presented per product category at AME. From Table 5 it is noted that inventory categories 'Passive' and 'Discrete' show most component commonality in terms of both component commonality measures. The functional inventory categories 'Analog', 'Digital' and 'Electromechanical' show an average amount of component commonality. The DCI for these three component categories is relatively low, but potential for component commonality shows through the relative high POCC.

The functional inventory categories concerning sub-assemblies show very little component commonality in comparison to other component categories.

Table 5: Component commonality (DCI and POCC) per product category

Component Commonality per Product Category	DCI	POCC
Passive	5,33	66%
Discrete	4,80	67%
Analog	2,80	58%
Digital	2,65	53%
Electromechanical	2,10	46%
Sub-Assemblies	1,49	26%
Purchased sub-assemblies	1,00	0%
Finished Products	1,00	0%
Packaging Materials	1,15	15%
Computer and Accessory	2,75	75%
Consumable Goods	1,40	30%
Office Supplies	1,00	0%
Assembly Tools	1,00	0%
Remaining	1,00	0%

Based on sections 5.1 and 5.2, the analyses show that most of the components (52.4%) are used multiple times in the product portfolio of AME, based on the POCC. However, common components are used in a limited number of major-subassemblies or final products. Common components are on average used in 5 of the 235 products under consideration.

Furthermore, the analyses revealed that cheaper components show more component commonality relative to more expensive components. However, components with a component value between €0.10 and €2.00 show potential for component commonality, due to relative high POCC levels, but do not utilize the advantages of component commonality due to the low level of degree of commonality index.

5.4   Customer specific stock

This chapter covers the current situation of inventories held at AME, the current level of component commonality and the current level of customer specific stock. In this final section a closer look is taken to the customer-specific stock. Customer-specific stock is defined as components that are used for a single customer only. Although component commonality shows the degree of component efficiency, it tells little risks concerned with holding specific inventory for specific customers. When a single customer terminates its cooperation with AME (e.g. defaults on his payment, goes into bankruptcy, or any other possible reason for terminating the contract), all stock can be considered obsolete and needs to be depreciated.

For the analysis of customer specific stock, the inventory data at December 31st, 2013 has been used, combined with the complete list of products produced at AME. For each component in inventory at the end of 2013, the number of customers has been determined that actually use the component in one of their products. If a component has only been used by a single customer, the components inventory was considered customer specific. The total customer specific stock at the end of 2013 was €1,354,000 spread across 20 customers, which is 57.8% of all stock in the central warehouse. It was noticed that a large spread exists in customer specific stocks. Some customers have over € 200,000 of customer specific inventory, whereas others only have € 3000 in customer specific inventories. This large difference can be explained by early stocking components for production in the first months of 2014.

The analysis on customer specific stock shows a large percentage of inventory holdings to be customer specific. Most of the customer specific stock consists of components with a high-item value, which is consisted with the relative high POCC in low-item value components. Technical considerations need to be made to assess whether these components can be standardized for component commonality.

In this chapter the current inventory situation of AME is discussed, including the current structure of inventory holdings, the current level of component commonality and the level of customer specific stocks. As can be observed from the first section, the inventory of AME consists mainly of relative cheap products, which account for a significant amount of inventory value. From the second section it is clear that 52.4% of components are used for multiple products. However, common components are used for a limited number of parenting products, on average 3. The POCC shows the potential for common components and the DCI shows the real use of common components. The potential at AME is still great, since almost 50% of components are not yet common and the components that are common have a large number of products to which these can still be applied.

To find the components to which component commonality can be additionally applied, cross section analyses have been performed. These analyses revealed that cheaper components show more component commonality relative to more expensive components. However, all components show potential for component commonality, due to relative high POCC levels but low levels of DCI.

Finally, customer specific stock has been analyzed. From the analysis it can be concluded that large customer specific inventories exist, totaling about 57.5% of total inventory value. The customer specific inventory varies per customer. The use of component commonality may reduce the level of customer specific stock and decreases the risk of depreciating stocks when the customer terminates the cooperation with AME. However, customer specific stocks consist of high-value components. Therefore, technical considerations need to be performed to determine whether these components can be standardized.

To investigate the possible effects of increased component commonality, a classical inventory model will be extended to facilitate any number of products with any number of components under service-level constraints. This model will be described in the following chapter.

6   Model

In the previous chapter the current situation at AME has been discussed. To assess the possible improvements an inventory model will be expanded to allow for component commonality. The requirements for the model are already explained in section 4.2: A multi-period model should be considered, that also allows for simple entry of a product structure with any number of (common) components and any number of products under service level constraints. In this chapter, the developed inventory model will be presented.

The model builds on a classical inventory model of De Kok (2005) for stock control for one location with one product. The model has been chosen for allowing multiple periods of inventory simulation and relative simple addition of new products and components. The model extension, as will be described, allows for derived demand of any number of products and any number of components in a two-level BOM structure, given service level constraints. However, allowing for multiple products and components given various component commonality settings requires the development and integration of a matrix notation for product structures. The extended inventory model will be discussed in section 6.1.

In chapter 3, a dual research question has been presented. The second part of the research question includes the effects of component commonality on the firm's cash position. The extended inventory model, allowing for component commonality, is further developed to allow for analyses of the cash position. This model development, including cash flows, will be described in section 6.2.

6.1   Model including commonality

In this chapter a periodic review model is constructed in which each period covers a day, to simulate a situation allowing for component commonality. The aim of the model is to provide insights in the effects of component commonality on inventories. To introduce the model, a basic model without component commonality is described first, similar for the model of de Kok (2005). The model of the Kok shows the stock control for a single item, the simple model, described below, is an extension to the classical since demand for components is derived from its parenting products. The safety stock calculation and inventory model simulations for components are based on the inventory model described by de Kok. In the model developed, component commonality settings will be added in by introducing a matrix allowing for various product structures. A limitation of the model of de Kok (2005) is not including operational costs (e.g. handling, holding and/or ordering costs).

To provide insights in the model of de Kok and the additional to the model, a basic model is discussed. The basic model consists of two products (resp. P_1 and P_2), which both consist of two unique components (components C_1, C_2, C_3 and, C_4). This product structure can be seen in Figure 12. Since the time to produce products is shorter than the customer lead time, the products are considered make-to-order (MTO). However, it is assumed that the customer lead time is shorter than the time it takes to produce a product plus component lead time. For this reason it is assumed that only components are ordered-to-stock and shortages of products only occur when insufficient components are available.
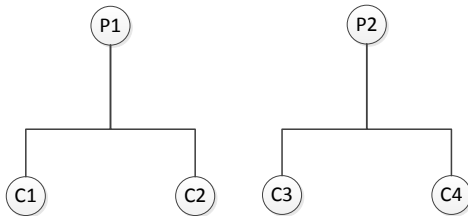

Figure 12: Graphical representation of model without commonality

In the adapted model, the supply is modelled using two products (P_1 and P_2). In general terms this can be j products. For each product $P_j, j = 1,2$ the presence of components $i, i = 1, 2, \ldots m$ is required to produce one product j. The requirement of components i for product j is defined by $a_{i,j}$ with $a_{i,j} = \{0,1\}$.

Prior to describing the model, the variables and notation will be introduced. The period index t is defined as $(t - 1, t]$ with T being the total model time span consisting of 5 years, each year consisting of 360 days, so $1 \leq t \leq 1800$.

- $D_j(t)$ independent demand for product j in period t
- $G_i(t)$ dependent demand for component i in period t (i.e. demand derived from products j).
- $G_i(t, t + x)$ dependent demand for component i in between period t and $t + x$
- $Q_i(t)$ quantity ordered of component i in period t
- $X_i(t)$ inventory level of component i at the start of period t
- $p_{i,k}$ the kth replenishment order moment of item i after time $t = 0$
- $Y_i(t)$ inventory position of component i at the start of period t,
- l_i delivery lead time, the time between the order and the physical receipt of items (i.e. component i ordered at $p_{i,k}$ are available for usage at $p_{i,k} + l_i$
- v_i value of component i.
- s_i safety stock (reorder level) for component i
- $X_i(t^-)$ inventory level of component i just before replenishment
- $U_{i,k}$ undershoot of component i in replenishment cycle k, Undershoot is defined as the amount of units the inventory position drops below the safety stock level at the moment of replenishment.
- $B_i(p_{i,k} + l_i, p_{i,k+1} + l_i]$ backorder of component i

The demand for both products (P_1 and P_2) is assumed to be identically and independently distributed given normally distributed demand, $D_j(t) \sim N(\mu_j, \sigma_j)$. Based on the demand for products j, the demand of all components i is derived: $G_i(t) = a_{i,j} \cdot D_j(t)$ assuming direct demand for components given the MTO policy described above.

Based on the derived demand of components, an (R, s, Q)-inventory model was constructed (de Kok, 2005) in which the performance criteria applied to all components is a P_1-service level, the non-stockout probability. This measure is defined as P_1-service level $= P\{X_i((p_{i,k} + l_i)^-) \geq 0\}$. For all components, this service level should be at least 95% (i.e., in 95% of the order cycles non-stockout occurs). A service level of 95% is chosen since the service level requirements used in literature generally vary between 90% and 99%. On the basis of the service-level requirement, the safety stock levels have been calculated. The safety stock is calculated using the following formula: $s_i = \alpha\sigma(G_i(0, l_i + R])$, in which the review period is confined to one day (R=1). The variable α is based on the standard inverse normal distribution of the 95%-service level constraint, so $\phi^{-1}(0.95)$. As can be seen in the parameter setting and in the settings for the service level, the lead time is deterministic for every component.

As is briefly mentioned before, in the current model, the service level depends on the difference between the customer lead time ($CuLT$) and the production time (PT) plus component lead time ($CoLT$). If this difference is larger than a single period, late arrival or order of components shall not directly impact the service level. In the current model it was assumed that customer lead time plus one period is equal to the production time plus component lead time, so $CuLT + 1 = PT + CoLT$. This is graphically depicted in Figure 13.

Customer Lead Time		T=1
Production Time	Component Lead Time	

Figure 13: Ratio of customer lead time vs. production time and component lead time

To determine the non-stockout probability in every review period, the following calculations regarding the described parameters have been made based on de Kok (2005). However, the demand and variance for each component derived from the demand parameters of its parenting products P_1 and P_2, is new to the model:

$$G_1(t) = a_{1,1} \cdot D_1(t), G_2(t) = a_{2,1} \cdot D_1(t), G_3(t) = a_{3,2} \cdot D_2(t), G_4(t) = a_{4,2} \cdot D_2(t)$$

$$Var(G_i) = a_{i,j}^2 \cdot \sigma_j^2$$

For all components, the demand between order arrivals is determined by means of the following formula:

$$G_i(p_{i,k} + l_i + 1, p_{i,k+1} + l_i) = \sum_{t=p_{i,k}+l_i+1}^{t=p_{i,k+1}+l_i} G_i(t)$$

The expression for the net stock just after replenishment is given by $X_i(t + l_i) = s_i + Q_i(t) - U_{i,k} - G_i(t, t + l_i)$. For the net stock just before the replenishment arrives the expression is derived $X_i\big((p_{i,k+1} + l_i)^-\big) = s_i - U_{i,k} - G_i(p_{i,k+1}, p_{i,k+1} + l_i)$. This is the reorder level minus undershoot and minus the demand during component lead time. The expected undershoot of every order cycle $(U_{i,k})$ are calculated based on $E[U_{i,k}] = \frac{\sigma^2(G_i)+E^2[G_i]}{2E[G_i]}$ and $\sigma^2[U_{i,k}] = E(U_{i,k}^2) - E^2(U_{i,k})$ in which $E(U_{i,k}^2)$ is calculated as $E[U_{i,k}^2] = \frac{1}{3}\left(1 + \left(\frac{\sigma_i}{\mu_i}\right)^2\right) \cdot \left(1 + 2\left(\frac{\sigma_i}{\mu_i}\right)^2\right) \cdot \mu_i$ given a normal derived demand distribution: $G_i \sim N(\mu_i, \sigma_i)$, de Kok (2005).

If the demand during component lead time is larger than the safety stock level minus undershoot, the model allows for backorders. Unsatisfied demand is backordered and demand is satisfied in the next period. Backorders in the replenishment period of the model are described by:

$$B_i(p_{i,k} + l_i, p_{i,k+1} + l_i] = \left(-X_i\big((p_{i,k+1} + l_i)^-\big)\right)^+ - \left(-X_i(p_{i,k} + l_i)\right)^+.$$

The x^+ describes the $max(0, x)$, giving the number of components which cannot directly be delivered from stock. The backorders in previous periods, which are generally zero, are deducted from the backorders of the period under consideration, which results in only the backorders from this period.

At the moment just before reordering $t = p_{i,k}^-$, the inventory position is equal to the reorder level s; $Y_i(p_{i,k}^-) = s_i - U_{i,k}$. In the model it is assumed that the inventory position at time $t = 0$ is equal to the reorder level (assuming no undershoot); $Y_i(0) = s_i \; for \; all \; i$.

With these last notations the complete inventory model is described based on two products with two components each. However, to facilitate the analysis of component commonality this model needs to be expanded to facilitate any number of products and any number of components. To illustrate the model including component commonality, the components 4 and 5 have been replaced by a single component, common component C; the other components stay equal and remain components 3 and 6. This altered component structure including the redesign can be seen in Figure 14.
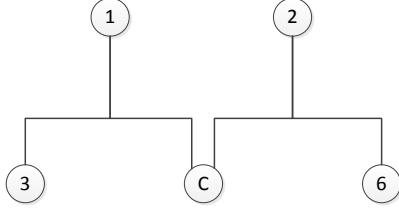
Figure 14: Graphical representation of model with component commonality

The variables and notations all remain equal. Also, the demand for products 1 and 2 remains equal to the situation discussed in the section above. The deviation from the model without component commonality comes in the form of derived demand. Since components can now have multiple parenting products, demand for components needs to be aggregated over several products of which the model in the precious section was a specific case. So the derived demand and variance of derived demand is presented as:

$$G_i(t) = \sum_{j=1}^{n} a_{i,j} \cdot D_j(t)$$

$$Var(G_i) = \sum_{j=1}^{n} a_{i,j} \cdot \sigma_j^2$$

This setting of products and components (two products with both a product specific component and a common component) is the most simple component commonality setting. Given the model extensions above, the model now allows for component commonality and determines all parameters described for all products and components. The way of representing component commonality will be presented in the following sub-section.

6.1.1 Model extension including matrix on common components

To adapt the model to ensure easy entry of product structures, a matrix $A_{i,j}$ is introduced. The requirement of components (0 if not used and 1 if used) for certain products is indicated by $a_{i,j}$, $a_{i,j} = \{0,1\}$ for all i,j. For a multiplicity of products $j = 1,2,\ldots,n$, the required components $i = 1,2,\ldots,m$ are listed. The structure of products and components (all values of $a_{i,j}$) will be presented in this matrix. To illustrate the matrix $A_{i,j}$, Figure 12 (with $j = 2$ and $i = 4$) is presented in matrix below:

$$A_{i,j} = A_{4,2} = \begin{pmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{pmatrix}$$

The matrix shows that product 1 (first column of the matrix) consists of components 1 and 2 (first two rows of the matrix), since only $a_{1,1}$ and $a_{2,1}$ are both one.

Based on the matrix $A_{i,j}$, the component commonality measure DCI can be calculated based on matrix calculations. A vector with all ones is called a ones vector and is commonly denoted by **1** or e. In this report we use the notation e for the ones vector, where e_i is used for a vector with i number of ones (the number of components) and e_j is used for a vector with j number of ones (the number of products). The degree of commonality index (DCI) can be calculated using matrix multiplications: $\beta = e_i^T \cdot (A_{i,j} \cdot e_j)$ and $d = i$. Based on these sub calculations, the DCI measure is calculated as $DCI = \frac{\beta}{d} = \frac{e_i^T \cdot (A_{i,j} \cdot e_j)}{i}$.

The percentage component commonality (POCC) can be derived from the matrix multiplication $(A_{i,j} \cdot e_j)$. Vector items that are used more than once are considered common: $\sum_{n=1}^{i} I(A_{i,j} \cdot e_j > 1)$, in which I represents the indicator function. The percentage of common components can then be derived as: $\frac{\sum_{n=1}^{i} I(A_{i,j} \cdot e_j > 1)}{i}$.

In this section the inventory model presented by de Kok (2005) is expanded to allow for component commonality. Component commonality is introduced by the addition of derived demand for components combined with a product structure matrix. Since the research question includes the effects of component commonality on liquidity, the model will be adapted to also facilitate the effects of component commonality on liquidity as well.

6.2   Financial model

This section covers the model adaption to facilitate the analysis of liquidity. As is explained in section 4.3, the effects of component commonality on a firm's liquidity are still open for debate in the current literature. To better understand this relation between a firm's liquidity and its inventory, the model will be enhanced to facilitate cash flows as well. This enables the examination of component commonality effects on liquidity and may provide additional insights inventory efficiency and liquidity on a micro-economic level.

6.2.1   Cash flow and cash balance

A firm's cash position is a result of an initial cash balance and a firm's cash flow. In general terms, cash flow is defined as money going into or out of the firm measured over the accounting period. Three types of cash flow are indicated:

- Operational cash flows: cash received or expenses paid as a result of a firm's business activity. In literature cash flows are defined as sales minus the costs of goods sold minus the selling, general, and administrative expenses and minus the taxes applicable.
- Cash flow from capital investment: cash used for the acquisition of fixed assets or the freed cash when selling fixed assets.
- Financing cash flow: cash received or paid to financial institutions and investors in the form of equity, debt, dividends and debt repayments.

Since component commonality can be best categorized as an operational activity, focus is placed on this type of cash flow. Investments in cash and/or cash equivalents are needed to perform business transactions but are out of scope of this master thesis project.

Skolnik (2007) investigates the relationship between inventory reductions and increased cash balances, as part of operational cash flows. If decreasing inventory investments result in an increased cash balance, the benefit of decreased inventory investments is reduced since the return on cash is considered low. To the best of my knowledge Skolnik (2007) was the last author to study the relations between decreased inventory requirements and changes in cash holdings. The author shows that a significant proportion of inventory reductions are used to increase cash balances. For this reason, Skolnik (2007) recommends further research into the ability of firms to reduce asset requirements following innovations in operations management to better understand the relation between inventories and financial assets.

To determine the impact of component commonality on cash flow and cash flow variability, the model of section 6.1 has been extended to facilitate the incoming and outgoing cash flows related to the procurement of components needed for production and sales of finished products.

6.2.2 Model extension including procurement and sales cash flows.

To model the cash flows based on the inventory holdings and order moments, additional variables were included in the model. The additional variables are presented below:

- t_i Payment term for orders of component i (number of periods between order arrival of order k at time $t = (p_{i,k+1} + l_i)$ and due date of the invoice), which is fixed per component.
- a Payment term (number of periods)
- $H_i(t)$ Shipment of component i in period t
- $C(t)$ Cash position of the firm based on the order, processing and sales of components/products, with initial cash position $C(0)$.
- $CI(t)$ Cash inflow of the firm in period t.
- $CO(t)$ Cash outflow of the firm in period t.
- T Number of periods (model time span)

Based on these variables, the cash position of the firm can be calculated for all periods.

$$C(t) = C(t - 1) + CI(t) - CO(t)$$

As discussed in section 6.1 the kth order of component i is ordered at time $t = p_{i,k}$ and delivered at $t = p_{i,k} + l_i$. It is assumed that with the delivery of the components the invoice is sent, meaning that the invoice is due at $t = p_{i,k} + l_i + t_i$ for orders of component i. This is the moment the cash outflow occurs, which amount totals $v_i \cdot (Q_i(t))$. So the cash outflow at time t is based on the order sent in period $(t - l_i - t_i)$, which results in:

$$CO(t) = \sum_{i=1}^{m} v_i \cdot \left(Q_i\big(t - l_{i,} - t_i\big)\right).$$

The cash inflow is realized when components are converted into final products and cash is received. The cash inflow is based on shipped products with a specified payment term for the customer (a number of periods (a_i)). So the cash inflow can be determined using the following formula:

$$CI(t) = \sum_{i=1}^{m} v_i \cdot \left(H_i(t - a)\right).$$

Combining all into the cash position in each period $C(t) = C(t - 1) + CI(t) - CO(t)$ (without margin) leads to:

$$C(t) = C(t - 1) + \sum_{i=1}^{m} v_i \cdot \left(H_i(t - a)\right) - \sum_{i=1}^{m} v_i \cdot \left(Q_i(t - l_i - t_i)\right)$$

Based on the cash position in each period, the volatility of the cash position is determined based on the coefficient of variation of the cash position (Minton and Schrand, 1998). The coefficient of variation is the standard deviation of the cash position divided by the absolute mean of the cash position over all periods. The average cash position over all periods is determined by $\bar{C} = \frac{\sum_{t=0}^{t=T} C(t)}{T+1}$, where the standard deviation is calculated as the squared root of the variance which is calculated: $Var\big(C(t)\big) = \frac{\sum_{t=0}^{t=T}(C(t) - \bar{C})^2}{T+1}$. This results in the coefficient of variation:

$$CV\big(C(t)\big) = \frac{\sigma\big(C(t)\big)}{\bar{C}(t)} = \frac{\sqrt{Var\big(C(t)\big)}}{\bar{C}(t)} = \frac{\left(\sqrt{\frac{\sum_{t=0}^{t=T}(C(t) - \bar{C})^2}{T+1}}\right)}{\left(\frac{\sum_{t=0}^{t=T} C(t)}{T+1}\right)}$$

The cash position and the cash inflows and outflows are included in the model and are related to the order moments and moments of shipment. The cash position and cash flows will be analyzed by the coefficient of variation, consisting of the average cash position and variation of the cash position based on cash flows. To show the effects of the cash position and cash flows on external financing, the next section will briefly describe borrowing and opportunity costs.

6.2.3   Cash position and external financing

In section 6.2.1 describes that a significant proportion of inventory reductions are used to increase cash balance, according to Skolnik (2007). Additional liquid assets are defined as cash or cash equivalents that are available to the firm after inventory investments have decreased. Since external finance can be costly, it can be advantageous to keep the cash from decreased inventory investments within the firm to lower the dependency on external financing.

The model, including cash flows derived from the inventory model is extended with an initial cash position and the dependence on external finance based on the initial cash position and the cash flow volatility. A tradeoff can be made between an initial cash flow position and the possibility of attracting external financing against a certain cost (e.g. interest rates) when required.

The initial cash position ($C(0)$ at $t=0$) of the firm is set and decreases with cash outflows and increases with cash inflows. To increase the fit to reality, the cash inflow is modelled as described in section 6.2.2, but a margin is added (M). It is assumed that the margin for all products and components is equal, making the total cash inflow in each period:

$$CI(t) = (1 + M) \cdot \sum_{i=1}^{n} v_i \cdot \left(H_i(t - a) \right),$$

The margin in the presented equation is defined in percentages (e.g. M=0.05 when the margin is 5%). The margin increases the cash position gradually in time. In order to prevent the cash position to increase continuously, the cash position is limited. When a threshold is reached, the model assumes immediate payout of all cash above the initial cash position, i.e., restore the initial cash position. This cash outflow can be explained by, for example, a payout to investors, investments in new machines and or repayment of loans.

Short-term external funds can be attracted to pay invoices at times of a negative cash position. In the model, periods with negative cash positions will be multiplied with percentage borrowing costs (b). From these costs the present value will be calculated using the firm's annual discounting rate r, for example if the discounting percentage is 2%, then r=0.02. The total present value of borrowing costs with compounding discount rate is then calculated accordingly:

$$Costs\ of\ borrowing = \sum_{t=1}^{T} \frac{\left(-C(t) \right)^{+} \cdot b}{(1 + r)^{\frac{t}{360}}}$$

To ensure the cash position is not set unrealistically high in order to prevent borrowing costs, the cash position is subject to opportunity costs. Opportunity costs are defined as return that is forgone by investing in the cash position, instead of investing elsewhere (e.g. in financial markets), according to Brealey et al. (2011). Opportunity costs are calculated by multiplying the cash position (when positive) in each period with the unit opportunity costs (o). The present value of these opportunity costs is calculated by dividing all opportunity costs by the weighted average costs of capital (WACC). Again with a WACC-percentage of, for example, 4%, the weighted average cost of capital for the model is WACC=0.04. Finally, the opportunity costs are summed over all periods to get the total opportunity costs.

$$Opportunity\ costs = \sum_{t=1}^{T} \frac{\left(C(t)\right)^{+} \cdot o}{(1 + WACC)^{\frac{t}{360}}}$$

The total costs of the cash position consist of the total costs of borrowing and total opportunity costs. The total costs of the cash position are:

$$\sum_{t=1}^{T} \left(\frac{\left(-C(t)\right)^{+} \cdot b}{(1 + r)^{\frac{t}{360}}} + \frac{\left(C(t)\right)^{+} \cdot o}{(1 + WACC)^{\frac{t}{360}}} \right)$$

Based on the model, the effects of component commonality on cash positions and cash flows will be examined and the effects to the total costs of liquidity can be determined.

Concluding, in this chapter a model is described that allows for all component commonality settings. The model builds on a classical inventory model of De Kok (2005) for stock control for one location with one product. The model has been chosen for allowing multiple periods of inventory simulation and relative simple addition of new products and components. The model extension, as described, allows for derived demand of any number of products and any number of components in a two-level BOM structure. However, allowing for multiple products and components given various component commonality settings required the development and integration of a matrix notation for product structures. Since the link between inventory initiatives and liquidity of a firm is still in debate in the current literature, the model was extended to facilitate the cash flows based on operational data such as order moments and moments of demand. Finally, the effects of component commonality on liquidity are translated into the effects on total costs of liquidity by using borrowing and opportunity costs.

In the following section, the model will be used for simulations to test the effects of component commonality on inventory levels and on the firm's cash position and cash flows.

7 Results

In this chapter, the model as explained in the previous chapter will be used to examine the effects of component commonality on inventory levels and the firm's liquidity in order to answer the research questions as stated in section 3.4. First, the component commonality measures described in section 5.2 will be tested for robustness: the degree of commonality index (DCI) and percentage of component commonality (POCC). The analysis of the robustness of both measures will be described in section 7.1. In section 7.2, the results of the safety stock calculations will be described. In section 7.3, the simulation results on inventory holdings will be considered. Finally, in section 7.4, the effects of component commonality on liquidity will be considered.

7.1 Component commonality measures

Before the analysis of component commonality will be described, the two component commonality measures DCI and POCC have been tested as input for the analysis of component commonality to ensure equal component commonality measures for similar product and component settings. Also, model results have been considered for consistent outcomes.

7.1.1 Component commonality measures tested empirically

In this section, the influence of the structure of the component commonality matrix $(A_{i,j})$ was tested empirically. Four scenarios have been tested using four different matrix structures:

1. <u>Low</u> degree of commonality index versus <u>low</u> percentage of component commonality
2. <u>Low</u> degree of commonality index versus <u>high</u> percentage of component commonality
3. <u>High</u> degree of commonality index versus <u>low</u> percentage of component commonality
4. <u>High</u> degree of commonality index versus <u>high</u> percentage of component commonality

This test structure is graphically depicted in Figure 15, with the degree of commonality (DCI) on the horizontal axis and percentage of component commonality (POCC) on the vertical axis.
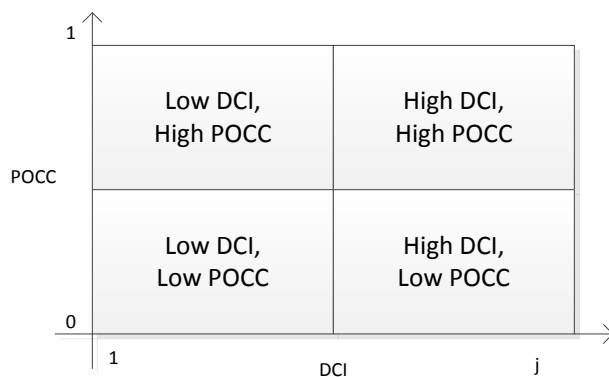

Figure 15: Scenarios to test robustness component commonality measures

For the first scenario, it was decided to use a DCI-measure of 1 (i.e. all components are used for one product and one product only). If DCI is equal to 1, the POCC is equal to 0. Based on the settings of DCI and POCC, various matrices where constructed[2] with $DCI < 0.5j + 0.5$ and $POCC < 0.5$ which can be seen in Appendix E. In theory the DCI is measured on a scale from 1 to β. However, in practice a component can be used in 1 to j products. For

---

[2] The DCI measure ranges from 1 to j (number of products). Half of the interval of DCI is marked by:
$1 + 0.5(j - 1) = 0.5 + 0.5j$

these matrices and the associated measure calculations, it can be seen that the structure of the matrix does not influence the outcome on the component commonality measures DCI and POCC, under the assumption that the number of zero entries is constant.

The second scenario measures a low DCI, consistent with the first scenario, and a high percentage of component commonality. The test matrices that were constructed are shown in Appendix E. Again, it can be deduced from the appendix that the structure of the matrix does not affect the outcome of both component commonality measures. The difference between the first and second scenario is primarily the number of common components, which is in accordance with the change in percentage of component commonality. Again, these matrices were used to calculate safety stocks, inventory levels, and order moments. The outcomes did not change using the various matrices as described.

The third scenario considered has a high level of DCI and a low level of POCC. Based on the DCI and POCC parameter setting, similar matrices where constructed that meet these criteria. Again it was noticed that the structure and size of the matrix did not influence the outcome of both measures and did not influence the results on the tested model variables.

In the final and fourth scenario, both the DCI and POCC are set high. As can be seen in Appendix E, the structure and size of the matrix does not seem to affect the outcome of both commonality measures. Also, the model measures, safety stock, inventory levels and, order moments are not affected by varying the matrix structures.

From this analysis, including new product introductions, it can be concluded that the matrix structure given a component commonality setting results in robust component commonality measures (DCI and POCC). Furthermore, the structure of the matrix does not affect the results of the model (e.g. inventory levels and safety stocks). Conclusively, the component commonality setting of products and components renders the same output, independent of matrix representation.

The empirical method including the four quadrants will be used for analysis in the next sub-sections.

7.1.2   Component commonality measures

In the previous section we saw that component commonality measures DCI and POCC do not change for different compositions of the product structure matrix, under the assumption that the number of zero entries is constant. IN this section this result is shown by using the formulas presented in section 6.1.1.

The degree of commonality index (DCI) is calculated as β divided by d. The component commonality structure was indicated by a matrix $A_{i,j}$. As can be seen in section 6.1.1, β is calculated as $\beta = e_j^T \cdot (A_{i,j} \cdot e_i)$ in which the structure of $A_{i,j}$ is not decisive. Since β is the summation of all matrix coefficients, the structure of the matrix $A_{i,j}$ does not impact the value of β and with that the DCI: $\beta = \sum_{j=1}^{n} \sum_{i=1}^{m} a_{i,j}$, given a constant value of d. The maximum value of β, given the current assumptions $(a_{i,j} = \{0,1\})$, is a multiplication of the number of products and the number of components $(i \cdot j)$.

The percentage of component commonality is determined by the indicator function of each row of the matrix multiplication $I(A_{i,j} \cdot e_j > 1)$. As can be seen from this formula, the structure of the matrix $A_{i,j}$ does again not affect the calculations of the percentage of component commonality. The summation per row is independent of matrix representation.

Concluding, based on the empirical and mathematical findings, the structure and size of the component commonality matrix $(A_{i,j})$ do not affect the outcome of commonality measures DCI and POCC. As is seen in the previous section, the results from the model did not change with varying matrix structures. From this analysis it is clear that a combination of DCI and POCC results in general applicable model results.

The analysis will continue with the calculations performed on inventory levels, starting with safety stock levels under different scenarios of component commonality.

7.2 Safety stock level and effects of component commonality

In this section the effects of common components on safety stock levels are described, however first the general characteristics of safety stock are discussed after which the relation between the DCI and POCC to safety stock will be considered using the quadrants discussed in the previous section.

7.2.1 Safety stock

In this section, the general characteristics of safety stock and its relation to component commonality will be discussed. When a component is used for multiple products (i.e., it will be used in various products in the portfolio), the variability of component demand will be pooled. To study the effects of variability pooling, the model has been used to calculate these pooling effects on safety stock levels. The safety stock level per component is calculated according to the formula's presented in chapter 6 using Excel VBA. A component was modelled to be used in one to eight products. With fewer products, the effect of demand pooling is difficult to see, however, including more products does not show additional value. Based on these component settings, the total safety stock level for this component has been evaluated. The results of these calculations are depicted in Figure 16.

For the calculations of safety stocks the following parameter setting has been used (variables specified in section 6.1): $E[D_j] = 50, \sigma[D_j] = 50, E[l_j] = 3, \sigma[l_j] = 0, E[l_i] = 3, \sigma[l_i] = 0, Q_i = 500$. For all components a P_1-service level needs to be achieved of 95%. The choice of parameters resulted in a coefficient of variation of 1. The dashboard of the model is shown in Appendix F.

In Figure 16, the upper (dotted) line represents the summed safety stock levels assuming all components are only used in a single product: no demand pooling effects exist. This can be explained as the upper level of aggregate safety stock levels. The lower (solid) line represents the safety stock level of a single component that is a common component (i.e. including pooled demand variability). As can be seen from the figure, the total safety stock holdings reduced significantly when pooling the effects of demand volatility, and can be considered a lower limit of aggregate safety stock levels. In case of a single product both scenarios are equal. However, if the number of products per component increases, the summed safety stock levels (no component commonality) deviate significantly from the aggregate safety stock levels (full component commonality).
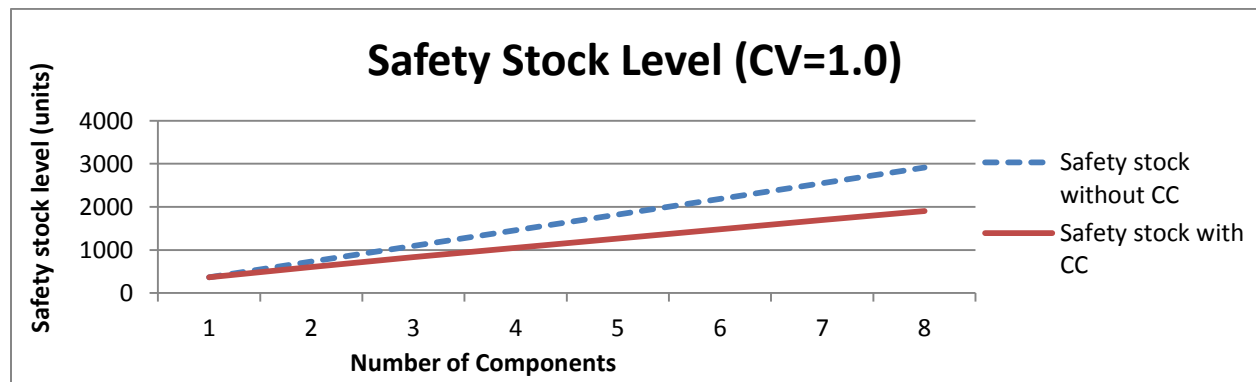

Figure 16: Aggregated and summed safety stock level

The safety stock levels are calculated using $s_i = \alpha\sigma(G_i(0, l_i + R])$, as stated in section 6.1. In this formula, the common component demand is the sum of all individual component demands. However, the variation of component demand is a result of summing individual component demand variations. This can be mathematically explained by:

$$Var(X + Y) = Var(X) + Var(Y)$$

Since X and Y are identically and independently distributed (the covariance is zero) and given this example of two components the standard deviation of X and Y becomes:

$$Var(\textstyle\sum_{i=1}^{m} X_i) = \sum_{i=1}^{m} Var(X_i).$$

$$\sqrt{Var(X) + Var(Y)} = \sqrt{2} \cdot \sqrt{Var(X)}.$$

In more general settings of component commonality (i.e. more components) this results in a standard deviation following:

$$\sqrt{Var(X) + Var(Y) + \cdots + Var(Z)} = \sqrt{n} \cdot \sigma(X).$$

In a situation without component commonality, the standard deviation of component demand would be $n \cdot Var(X)$. The reduction in volatility of component demand can be calculated using:

$$n \cdot \sigma(X) - \sqrt{n} \cdot \sigma(X) = (n - \sqrt{n}) \cdot \sigma(X)$$

As can be seen from the formula calculating the reduction in variance of component demand, the difference in summed and aggregate variance becomes larger with every additional component. Only in case of a single component ($m = 1$) the effects on safety stock levels are equal in cases with and without component commonality.

To assess the sensitivity of the aggregated and summed safety stock levels, the coefficient of variation was altered using a small, normal and, large coefficient of variation (resp. 0.5, 1.0 and 2.0). The results of these analyses can be found in Appendix G. From these figures I concluded that the difference between summed and aggregate safety stock levels increases when the coefficient of variation is increased. Increasing the demand variability of components increases the possible safety stock savings due to risk pooling. This can be explained by a relative increase of the standard deviation, which has a direct effect on the benefits of risk pooling as can be seen in the derived formulas above.
These findings can be explained in two ways:

- Equal safety stock levels result in higher service levels when a component becomes common.
- Equal service level measures can be achieved with lower safety stock levels in case of common components.

The choice between the options provided depends on the objective of the firm. If the firm is aiming for increasing service levels, component commonality can be a way of improving service levels without additional investments in inventory. However, is the firm aiming for reducing inventory holdings with constant service levels, component commonality can be a way of achieving this objective.

Given the 95% P_1-service level requirement of no stock-outs, the requirement can be met with lower levels of safety stocks. The effect of component commonality on total inventory holdings is discussed in section 7.3. Section 7.2.2 continues with the effect of component commonality measure DCI on safety stock levels.

7.2.2   Degree of commonality index

In the previous section, the general effects of component commonality on safety stock levels have been discussed, without considering increased component commonality levels DCI or POCC. The analysis showed that for a single component being used in a selection of products, the (additional) benefits grew with the use of the component. Also, component commonality is most favorable for components with large demand variability. In this section, the relation between component commonality, specifically the degree of commonality index (DCI), and the aggregate safety stock level is considered. The DCI will be increased from low to high, testing the bottom quadrants of the empirical model. The analysis that is performed involved an initial product portfolio of a single product consisting of two components, which results in a DCI-measure of one. Gradually, products were added to the portfolio, all consisting of two components. In every additional product one component was common and one component was product specific. The adding of components is represented in Figure 17, where the increasing portfolio is presented using matrix notation.

$$\begin{pmatrix}1\\1\end{pmatrix} \rightarrow \begin{pmatrix}1 & 1\\1 & 0\\0 & 1\end{pmatrix} \rightarrow \begin{pmatrix}1 & 1 & 1\\1 & 0 & 0\\0 & 1 & 0\\0 & 0 & 1\end{pmatrix} \rightarrow \begin{pmatrix}1 & 1 & 1 & 1\\1 & 0 & 0 & 0\\0 & 1 & 0 & 0\\0 & 0 & 1 & 0\\0 & 0 & 0 & 1\end{pmatrix} \rightarrow etc.$$

Figure 17: Product portfolio (matrix notation)

Since the product consists of a common and a product-specific component the product portfolio extensions expand the DCI-measure, ranging from one to two, with low percentage of component commonality. As described, the DCI measures the average number of products a component is used for, which in the current settings ranges to two (i.e. every product consists of two components). When adding products to the common components portfolio, this component becomes subjected to benefits of variability pooling. The effect is depicted in Figure 18. The safety stock without component commonality depicts a similar product structure with a constant DCI.
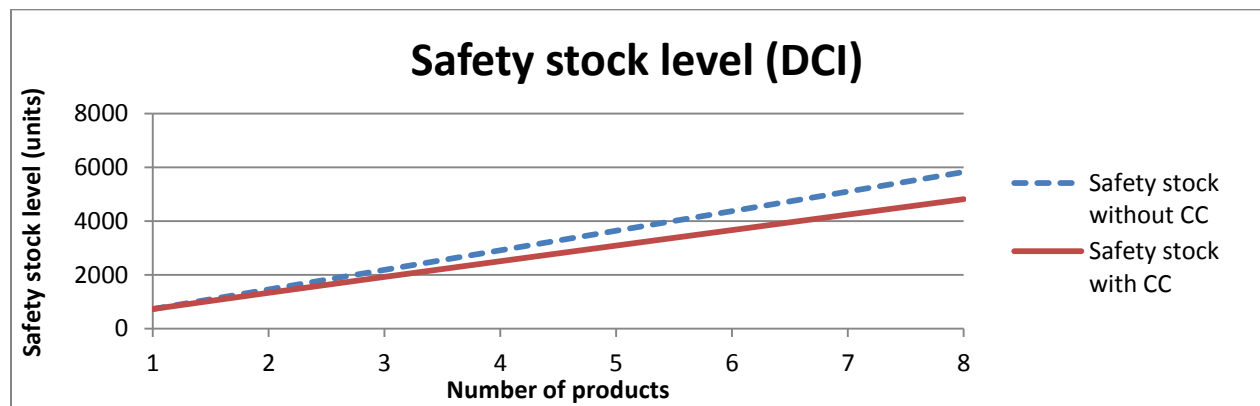

Figure 18: Aggregate safety stock level (DCI)

As can be seen in the figure above, benefits of component commonality increase with larger numbers of common components, given the aggregate safety stock level. The DCI measure grows from 1 (one product) to 1.78 (8 products). This can be explained by the common component (component 1) which is used for multiple products.

The more frequent a component is used in a given portfolio of products, the larger the (additional) benefit becomes, as is explained in section 7.1.2. In Figure 19, the effect of DCI on aggregate safety stock levels is depicted.
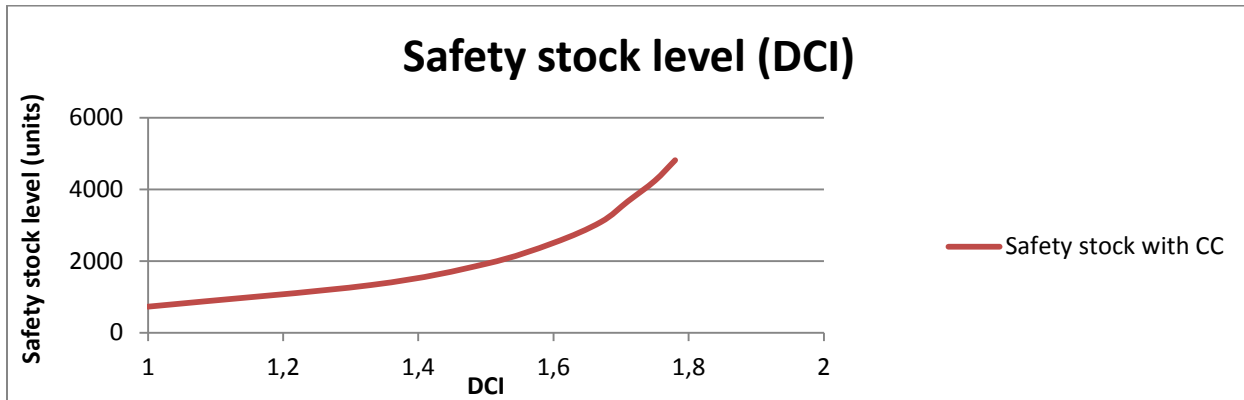
Figure 19: Aggregate safety stock level (DCI) with DCI on horizontal axis

As is seen from Figure 19, the DCI shows an exponential growth when approaching the upper limit of DCI. Since the products consist of two components (one common and one product specific), the upper limit of DCI is two. In Appendix H, multiple upper limits have been tested. Appendix H shows more benefits in safety stock levels for component commonality if the upper limit of DCI is raised.

However, Figure 19 shows that the upper limit of the DCI measure become less reachable. Since more components have to meet the requirement of being used in multiple products the requirement becomes increasingly difficult to meet. This can be seen from the equations and matrix representations in Appendix H. The fixed number in the denominator increases, which explains the difficulty of reaching the DCI limit.

From the analyses it is clear that component commonality is most beneficial when DCI is increased, and the upper limit for DCI is high. The degree of commonality index uses the demand variability pooling, as is shown in the previous section, to decrease the aggregate safety stock levels. However, at a certain point the increase in DCI becomes exponential.

7.2.3   Percentage of component commonality

The empirical test presented in 7.1 includes four quadrants to investigate. In the previous section the DCI was increased from low to high testing the bottom quadrants. To test the effects of the percentage of component commonality a scenario of two products has been chosen, one product consisting of 7 components (including all features) and the other consisting of a single component, finally resulting in a total of 8 products. The portfolio of products with a single component could be expanded, resulting in a product portfolio also including all products with only a single component as is noted in matrix notation below:

$$
\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \rightarrow etc.
$$

Figure 20: POCC increasing measures

Given the matrices above, the POCC increases with every additional product. However, the DCI will not significantly increase. Also for this analysis the default parameter setting has been used ($[D_j] = 50$, $\sigma[D_j] = 50$, $E[l_j] = 3$, $\sigma[l_j] = 0$, $E[l_i] = 3$, $\sigma[l_i] = 0$, $Q_i = 500$). Components that become common, due to the use in one other product, benefit from the pooling effects as described above. The effect of component commonality by increasing the percentage of common components is shown in Figure 21. The safety stock without component commonality depicts a similar product structure but with a constant POCC.
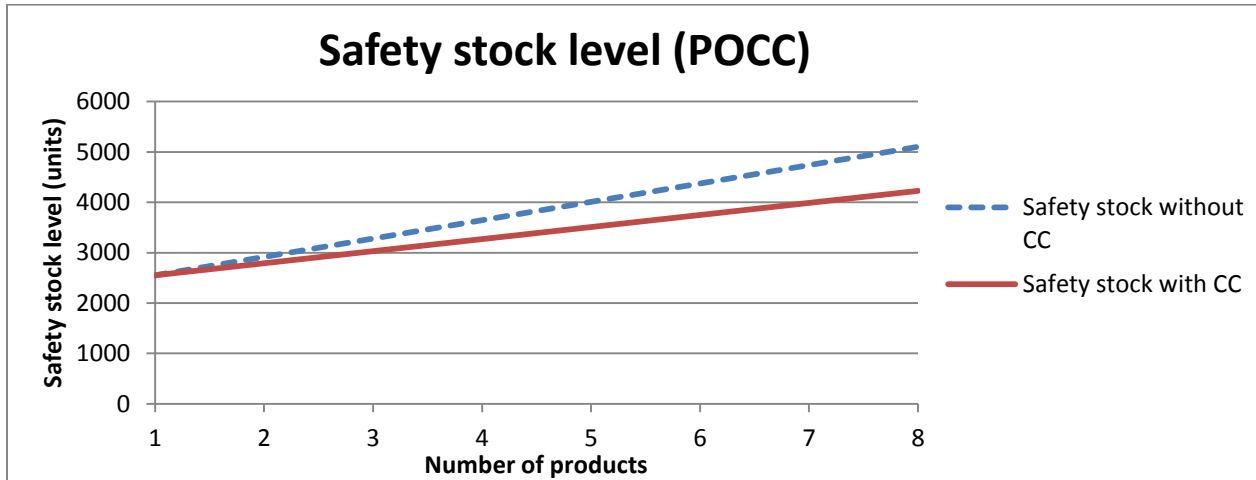
Figure 21: Summed safety stock (POCC)

As can be seen in the figure above (Figure 21), the additional safety stock savings are linear. This can be explained by looking at the gains of every component that becomes common. The safety stock of two non-common components combined is larger than the safety stock of a common component replacing both components (see also section 7.2.1). More common components lead to increasing savings in safety stocks. However, the additional savings from increased levels of POCC are constant, whereas in the case of DCI, these additional savings were increasing.
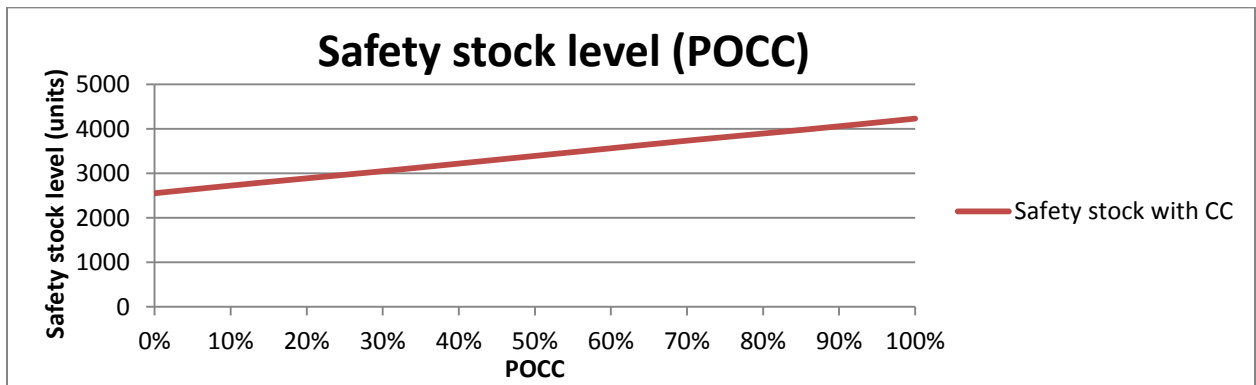
Figure 22: Summed safety stock (POCC) with POCC on horizontal axis

Figure 22 confirms the linear relation between the increase in POCC and the increased in total safety stock levels. To explain the decrease in safety stocks, a sensitivity analysis, based on the formulas used in section 7.2.1, will be performed on the effect of percentage of component commonality and safety stocks by changing the level of demand variation. As can be seen in Appendix I, the savings in safety stocks increase when uncertainty in demand

grows. However, the safety stock savings will decline when the demand variability decreases, although, the safety stock levels in case of increased POCC are in all cases lower than in cases without increased POCC.

A close look was taken into the quadrants low DCI & low POCC, low POCC & high DCI and low DCI & high POCC (quadrants 1, 2, and 3). Now, the quadrant with both DCI and POCC set high will be considered. This is done by increasing the product portfolio by adding a product consisting of two components, as is depicted in Figure 23.

$$
\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \rightarrow
\begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \end{pmatrix} \rightarrow
\begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \rightarrow
\begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \rightarrow etc.
$$

Figure 23: POCC and DCI increasing measures

Based on the increase of both DCI and POCC safety stock measures have been calculated and are presented in the figure below, Figure 24:
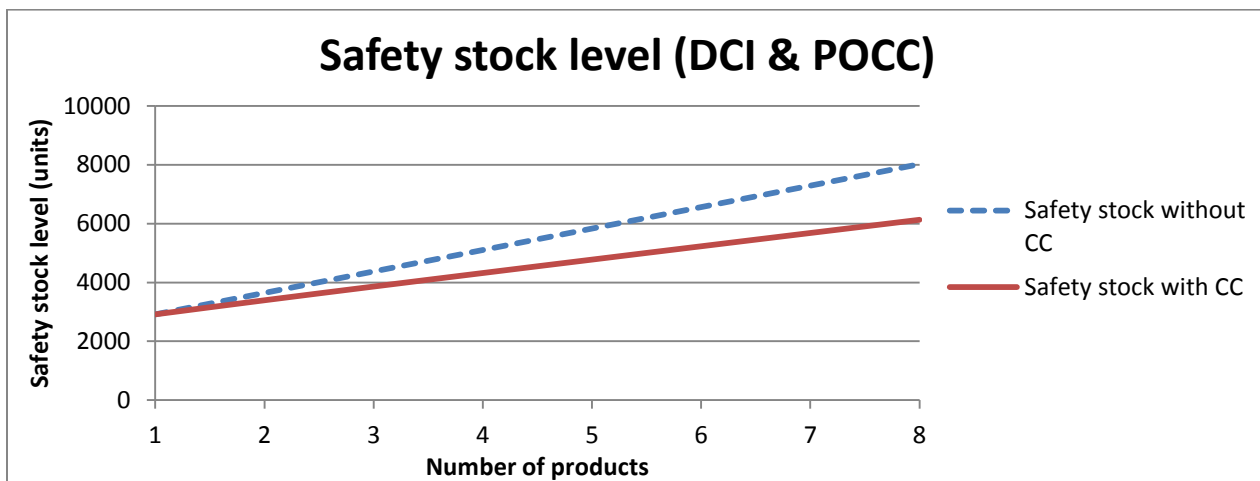
Figure 24: Aggregated safety stock with DCI and POCC

The figure shows that when both the DCI and POCC measure are increased, the effect of component commonality on safety stock inventories is largest, based on all the quadrants that have been investigated. This is explained by using both the potential of component commonality (POCC) as the additional increasing safety stock savings of DCI.

By looking at the analyses performed in combination with the four quadrants described in section 7.1 the effects of component commonality on safety stock levels can be considered.

- Low DCI, low POCC; in this scenario component safety stock levels are not able to benefit from a large level of commonality. The safety stock measures do not make optimal use of the effects of demand pooling at a low DCI level. Low level of POCC signals fewer possibilities of component commonality and with that, the possibility of demand pooling in safety stock levels.

- High DCI, low POCC; A relative small number of components is subjected to component commonality. However the components that are subjected to commonality benefit to a large extent from the demand pooling effects as discussed above.
- Low DCI, high POCC; High POCC signals high potential for component commonalty and the reduction of safety stock levels. However, again with low levels of DCI, the benefits of demand pooling are not used to the maximum extent.
- High DCI, high POCC; Most components allow for commonality and common components utilize the effects of demand pooling on safety stock to a large extent, resulting in the largest savings of all four quadrants.

Based on the analysis that has been performed, most safety stock reductions can be achieved with a large percentage of component commonality complemented and a large product base per component (high DCI and high POCC). From the description of the analysis it was clear that in the case of both low measures, the savings are least. When deciding between the two remaining quadrants in terms of safety stock savings, most savings in term can be made in the quadrant where DCI is high and POCC is low, instead of low DCI and high POCC measures. The effects of demand pooling of multiple products for a single component are larger than many components being used twice. This effect is depicted in Figure 25.
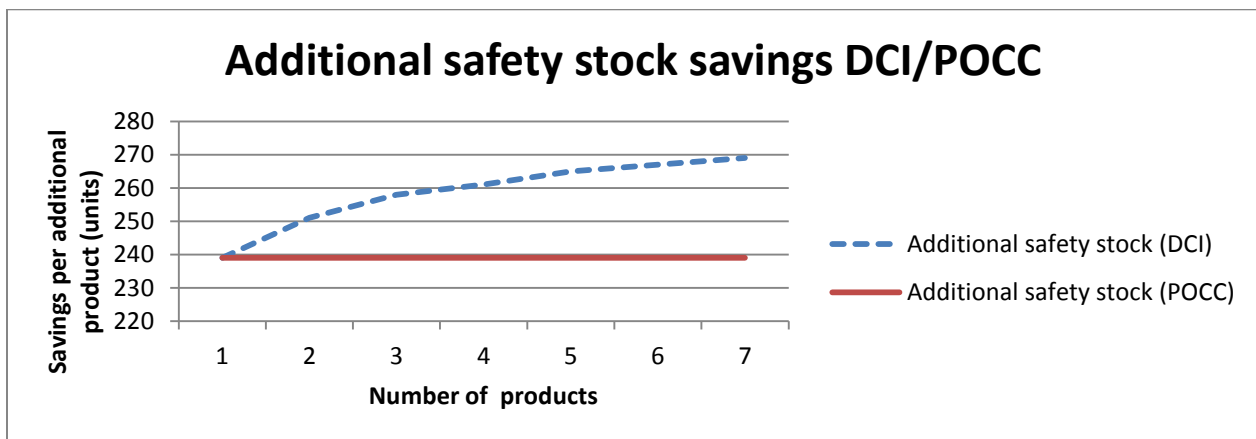
Figure 25: Additional safety stock savings DCI/POCC

This figure shows the safety stock savings when an additional product is added to the portfolio. As can be seen, the savings in safety stock investments increase with DCI and remain constant with POCC. This confirms the preference for high DCI over high POCC.

In this section the effects of component commonality on safety stock levels have been discussed, based on the empirical method described in the first section of this chapter. In the next section, the effects of component commonality on total inventory holdings will be discussed in line with the analysis on safety stock levels.

7.3 Effects of component commonality on total inventory levels

In this section the effects of component commonality on overall inventory holdings ($\bar{X}(t)$) will be discussed. Again, the two measures of component commonality will be used to assess the impact. First, the impact of the degree of commonality index is discussed in 7.3.1. Second, the impact of the percentage of component commonality is considered in section 7.3.2. Finally, the impact of both measures is tested to create a complete coverage of the four quadrants of the empirical method described.

7.3.1 Degree of commonality index

In the previous analyses the results are based on calculations. In this section, the results are based on model simulations. The simulations in this analysis are performed with the same parameter setting that has been used in the previous section $[D_j] = 50, \sigma[D_j] = 50, E[L_j] = 3, \sigma[L_j] = 0, E[L_i] = 3, \sigma[L_i] = 0, Q_i = 500$.

In the simulations of the model a total of 1800 periods have been considered for every parameter setting. An average was taken from 5 iterations to calculate the average inventory holdings. A total of five iterations per commonality scenario seems sufficient since the variation between simulation runs is small. For the effect analysis of DCI on inventory holdings, the component setting as explained in section 7.2.2 has been used: a product consists of two components and all additional products have one common component and one product specific component. The results of the analysis can be seen in Figure 26.
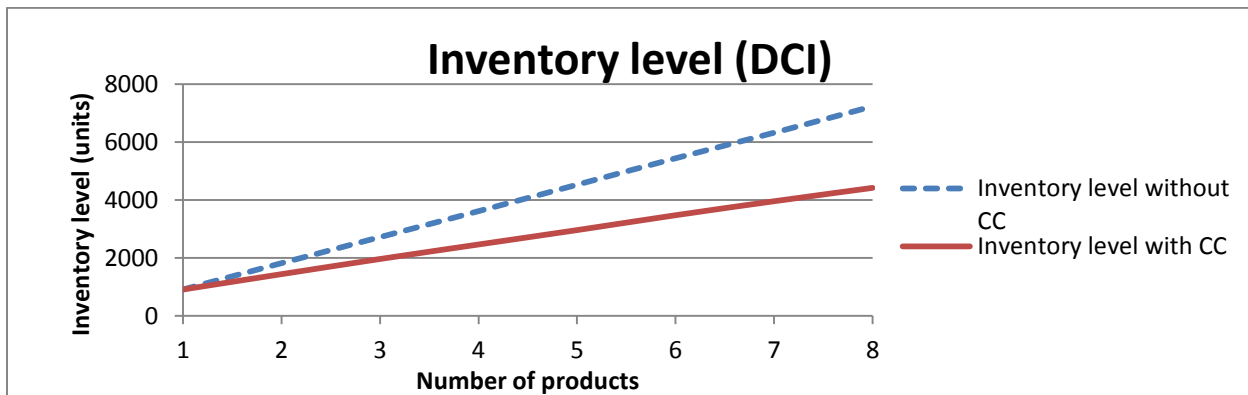
Figure 26: Inventory level (DCI)

Figure 26 shows that the inventory level with component commonality is significantly lower than the inventory level without component commonality, especially when the DCI is high. This analysis shows that a higher DCI results in lower inventory levels.

To assess the savings resulting from component commonality, the increase of inventory levels per additional product have been considered. The additional inventory required is plotted against the number of product in the portfolio; this can be seen in Figure 27. The increase of the inventory level with every product addition shows a downward sloping trend: with every product added to the portfolio the increase in additional inventory decreases. However, in the scenario without component commonality, the addition to the inventory level remains equal for all products added to the portfolio. This explains the increasing difference in net stock in Figure 26.
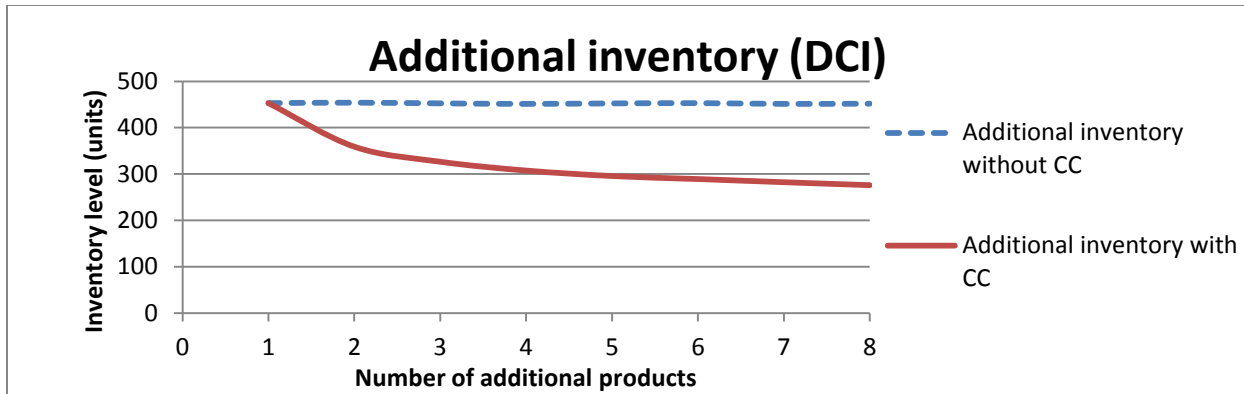
Figure 27: Additional inventory level (DCI)

The analysis reveals that component commonality (increased DCI) reduces the average inventory holdings. However, under what parameter settings component commonality is beneficial is not clear immediately, since the analysis is currently based on a single set of parameters. To make the analysis more robust, various parameters were altered to test the effect of component commonality on inventory holdings under different conditions. First the effect of order quantities on inventory levels has been considered by using various order quantities: $Q_i =$ 500, $Q_i = 1000$, $Q_i = 2000$ for all i. Order quantities are varied since they, in combination with safety stock levels, determine the overall inventory level. These results are depicted in Appendix J. This appendix shows that inventory levels increase with increased order quantities. However, in case of component commonality (increased DCI), the inventory levels are significantly lower. In case of large order quantities the overall inventory level is higher but the reductions in inventory as effect of component commonality are more significant. Component commonality seems mostly beneficial for inventory holdings when order quantities are high.

In addition to the sensitivity based on order quantities, the variability of demand is taken into account as well by varying the coefficient of variation of demand. This has been done based on the findings of the previous section on safety stock levels. The analysis on safety stock levels revealed larger benefits of component commonality when demand variability is high, due to the increased effects of demand pooling. This increased effect can be seen from the equations of section 7.1, concerning demand variability. The coefficient of variation has been set to three different values: small at 0.5, normal at 1.0 and large at 2.0. The measures of demand variability are high assuming a normal distribution of demand. However, the demand variability is set high to best show the effects of component commonality on inventory positions, since with relative low variability the effect is less well visible. This is done since the simulations do not allow for negative demands: negative demands are truncated to zero. The effects of different levels of demand variability can be seen in Appendix K.

Furthermore, the figures in Appendix K show that component commonality is more beneficial (DCI) when demand variability of components is high. Also, increasing the degree of commonality index increases the benefits of commonality to inventory levels; the difference between inventory levels with and without component commonality grows. In all cases of demand variability, the inventory levels with component commonality were lower than without component commonality. So, with lower inventory levels, the same performance of the system can be achieved, which confirms earlier findings. Again, considering the empirical model described in the first section of this chapter, the two bottom quadrants have been discussed. Increasing the degree of commonality index (DCI) results in lower inventory levels (Figure 26).

7.3.2   Percentage of component commonality

In this section the effects of component commonality measured by the percentage of component commonality (POCC) are considered. This corresponds with the quadrants on the left of the empirical method. Again, the initial setting as discussed in section 7.3.1 has been used. The findings of the analysis are depicted in Figure 28. The figure shows the total inventory level for the product setting as explained in Figure 20. The figure below shows the relation between the percentage of component commonality and the inventory level increase is linear and increasing since the POCC is increasing with every product introduction by 14.3 percentage points. The increase in inventory level in cases without commonality is larger than in cases with commonality, based on simulation results.
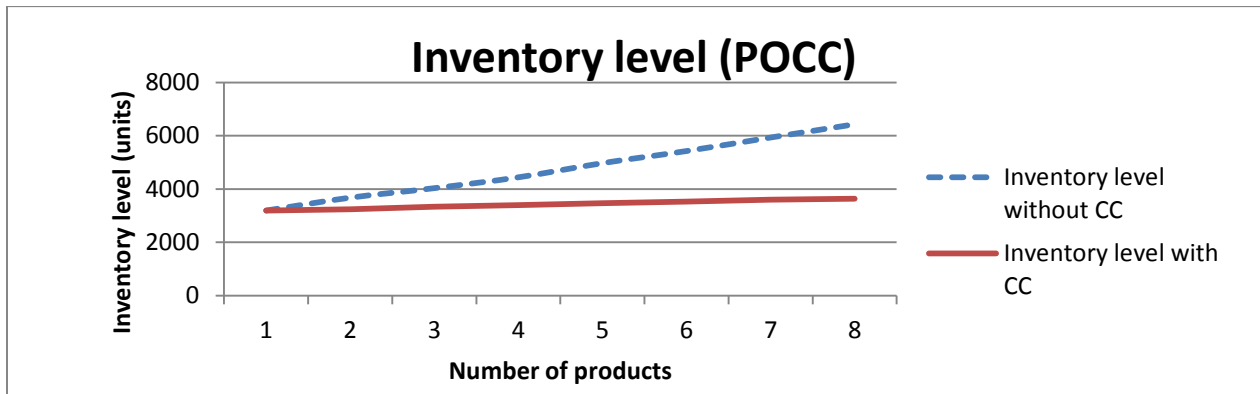
Figure 28: Inventory level POCC

As could be seen in the previous section about the effects of DCI on the inventory level, the additional inventory level for new products is non-linear. From this, it can be concluded that the effects on inventory levels can be larger with an increasing DCI measure, compared to an increasing level of POCC. The effects of order quantities and demand variability are considered in the Appendices (Appendix L and Appendix M). The figures in the appendices show that inventory levels with common components are in any case lower than inventory levels without common components. Increased demand variability raises the overall inventory level, which is the same conclusion as in the section on the effects of DCI on inventory levels. The POCC has been increased by adding new products to the product portfolio, which resulted in increased inventory levels. However, the figures in Appendix L show, the increase in common component inventory levels (with an increasing POCC measure) are less than the increase of non-common component inventory levels. This phenomenon holds for both the demand variability and the order quantities.

Returning to the empirical method described in section 7.1, the lower left, upper left and lower right quadrant have been considered. To complete the analysis, the upper right quadrant (quadrant 4) will be considered as well.
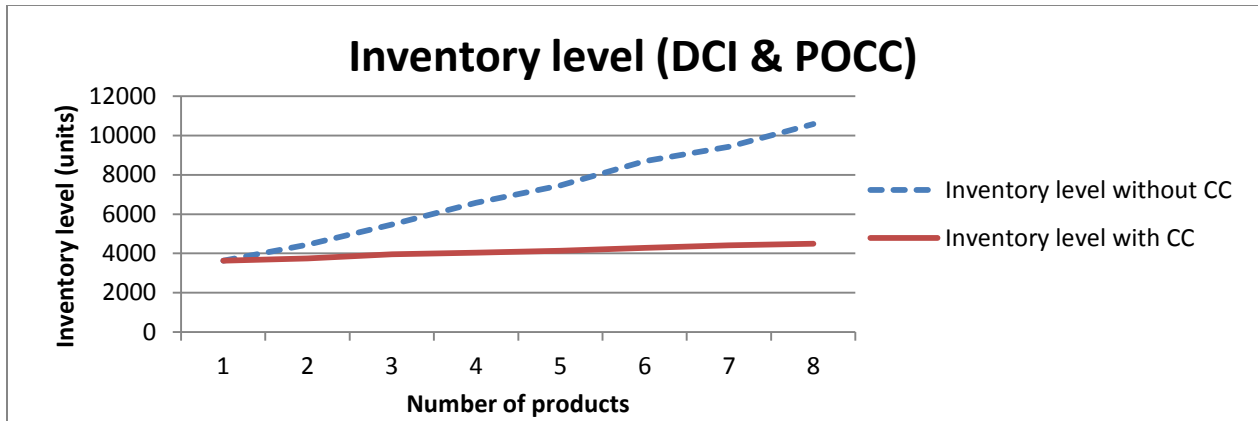
Figure 29: Aggregated inventory level with DCI and POCC

The figure above (Figure 29) shows a significant decrease in inventory levels when component commonality is introduced (increasing both DCI and POCC). With the introduction of new products the inventory level increases in both a scenario including and a scenario excluding common components. Introducing new components has been done, as is depicted in the matrices of Figure 23. However, the increase of inventory levels in case of common components is significantly lower than in case of non-common components. The savings in terms of the overall inventory level seem to be most significant when both the degree of commonality index (DCI) and the percentage of component commonality (POCC) are increased.

Since all quadrants have now been considered regarding inventory levels, a conclusion can be drawn on the effect of component commonality on inventory levels. The empirical method, as described at the beginning of the chapter, will be used. All the analyses regarding inventory levels show reductions in inventory levels when component commonality is introduced (both DCI and POCC). Increasing both the level of DCI and POCC revealed that most inventory savings could be obtained in this scenario. However, if the choice needs to be made whether to increase the DCI or the POCC, it is advised to increase the DCI measure when aiming for decreased inventory levels. More inventory savings can be obtained by increasing the DCI than by increasing the POCC.

So, from the analysis above it seems that the POCC makes a significant but relative small impact on inventory holdings compared to the DCI. The DCI measure can make a significant impact on total safety stock and total inventory levels when new products are introduced. The POCC already creates savings on both safety stock and inventory levels. However, to make a large impact, the DCI should be high (i.e., if components are common these should be used on a large number of products). The potential of DCI is based on the size of the product portfolio (total number of products) and the percentage of component commonality. This corresponds with the findings of (Gerchak et al., 1988), who find that commonality reduces the total inventory required to meet a specified service level. The optimal stock of common components is lower than the combined optimal stock it replaces.

The sensitivity of component commonality, both DCI and POCC, and its effect on various parameters was considered. First, the effects of the variability of component demand were tested using three scenarios; low variability, normal variability and, high variability of demand. Variability was measured by the coefficient of variation of demand (standard deviation divided by expected value of demand). The effects of component commonality on both safety stock levels and inventory levels seem to be largest in case of high variability. In this case, the effects of DCI are larger than the effects of the POCC. Low levels of variability have a smaller effect on both safety stock and inventory levels. From this sensitivity analysis, it shows that component commonality delivers most benefits to firms that have normal to large variability in demand. However, in case of demand

variability (low, normal or high), component commonality will always be beneficial to the service level. Only in case of deterministic demand, component commonality will not be beneficial in terms of safety stock, average inventory holdings and service levels.

Second, the effect of order quantities has been considered for inventory levels. The analyses with both the DCI and POCC measure show that with higher order quantities, the benefits of both DCI and POCC have been increased. The figures of the additional inventory level for DCI show that in case of large order quantities, commonality of components results in the largest reduction of inventory holdings. In case of small order quantities, the absolute decrease of net stock is less prominent. Considering the POCC, the additional stock needed per component and the benefits from adding a product to the portfolio remains equal. The most significant decrease in inventory, given both increased levels of DCI and POCC, can be explained by the pooling of demand. Instead of ordering some times, orders for common components are placed more frequent (assuming constant order quantities). The more frequent ordering lowers the overall inventory level. However, as is already mentioned in chapter 6, ordering and holding costs are not included in the model. Component commonality might be less beneficial for firms experiencing high ordering costs since ordering of common components becomes more frequent. For firms with relative high holding costs, component commonality might be better suited.

From the analysis it can be concluded that component commonality has most benefits in case of high demand variability and large order quantities. Cases of low demand variability and small order quantities prove to be less suitable for component commonality implementations. In these cases POCC shows the potential for component commonality but most benefits result from a large product base, measured with the degree of commonality index.

In the next section the cash position and possible effects of commonality will be discussed.

7.4   Effects of component commonality on cash flows

As explained in section 6.2, the relation between inventory holdings and a firm's cash position may require some additional attention. The benefits of component commonality as described in the previous sections can have its effects on the cash position of the firm. The operational cash flow is considered, based on the model described in section 6.2. In this section, the relation between the use of component commonality and the variability of the cash position will be considered. This is done by running multiple simulations with again 5 iterations of the model described in section 6.2. The analyses of the cash position will be structured according to the empirical research model described in section 7.1. First, the effects of degree of commonality index on cash positions will be discussed (lower quadrants 1 and 3). Second, the effects of the percentage of component commonality will be investigated (left quadrants 1 and 2). Finally, to cover all quadrants of the empirical model, both the DCI and POCC are increased (quadrant 4).

7.4.1   Cash position volatility

In this section the effects of component commonality on the volatility of the operational cash position will be considered. Volatility of the cash position is measured by the coefficient of variation of the cash position (Minton and Schrand, 1998), as discussed in section 6.2.2. In this analysis the following parameter setting was used as default setting: $[D_j] = 50, \sigma[D_j] = 50, E[L_j] = 3, \sigma[L_j] = 0, E[L_i] = 3, \sigma[L_i] = 0, Q_i = 500$. This parameter setting is consistent throughout all previous analyses as well.

For investigating the cash position, additional variables and assumptions need to be included. First, the initial cash position set at $t = 0$ is equal to 0 ($C(0) = 0$), and all components have a unit value of 1 ($v_i = 1\ for\ all\ i$) and are paid after 1 period ($t_i = 1$). The simulations assume that inventory levels are equal to the safety stock at $t = 0$, meaning investments in safety stock have already been made. As is clear from the default parameter setting, the component lead time is three ($E[L_i] = 3$). To allow for backorders and unfulfilled demand, demand and

production are decoupled by the introduction of the moment of shipment ($H_i(t)$). All components shipped from the firm are paid three periods later (a=3).

The model also describes margin for products, borrowing and opportunity costs. To introduce the cash position and its volatility these variables are introduced in latter analyses. First, a simple cash position will be considered. In Figure 30 below, the cash position of a product consisting of two components is depicted. Since products are sold against cost price (no margin) the cash position is generally below the initial cash position. Components are purchased (decrease in cash position) and sold later depending on product demand increasing the cash position back to its initial value. When almost all components have been sold and the cash position is almost back at its initial level, a new order is placed and the cash position decreases again. This explains why the cash position is below the initial cash position.
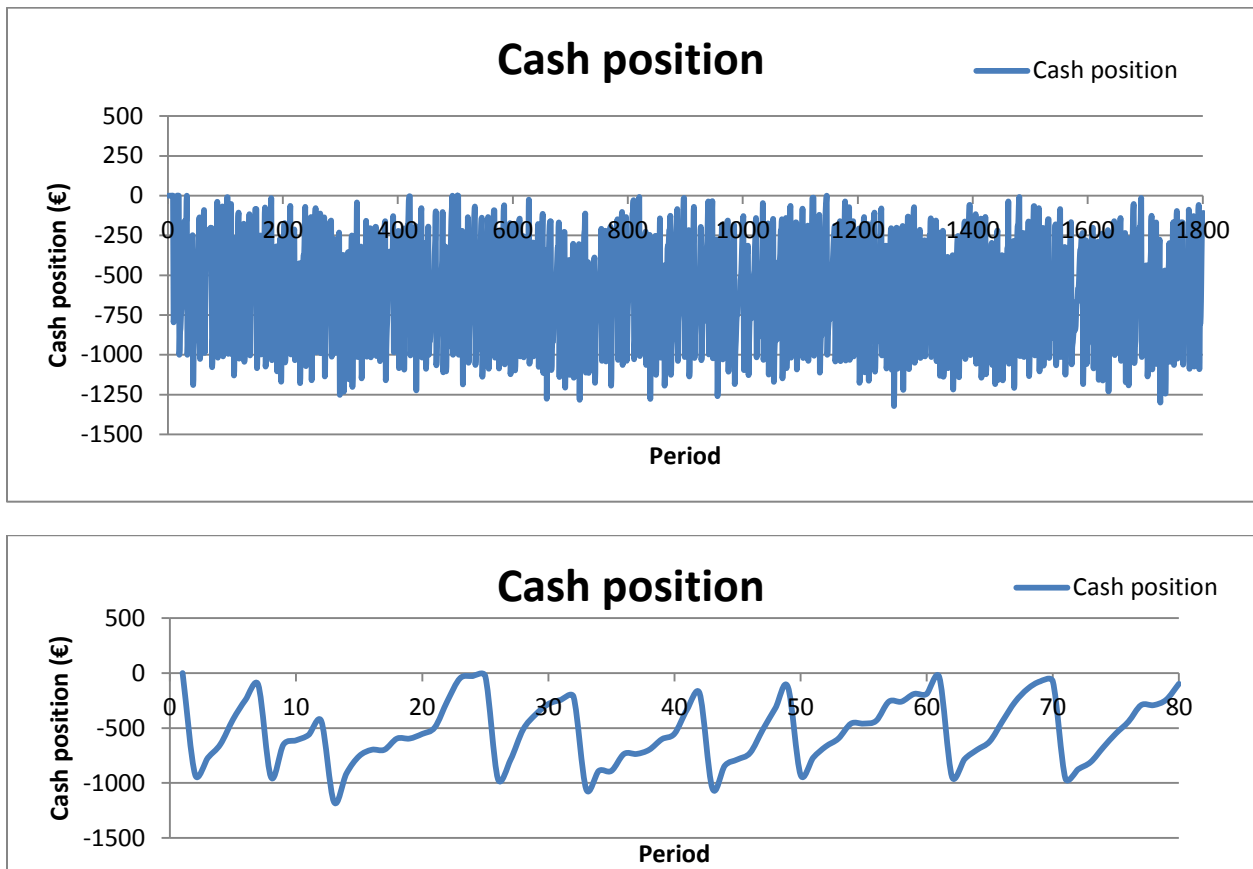
Figure 30: Cash position for a single product with two components (no margin)

However, when allowing margins to products, the cash position can grow. To cap the cash position, an upper limit is used to ensure unlimited growth of the cash position. For the analyses below, a margin of 10% (M=0.10) was used and a cash position limit of 1000. The addition of margin to the analysis changes the structure of the cash position. As Figure 31 shows the cash position now increases due to the effect of the margin, to the cash position limit. When the cash position limit is reached, the cash position is set to its original level and the difference is used for other purposes (e.g. savings, investments, payout to investors).
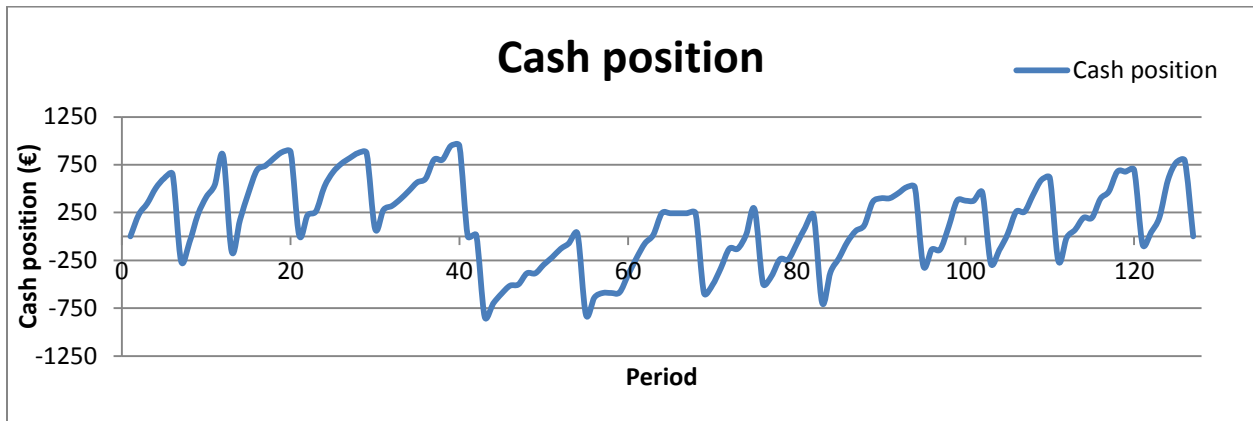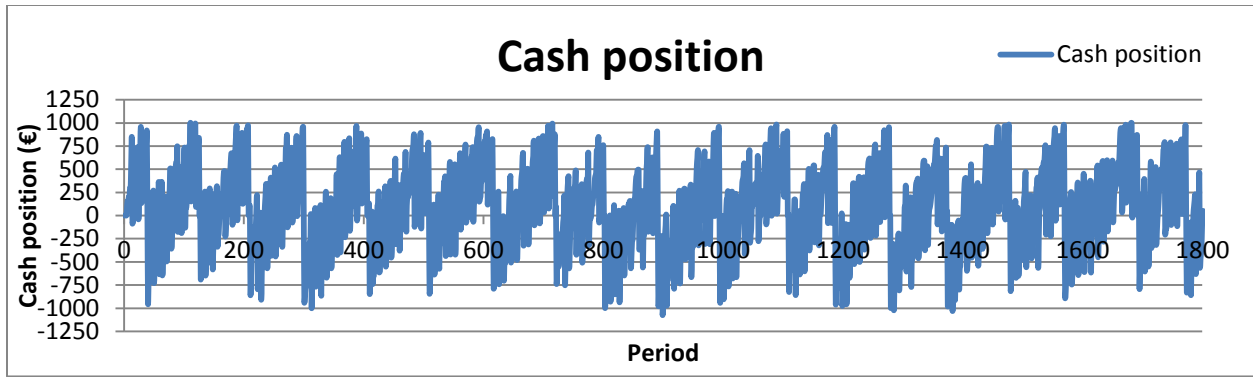
Figure 31: Cash position for a single product with two components including margin and cash position limit

The analysis shows that with a margin being introduced, the cash flow becomes closer to reality and the cash position varies around the initial cash position with an average approximating the initial cash position ($\bar{C} = 16.4$). However, as explained, this analysis provides an introduction in the model used to determine the effects of component commonality on the cash position.

This model set-up is used to analyze the effects of component commonality on the cash position. In the next sections, the DCI and POCC will be discussed.

7.4.2   Cash position and the degree of commonality index (DCI)

In this section component commonality is introduced in the form of the degree of commonality index (DCI). The effects of POCC will be described in the next section. The effect of increased DCI is depicted in Figure 32. In both parts of the figure, it is assumed that investments in safety stock already have been made, consistent with the model descriptions above. This figure shows that the average cash position (including margin) does not change in case of component commonality. However the cash position in case of common components shows less volatility (i.e. the standard deviation of the cash position drops). This can be seen by the higher peaks and lower dips of the cash position without component commonality (blue line). The number of periods in which the cash position limit was reached is very similar in cases with and without component commonality (resp. 39 and 41).

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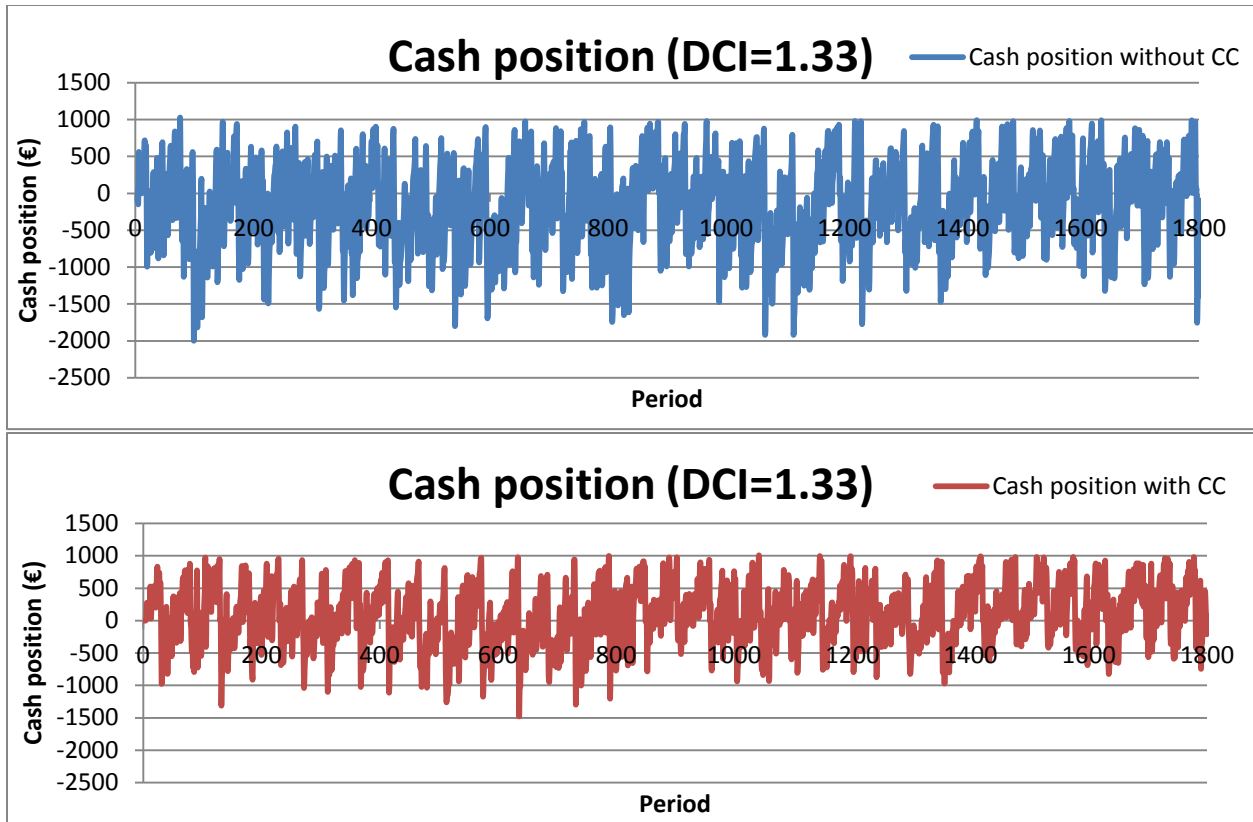
Figure 32: Cash position (DCI=1.33)

The first figure including component commonality (DCI), Figure 32, reveals that the average cash position remains equal with and without component commonality. However, the volatility of the cash position decreases when common components are introduced. To investigate whether the effect of the degree of commonality index holds for increasing levels of DCI, multiple analyses have been performed with increasing DCI levels. The results of these analyses, showing the effect of increased component commonality (DCI) on the cash position, are presented in the table below (Table 6), with $A_{i,j}$ setting the product structure as indicated in Figure 17.

Table 6: Cash position volatility with increasing component commonality (DCI)

No component commonality				Component commonality			
DCI	$A_{i,j}$	$\bar{C}(t)$	$\sigma(C(t))$	DCI	$A_{i,j}$	$\bar{C}(t)$	$\sigma(C(t))$
1.00	2,1	63	433	1.00	2,1	63	433
1.00	4,2	-95	562	1.33	3,2	51	401
1.00	6,3	-119	649	1.50	4,3	72	404
1.00	8,4	-151	748	1.60	5,4	62	377
1.00	10,5	-200	801	1.67	6,5	41	348

This table shows that the average cash position given increased component commonality is almost constant, based on simulation results, and the standard deviation of the cash position decreases. In cases without common components, the decrease in average cash position can be explained by the capping of the upper limit of the cash position. Since the volatility of the cash position increases, the downward dips become lower, while upper limits

stay equal (capped). The analyses show that in cases without common components, the standard deviation of the cash flow increases and in cases with common components, volatility of the cash flow decreases.

To investigate the effect of margins and cash position capping, the same analyses have been performed without margins and upper cash position limits. In these simulation results, the average cash position remained at a constant level. However, the standard deviation of the cash position in cases with and without common components showed very similar results, as is described in Table 6.

This can be explained by decreasing the cash position with every order for components. However shipment of components will result in a cash inflow. The average cash flow is independent of the number of components (with and without component commonality). Besides, the cash position volatility increases with the number of components in scenarios with and without component commonality. However, the increase of cash position volatility is greater in cases without component commonality included than in cases with component commonality when the DCI has been increased. This effect can be explained by the demand pooling effects as discussed in section 7.2. The demand to a common component is more stable (less deep dips and less high peaks): fewer fluctuations occur in comparison to non-common components. This has a direct effect on the cash position, since cash inflows are less volatile due to a more stable demand pattern. Also, cash outflows occur more regularly for common components due to increased demand of the common component which replaces demand of the non-common components, given constant order quantities.

Table 6 shows that cash position volatility decreases with increasing component commonality for cases with common components, but increases for cases without common components. However, the average cash position is independent of the increased commonality. The volatility of the cash position is measured by the coefficient of variation: standard deviation of the cash position over the average cash position (Minton and Schrand, 1998). The decreasing cash variability (standard deviation) for common components and the constant average cash position result in a decrease of the cash position volatility.

7.4.3 Cash position and the percentage of component commonality (POCC)

This section covers the effects of component commonality (POCC) on the cash position (quadrants 1 and 2). The analysis is similar to the analysis of DCI-effects on the cash position. The average cash position and standard deviation of the cash position for increasing levels of component commonality (POCC) are presented in Table 7, with low levels of DCI.

Table 7: Cash position volatility with increasing component commonality (POCC)

No component commonality				Component commonality			
POCC	$A_{i,j}$	$\bar{C}(t)$	$\sigma(C(t))$	POCC	$A_{i,j}$	$\bar{C}(t)$	$\sigma(C(t))$
0.00	4,1	-268	701	0.00	4,1	-268	701
0.00	5,2	-294	711	0.25	4,2	-162	594
0.00	6,3	-296	742	0.50	4,3	-116	524
0.00	7,4	-333	758	0.75	4,4	-124	474
0.00	8,5	-362	782	1.00	4,5	-93	471

The analysis shows decreasing levels of cash position variability when increasing the percentage of component commonality by the introduction of new products. The demand of common components, derived from the demand of non-common components, is again subjected to demand pooling effects. The average cash position drops slightly in case of increased component commonality (POCC). In cases without common components the variability and average of the cash position increase. The decrease in variability is slightly larger in case of

increasing POCC than in case of increasing DCI. However, considering the difference between cases with and without component commonality the DCI has a larger impact than the POCC when introducing new products.

Again, the effects of the cash position cap and the standard deviation of the cash position have been controlled for in an analysis using no margin and no cash position cap. This analysis revealed that cash position averages remained equal. Only the variability of the cash position increased without component commonality (POCC) and decreased with the introduction of common components.

7.4.4 Cash position and the percentage of component commonality (DCI and POCC)

In the previous sections, the bottom and left quadrants (1, 2 and, 3) of the empirical method have been considered. The analyses showed decreasing cash position variability in cases of increased DCI and POCC when introducing new products. The relative decrease in cash position variability as result from increased DCI is larger than the decrease in cash position variability as a result from increased POCC.
To investigate the combined effect of both DCI and POCC (quadrant 4), an analysis has been performed by increasing both measures with new product introductions, consistent with previous sections (see Figure 23).

The results of the analysis are shown in Table 8.

Table 8: Cash position volatility with increasing component commonality (DCI and POCC)

No component commonality				Component commonality			
DCI [POCC]	$A_{i,j}$	$\bar{C}(t)$	$\sigma(C(t))$	DCI [POCC]	$A_{i,j}$	$\bar{C}(t)$	$\sigma(C(t))$
1.00 [0.00]	4,1	-248	698	1.00 [0.00]	4,1	-248	698
1.00 [0.00]	6,2	-283	784	1.50 [0.50]	4,2	-168	585
1.00 [0.00]	8,4	-312	867	2.00 [0.75]	4,3	-93	493
1.00 [0.00]	10,4	-356	904	2.50 [1.00]	4,4	42	402

The table shows that with increasing levels of component commonality, increase in both DCI and POCC, the variability of the cash position drops most significantly. In similar equal scenarios without common components, the variability of the cash position increases.
Again, with increasing variability the average cash position increases, due to the cash position cap as has been discussed above. The opposite effect can be seen in case of component commonality: the decreasing variability decreases the average cash position due to the same effect.

These three analyses (increasing DCI, POCC and DCI&POCC) reveal that a combination of increased DCI and POCC result in the most significant decrease of cash position volatility in comparison to a scenario without component commonality. Both an increased DCI and increased POCC measure create a more stable cash position, defined by less high peaks and less low dips in the cash position. However, choosing between increasing DCI and increasing POCC, the analyses show preference for increasing DCI. This effect can be explained by the demand pooling effect, which shows a more stable demand pattern for common components for increased DCI.

7.4.5 Borrowing and opportunity costs

In this section, the effects of the findings on borrowing and opportunity costs will be considered. The previous sections showed that increasing component commonality does have a small effect on the average cash position level but decreases the volatility of the cash position, resulting in a more stable cash position. Section 6.2.3 covers the cash position and the effects on external financing. Borrowing costs are incurred when the cash position becomes negative, and external (short term) finance is required when invoices are due. Opportunity costs are

based on positive cash positions. It is assumed that operational cash does not earn interest or cannot be used for other purposes.

In the analyses the average cash position is varies around zero and drops below zero when margins for components, and the cash position limit are introduced. Assuming an average cash position of zero, all peaks above zero incur opportunity costs and all dips (below zero) incur borrowing costs. In case of component commonality, the cash position becomes more stable (less high peaks and less deep dips). This decreases both borrowing costs and opportunity costs, given the average cash position of zero and assuming borrowing costs and opportunity costs are equal.

In case of relative high opportunity costs (opportunity costs > borrowing costs), it is beneficial to borrow funds when required and decrease the initial cash position. This balances the opportunity and borrowing costs. The other way round, when borrowing is relatively expensive (borrowing costs > opportunity costs) the cash position needs to be lowered. However, in all cases it is beneficial to create a more stable cash position to minimize the effect of both costs combined.

Component commonality results in a less volatile cash position, reducing the need of external financing. External (short term) financing will be required when the cash position becomes negative. In case of a more stable cash position, the possibility of negative cash positions and the amount of external funds required would both decrease. Opportunity costs will be used to prevent unrealistic high cash positions to balance borrowing costs.
Due to time constraints, no simulations have been performed to analyze the effect of cash position characteristics (average and variability) on borrowing and opportunity costs. The effects are recommended for future research.

As was discussed in section 6.2, Skolnik (2007) investigates the relationship between inventory reduction and increased cash balances. Before starting the analysis of the effects of component commonality on the cash position, the robustness of both component commonality measures (DCI and POCC) has been tested. The component commonality measures proved to be consistent in similar component commonality settings. The structure of the matrix proved to be irrelevant for the outcome of the component commonality measures and for the model outcomes.
First, the two measures where used to investigate the effect of component commonality on safety stock, by calculating these effects from the formal model representation. From the calculations it is concluded that safety stock levels are structurally lower in cases with component commonality given equal service level requirements. The analysis showed that increasing both measures results in the most savings in safety stock. From the two component commonality measures described, increasing DCI had most impact on safety stock level savings in comparison to the percentage of component commonality. Also, higher levels of demand variability increased the reduction of safety stock levels under conditions including component commonality.

Besides the calculations on safety stocks, the total inventory holdings where simulated under scenarios with and without component commonality. These analyses showed results comparable with the results on safety stocks. The average inventory holdings decrease when component commonality is introduced. More component commonality (measured by both DCI and POCC) leads to lower levels of the inventory level. The lower inventory levels free investments in inventories. Again, the effect of both measures combined is greatest and when choosing between DCI and POCC, an increase in DCI is preferred over POCC in terms of inventory savings.

As Skolnik (2007) indicated, the freed inventory investments are likely to result in increased cash positions. To investigate this effect, the financial model of 6.2 was used to perform simulations. From this analysis I conclude

that in cases with component commonality, the required cash position does not change in comparison to cases without component commonality. However, the cash position becomes less volatile when component commonality is introduced, meaning less deep dips and less high peaks. The analyses on component commonality effects on cash flows showed that increasing both the DCI and POCC results in the most stable cash position. When considering DCI and POCC, increasing the DCI is preferred in terms of cash position stability over increasing the POCC.

A more stable cash position is preferred by the introduction of borrowing and opportunity costs since it minimizes the total costs incurred. The required short term financing needs becomes less due to less deep dips, and opportunity costs decrease due to less high peaks.

These findings of the effect of increased component commonality on safety stock levels, average inventory holdings and, the cash position, show that the freed inventory investments are not required for increasing cash position levels and cash positions become more stable reducing the dependence on external finance.

8   Conclusion, limitations, implementation and recommendations

In this chapter the conclusion, limitations and possible implementation of the analysis will be set out. Also, recommendations for further research will be provided. Section 8.1 provides the main conclusions to the research questions as described in chapter 3. Also, the limitations of the research will be described, followed by the directions for implementation in section 8.2. Finally, directions for future research will be provided in section 8.3.

8.1   Conclusion

This study focusses on the use of component commonality to increase control over both the inventory level and cash position. For this purpose, an inventory model was adapted to facilitate both component commonality and cash flows. This conclusion provides an answer to the main research question:

What possible benefits in inventory can be achieved if component commonality becomes a more dominant requirement in product development, and if so, what is the impact on the cash position?

In order to answer this question, five sub-questions have been that will be answered first. By answering the first sub-questions, insights are provided in the current level of inventories and its characteristics:

- *Given the current level of inventory and the indicated inventory categories, what are the characteristics of inventory at AME (value distribution and functional inventories)?*

As is clear from the results of chapter 5, the inventory of AME constitutes a significant percentage (22-25%) of the firm's assets. Most inventories of AME consist of components (77% of inventory value, 80% of all stock keeping units). The remaining 20% of inventory consists of sub-assemblies and other resources.   The majority of components held by AME are low-value components with a value between €0.01 and €2.00. The total value of these low-value components is almost 80% of all components and 60% of total inventory investments.

Secondly, a benchmark has been set by investigating the current situation concerning component commonality. The analyses have been performed on products manufactured between June and December of 2013, to ensure only relevant products were included. This analysis makes it possible to answer the next research question:

- *What is the current level of component commonality of the inventory?*

The analyses of sections 5.1 and 5.2 show that the majority of the components (52.4%) is used multiple times in the product portfolio of AME. However, common components are used in a limited number of major-subassemblies or final products. On average, common components are used in 5 of the 235 products under consideration. Furthermore, the analyses revealed that the cheapest components show slightly more component commonality than other components. However, more expensive components show potential for component commonality due to relative high POCC levels, but do not utilize the advantages of component commonality due to the low DCI. For these more expensive components technical feasibility needs to be considered in order to determine possible implementation of component commonality.

To analyze the effects of component commonality, an inventory model was expanded. The model has been used to analyze the effects of component commonality on safety stocks and total inventory holdings in order to answer the third sub-question:

- *Based on the possible effects of component commonality, determine the inventory effects of component commonality on safety stocks and overall inventory holdings when increasing the use of commonality?*

The analyses into the effects of component commonality are based on an empirical method, as described in 7.1. The model assumes four quadrants with different settings of component commonality: low DCI & low POCC, high DCI & low POCC, low DCI & high POCC and high DCI & high POCC. Based on the analyses, most safety stock reductions can be achieved with a high DCI and high POCC. From the analysis it was clear that in the case of low DCI and low POCC the savings are least. When deciding between the two remaining quadrants (high DCI & low POCC or low DCI & high POCC), most savings can be made in the quadrant where DCI is high and POCC is low: the effects of demand pooling of multiple products for a single component are larger than many components being used twice.

The analyses regarding overall inventory levels show reductions in inventory levels when component commonality is introduced (both DCI and POCC). Again, increasing both the DCI and POCC revealed the highest inventory savings. However, when choosing between increasing DCI or POCC, it is advised once more to increase the DCI. The DCI measure can make a significant impact on total safety stock and total inventory levels when new products are introduced. The percentage of common components already creates savings on both safety stock and inventory levels. However, to make a large impact the degree of commonality index should be high (i.e. if components are common these should be used on a large number of products).

In order to answer the dual research question, the effects of component commonality on the cash position have been considered as well, as is stated in the following sub-section:

- *Based on the possible effects of component commonality on inventory investments, what is the impact on the cash position?*

The analyses performed in section 7.4 reveal that a combination of increased DCI and increased POCC result in the most significant decrease of cash position volatility, in comparison to a scenario without component commonality, as it creates a more stable cash position defined by less high peaks and less low dips in the cash position. However, choosing between increasing DCI and increasing POCC, the analyses show yet again a preference for the degree of commonality index. This effect can be explained by the demand pooling effect, which shows a more stable demand pattern for common components for increased DCI. The average cash position does not change in scenarios with and without component commonality, resulting in a less volatile cash position measured by the coefficient of variation.

Fifth, based on the analyses of component commonality effects on safety stock, overall inventory and cash positions, the relation to external financing has been discussed. With this analysis the following sub-question can be answered:

- *What is the impact on short term financing needs (cash position) of implementing increased component commonality?*

Component commonality results in a less volatile cash position, reducing the need of external financing. External (short term) financing will be required when the cash position becomes negative. In case of a more stable cash position, the possibility of negative cash positions and the amount of external funds required would both decrease. Opportunity costs will be used to balance borrowing costs, in order to prevent unrealistic high cash positions. The dependence on short-term financing needs decrease when component commonality becomes more dominant.

Following the answers to the sub-questions, I conclude that increasing the level of component commonality reduces not only safety stock levels under equal service-level conditions, but also reduces the total inventory holdings. Increased component commonality only has a stabilizing effect on the volatility of the cash position.

However, component commonality does not have an effect on the average cash position. The investments freed by decreasing overall inventory levels can be reinvested elsewhere and do not have to be reinvested in the cash position.

8.2   Limitations and recommendations

The simulation setup and the variable setting have been chosen to reduce firm blindness. Still, the results presented in this study do strongly depend on the input parameters. The parameters settings have been well considered but are not tailored to the actual situation at AME. For that reason, the simulation results show the effects of component commonality in more general terms. This means that no specific savings in inventory investments of reduction in cash position variability can be derived from the model simulations. To gain more insight in the numerical effects of component commonality on inventory holdings and the cash position it is required to parameterize the variables used. Since the parameter settings will vary between components and products it is advised to start with a relative small sample of products and assess the effects of component commonality. When the effects of component commonality between the selected products and components is clear, these findings can be generalized or additional analysis with different component can be performed to numerically show the total effects of component commonality.

The current model allows for various parameter settings and can therefore be applied to a broad set of analyses. However, the current model does not allow for operational costs (holding, handling, ordering costs). The analysis does not show the costs of the chosen component commonality setting and for that reason the parameter setting might not result in a cost optimal scenario of component commonality.
Operational costs should be included in the model to ensure a balanced component commonality setting. Component commonality proved to be most beneficial in situations with large order quantities. However, large order quantities are less beneficial in cases with high inventory holding costs and low ordering costs. To test these effects on the component commonality settings, these costs need to be included in the model.

In the current calculations and simulation results, no distinction has been made between different types of components (e.g. tapes and non-tapes). The analysis on the current inventory situation has shown various component categories. However, in the analysis on the effects of component commonality all components have been assumed equal and no distinction has been made into different component categories. Also, products have been considered equal; no distinction has been made between products developed at AME and product developed externally.
In addition to model improvements and parameterization of the firm's variables to calculate costs and revenues, product categories and component categories need to be considered to indicate the best possible use of component commonality. In this analysis a clear distinction should be made between products developed at AME and externally developed products.

Summarized, three recommendations are provided:

- Parameterization of firm variables to determine the numerical costs and revenues of increased component commonality implementation.
- Model improvements to facilitate the use of operational costs (e.g. holding, handling and ordering costs) to obtain a better estimation of the component commonality effects.
- Create a clear distinction of products and components, and analyze the effects of component commonality per product category in order to assess the best possible direction for implementation.

The recommendations provided could improve the research. It is interesting to provide the firm with business cases whether or not to implement increasing levels of component commonality to certain categories of products and/or components. Also, the extension of the model, including operation costs, would be interesting to investigate further to gain better insights in the effects of component commonality on operational tradeoffs.

8.3   Directions for implementation

In this section, directions for implementation are described given the current level of component commonality at AME. The analysis showed that slightly more than half of the components at AME are common and that common components are, on average, used in 5 products or major sub-assemblies. The situation of AME is depicted in the quadrants of the empirical method below (Figure 33).
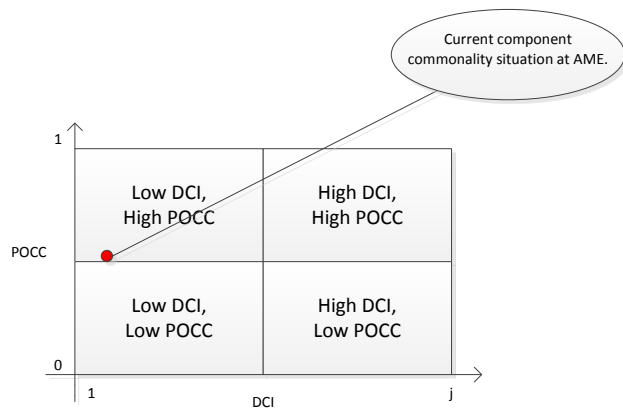
Figure 33: Current component commonality situation at AME.

The figure shows that the level of percentage of component commonality is on the line between low and high POCC. However, DCI is low. This indicates a large potential for improvement of the degree of commonality index. AME should focus on increasing the number of products a component is used for. With the introduction of new products and components, it is beneficial to select components that are already being used for production. The introduction of new components should not be preferred for component commonality reasons.

Component selection at AME is done in the early phases of new product development, as is described in section 2.2. In the component selection, not only the technical aspects and costs aspects should be considered but also whether or not the component is already available at AME.

Non-common components in the current inventory of AME need to be considered to determine whether it is beneficial to redesign products to allow for increased component commonality. To determine the savings of component commonality and provide the firm with a business case for a redesign, the model has to include operational costs. Besides, the model needs to be parameterized to represent the actual situation of AME. These recommendations are also described in the previous section. However, the analysis of the simulation results shows that components with large demand variability and/or large order quantities benefit most from component commonality. This is a good initial direction for an investigation into a specific group of components.

Apart from the reductions in inventory investments and the reductions in the volatility of the cash position, component commonality has additional benefits that can be of value to AME. Management of components will become easier due to the decrease or declining increase of the number of components under management. Also, component commonality allows for a more thorough component selection due to data already available. Although component commonality may seem disadvantageous in case of obsolescence, it can be advantageous since the

common component allows for an in-depth selection of possible alternative components due to the decrease in number of components under management.

These directions for implementation show possibilities for AME to introduce component commonality as a more dominant requirement in component selection. Besides, these directions show which components are most useful for further analysis.

9   References

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10 Appendices
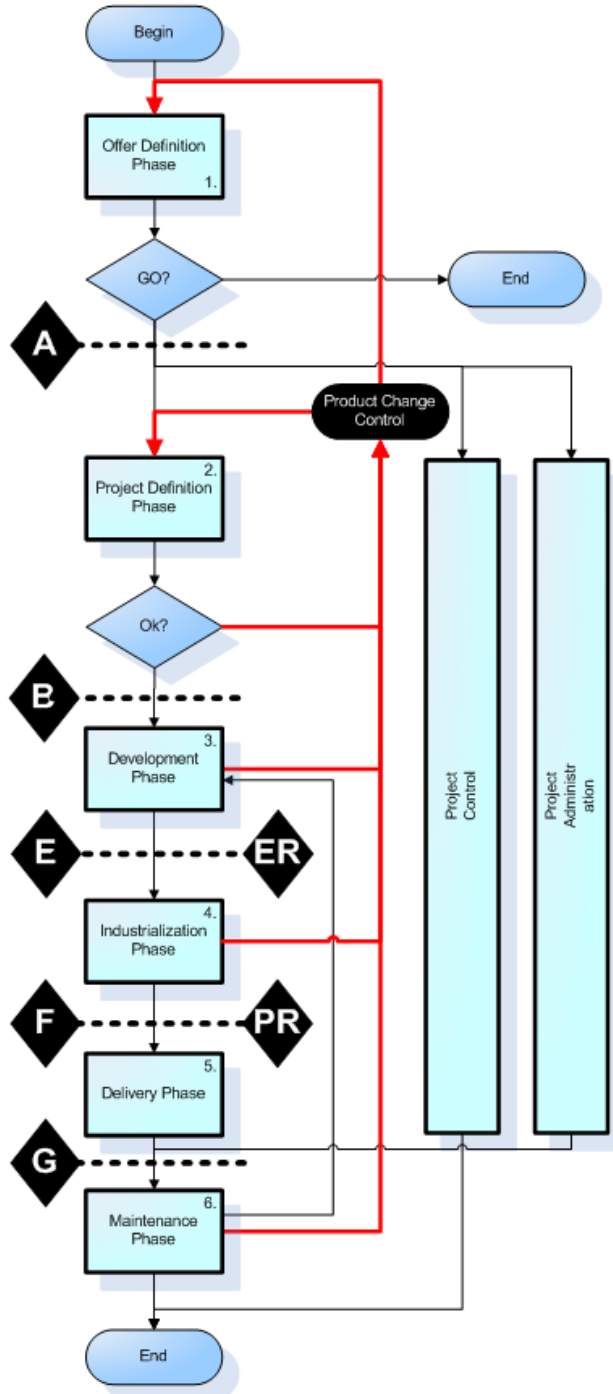
Value of SKUs

Legend: ■ Value of SKUs

Y-axis:
- €600.000,00
- €500.000,00
- €400.000,00
- €300.000,00
- €200.000,00
- €100.000,00
- €-

X-axis categories:
- €0 - €0,1
- €0,1 - €0,5
- €0,5 - €1
- €1 - €2
- €2 - €5
- €5 - €10
- €10 - €25
- €25 - €50
- €50 - €100
- €100 - €250
- €250 - €500
- €500 - €1000
- €1,000 - €100,000

Inventory value per functional component category [Passive]

Inventory value per functional component category [Discrete]
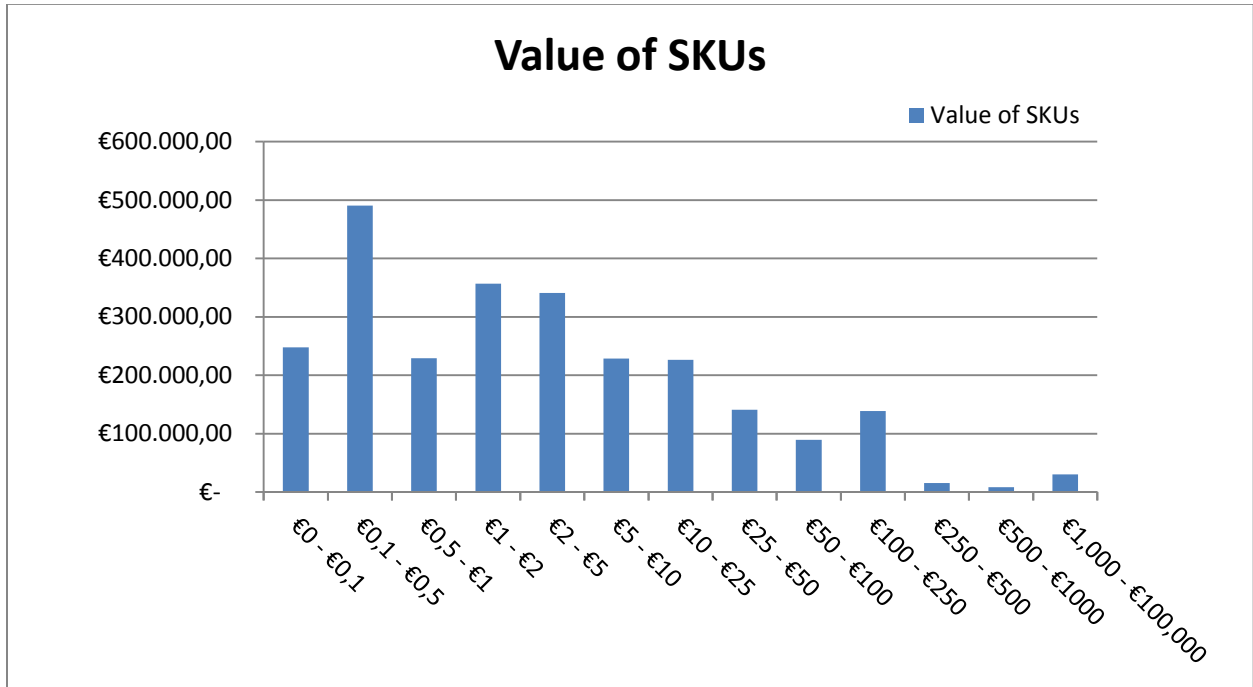
Inventory value per functional component category [Analog]
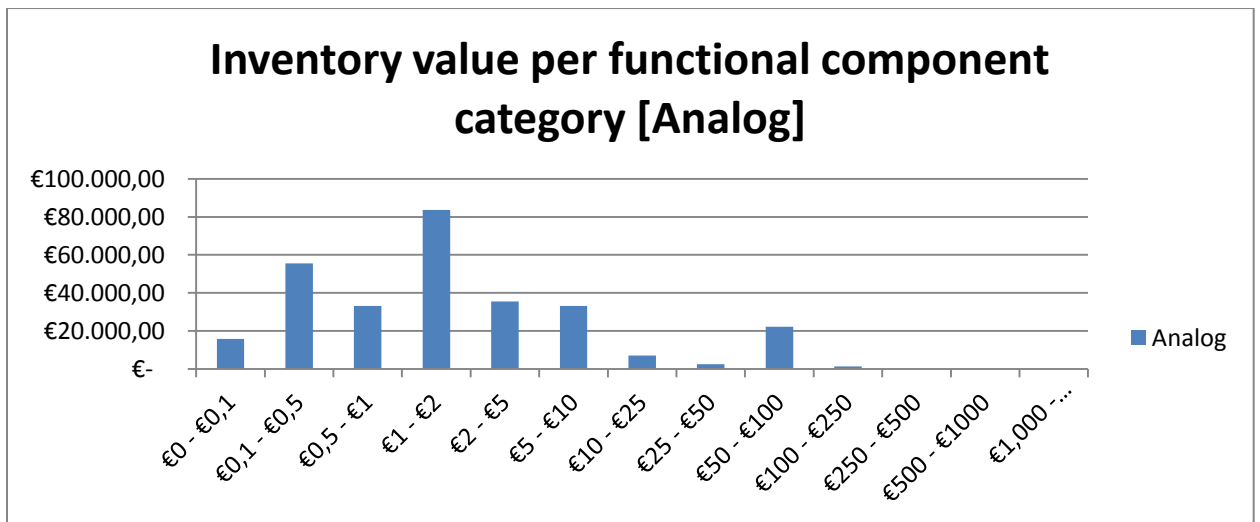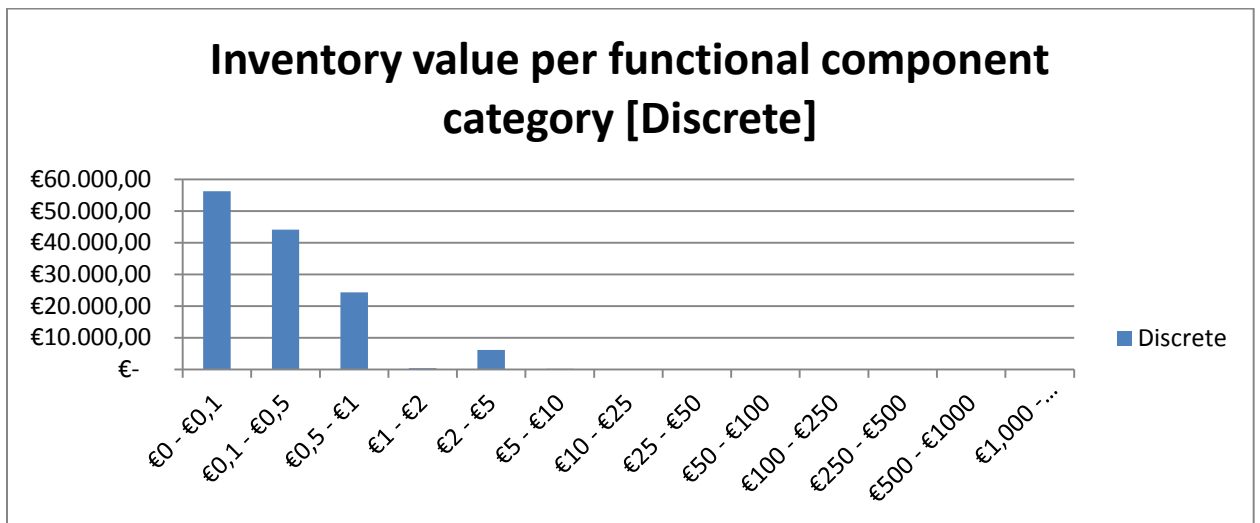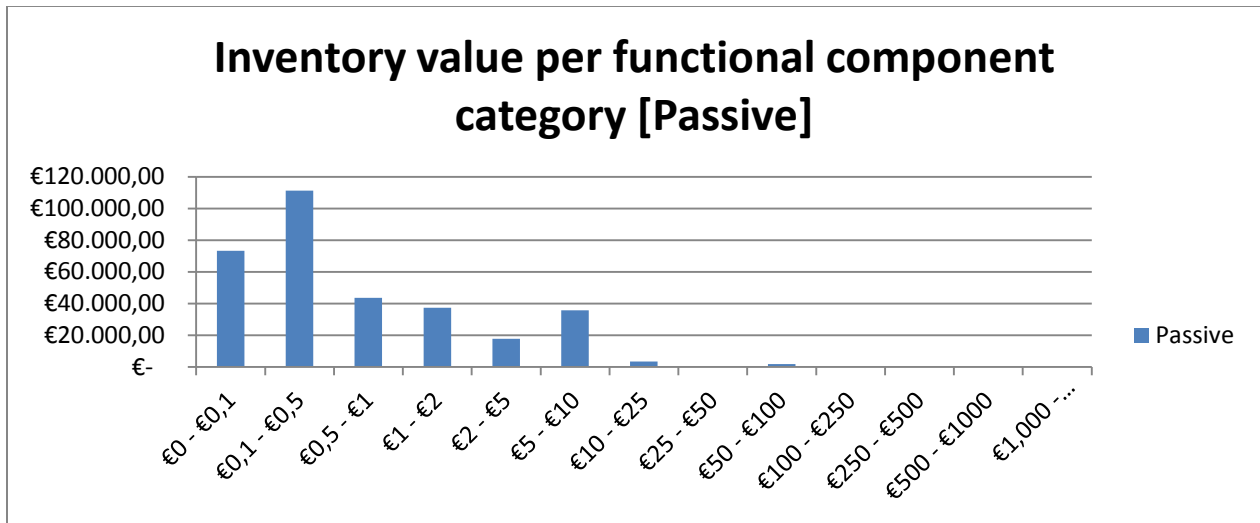
Inventory value per functional component category [Digital]
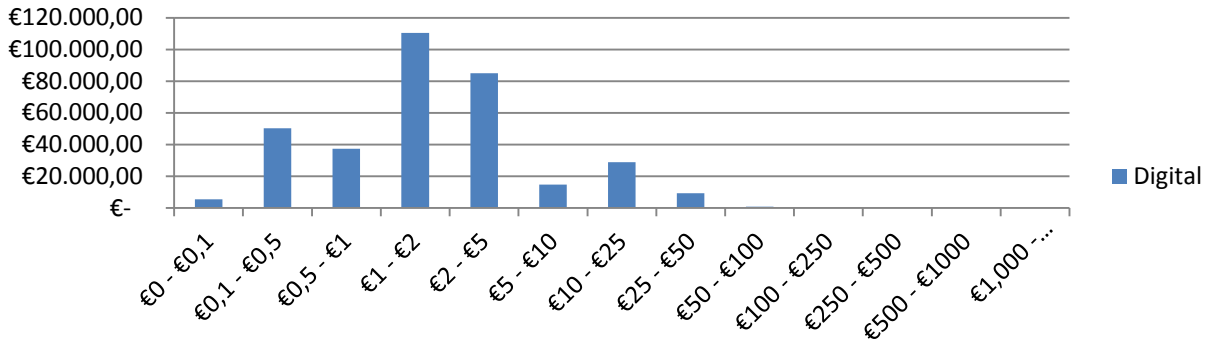
Inventory value per functional component category [Electromechanical]
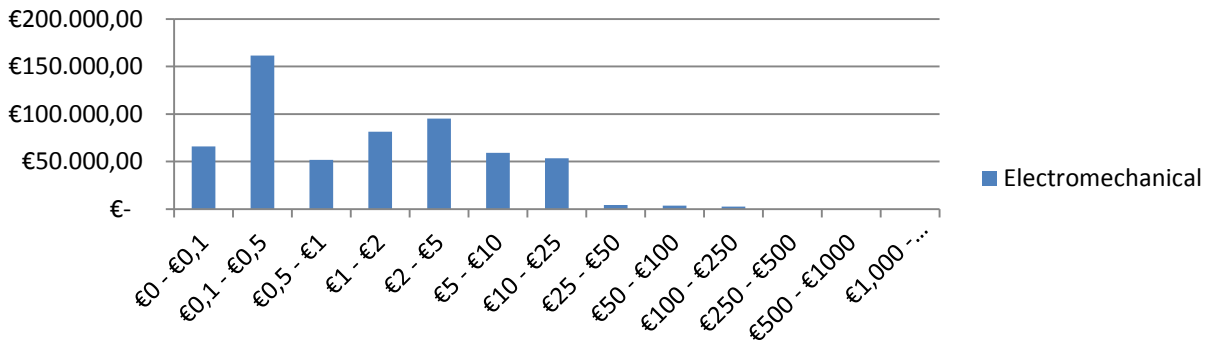
Inventory value per functional component category [Sub-Assemblies]
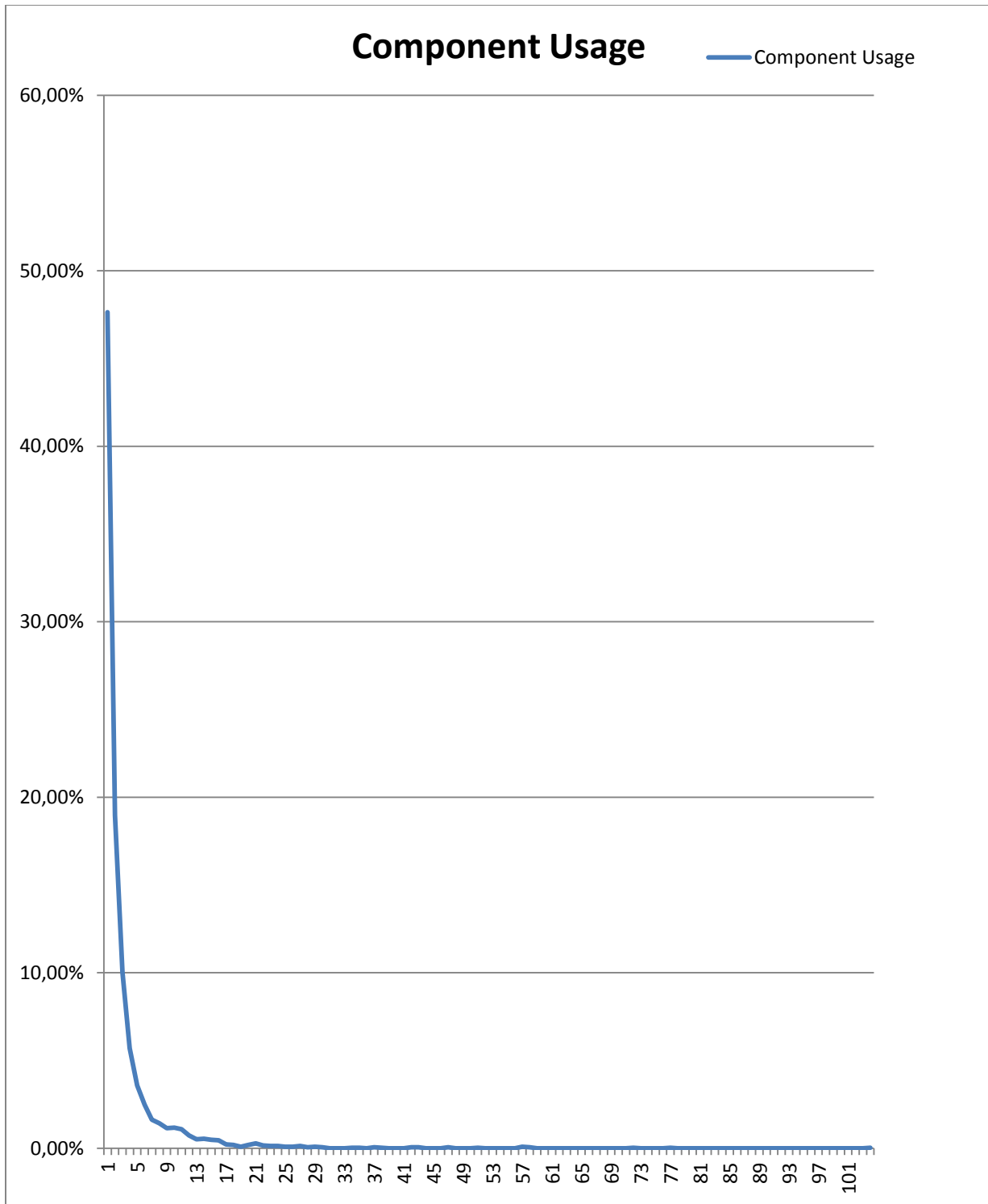
Appendix E: Component commonality matrices with DCI and POCC calculations (low DCI, low POCC)

Matrices in which component commonality is limited DCI=1 and POCC=0

$$\begin{pmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{pmatrix} = \frac{DCI=1}{POCC=0}$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1}{POCC=0}$$

$$\begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix} = \frac{DCI=1}{POCC=0} \quad \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1}{POCC=0}$$

Matrices in which DCI < 0.5j+0.5 and POCC < 0.5 (with j the number of products)

$$\begin{pmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.17}{POCC=0.17} \quad \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.17}{POCC=0.17} \quad \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 1 \end{pmatrix} = \frac{DCI=1.17}{POCC=0.17}$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.17}{POCC=0.17} \quad \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.17}{POCC=0.17} \quad \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.17}{POCC=0.17}$$

Matrices in which DCI < 0.5j+0.5 and POCC ≥ 0.5 (with j the number of products)

$$\begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.67}{POCC=0.67} \quad \begin{pmatrix} 1 & 0 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.67}{POCC=0.67} \quad \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{pmatrix} = \frac{DCI=1.67}{POCC=0.67}$$

$$\begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix} = \frac{DCI=1.83}{POCC=0.83} \quad \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix} = \frac{DCI=1.83}{POCC=0.83} \quad \begin{pmatrix} 1 & 0 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 0 \end{pmatrix} = \frac{DCI=1.83}{POCC=0.83}$$

$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} = \frac{DCI = 1.75}{POCC = 0.75} \quad \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \end{pmatrix} = \frac{DCI = 1.75}{POCC = 0.75} \quad \begin{pmatrix} 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 \end{pmatrix} = \frac{DCI = 1.75}{POCC = 0.75}$$

Matrices in which DCI ≥ 0.5j+0.5 and POCC < 0.5 (with j the number of products)

$$\begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \end{pmatrix} = \frac{DCI = 1.50}{POCC = 0.50} \quad \begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} = \frac{DCI = 1.50}{POCC = 0.50}$$

$$\begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} = \frac{DCI = 2.50}{POCC = 0.50} \quad \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} = \frac{DCI = 2.50}{POCC = 0.50} \quad \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{pmatrix} = \frac{DCI = 2.50}{POCC = 0.50}$$

Matrices in which DCI ≥ 0.5j+0.5 and POCC ≥ 0.5 (with j the number of products)

$$\begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 0 & 1 \end{pmatrix} = \frac{DCI = 1.75}{POCC = 0.75} \quad \begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 1 & 1 \end{pmatrix} = \frac{DCI = 1.75}{POCC = 0.75} \quad \begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 0 & 1 \\ 1 & 1 \end{pmatrix} = \frac{DCI = 1.75}{POCC = 0.75}$$

$$\begin{pmatrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} = \frac{DCI = 2.17}{POCC = 0.83} \quad \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix} = \frac{DCI = 2.17}{POCC = 0.83} \quad \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \\ 1 & 1 & 0 \end{pmatrix} = \frac{DCI = 2.17}{POCC = 0.83}$$

$$\begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \end{pmatrix} = \frac{DCI = 3.13}{POCC = 0.88} \quad \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \end{pmatrix} = \frac{DCI = 3.13}{POCC = 0.88} \quad \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{pmatrix} = \frac{DCI = 3.13}{POCC = 0.88}$$

Appendix F: Dashboard of Excel model

Number of Products	Number of Components		Iterations		Income term	
2	8		1800		5	

Create Commonality Matrix	Product 1		Product 2	
	R	1	R	1
	E[DP1]	50	E[DP2]	50
Calculate Component Commonality and Create Input Fields	sigma[DP1]	10	sigma[DP2]	10
	E[LP1]	3	E[LP2]	3
	sigma[DL1]	0	sigma[DL2]	0
	Q	500	Q	500
Calculate Parameters	E[D1(0,L]]	150	E[D2(0,L]]	150
	sigma[D1(0,L]]	17	sigma[D2(0,L]]	17

Create Data	Component 1		Component 2		Component 3		Component 4		Component 5	
	R	1	R	1	R	1	R	1	R	1
	E[DP1]	50	E[DP2]	50	E[DP3]	50	E[DP4]	50	E[DP5]	50
Create Financial Data	sigma[DP1]	10	sigma[DP2]	10	sigma[DP3]	10	sigma[DP4]	10	sigma[DP5]	10
	E[LP1]	3	E[LP2]	3	E[LP3]	3	E[LP4]	3	E[LP5]	3
	sigma[DL1]	0	sigma[DL2]	0	sigma[DL3]	0	sigma[DL4]	0	sigma[DL5]	0
	Q	500	Q	500	Q	500	Q	500	Q	500
	E[D1(0,L]]	150	E[D2(0,L]]	150	E[D3(0,L]]	150	E[D4(0,L]]	150	E[D5(0,L]]	150
	sigma[D1(0,L]]	17,3205	sigma[D2(0,L]]	17,32050808	sigma[D3(0,L]]	17,321	sigma[D4(0,L]]	17,321	sigma[D5(0,L]]	17,321
	s	214,924	s	214,9	s	214,9	s	214,92	s	214,92
	P1 service C 1	0,939	P1 service C 2	0,939	P1 service C 3	0,939	P1 service C 4	0,939	P1 service C 5	0,9282
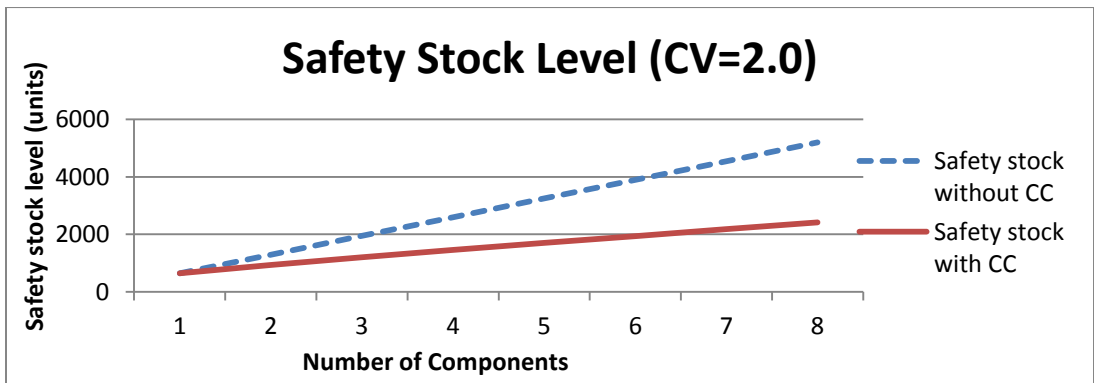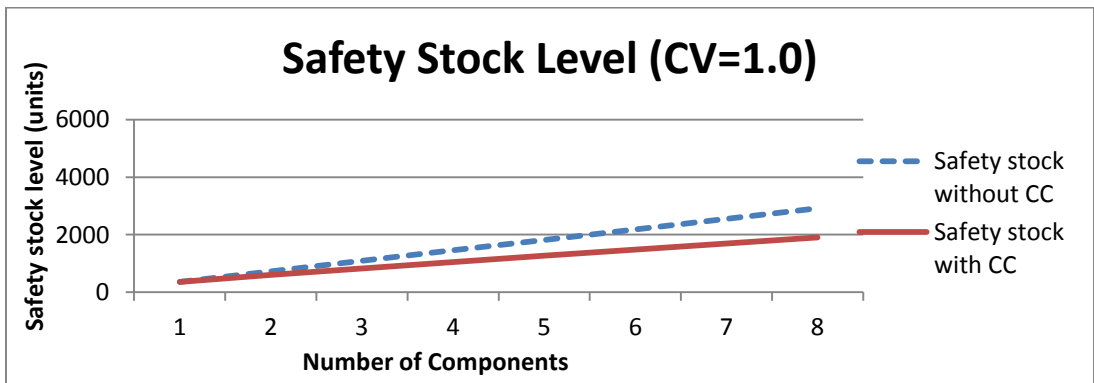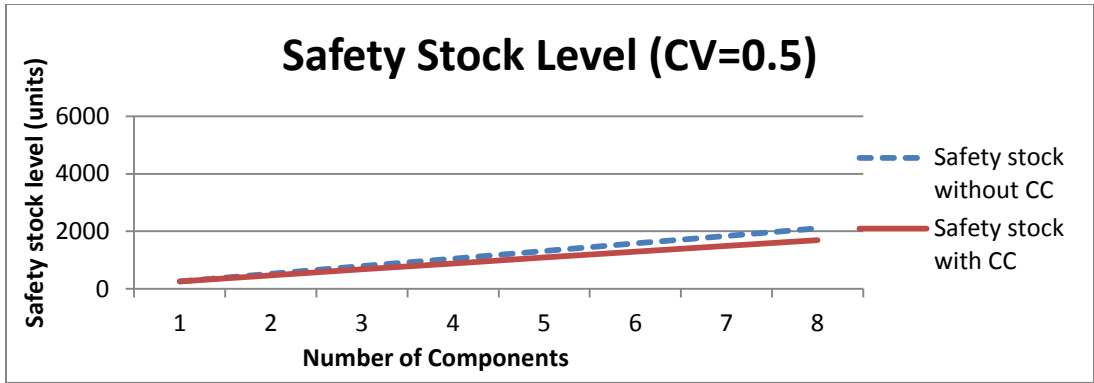
Safety Stock Level (CV=0.5)

Safety Stock Level (CV=1.0)

Safety Stock Level (CV=2.0)

$$\begin{pmatrix} 1 \\ 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \rightarrow etc.$$
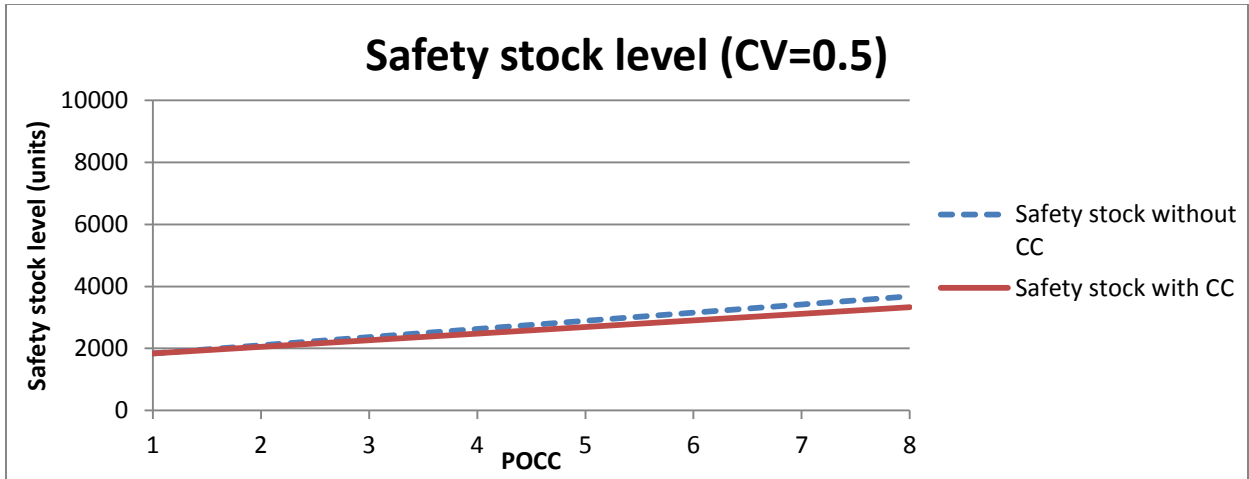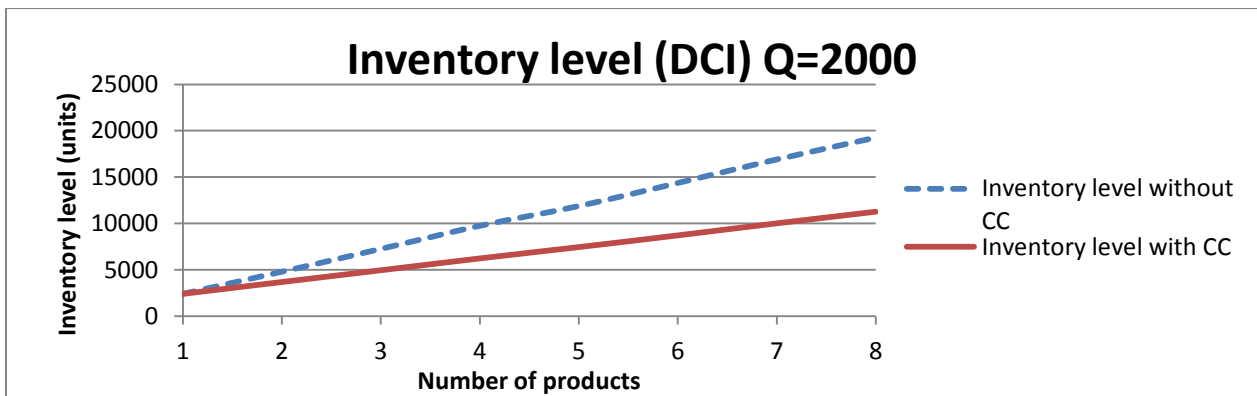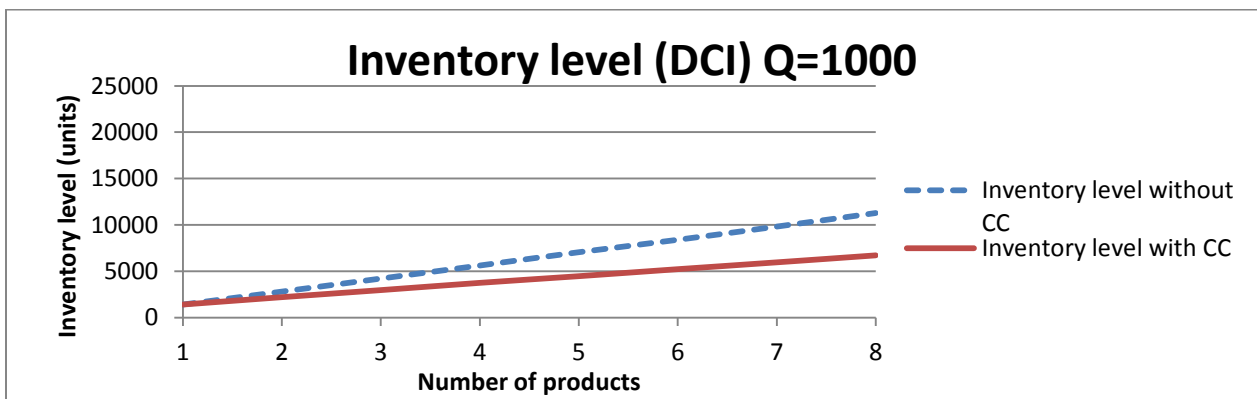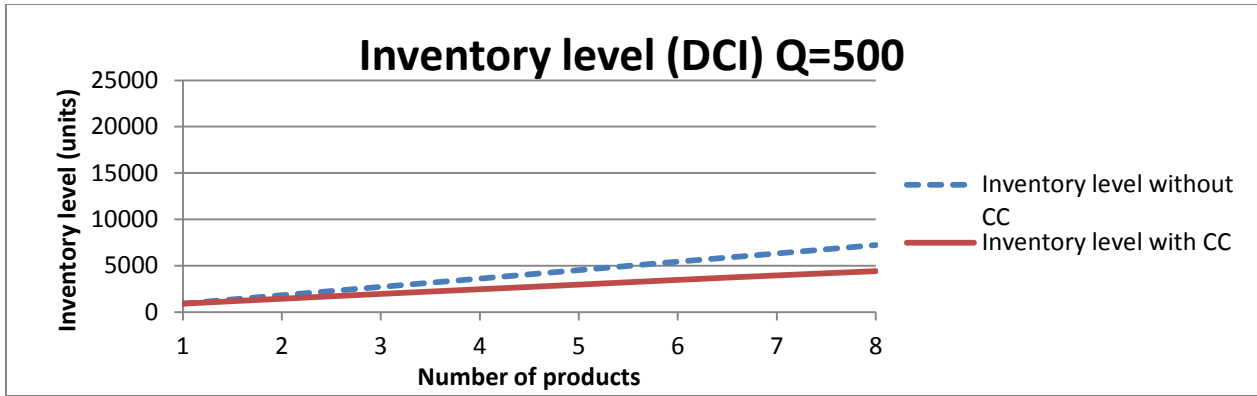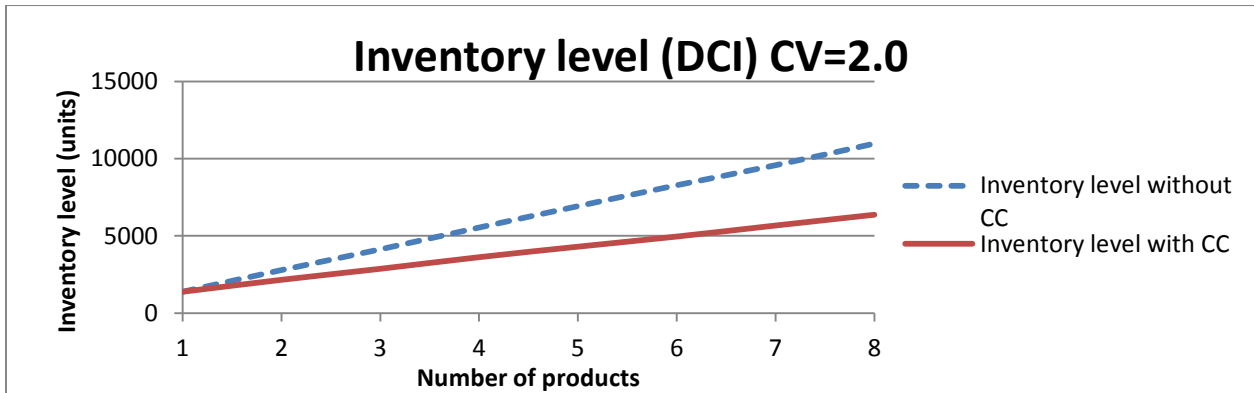
$$DCI = \frac{2j}{j+1}$$

$$\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \rightarrow etc.$$

$$DCI = \frac{3j}{j+2}$$
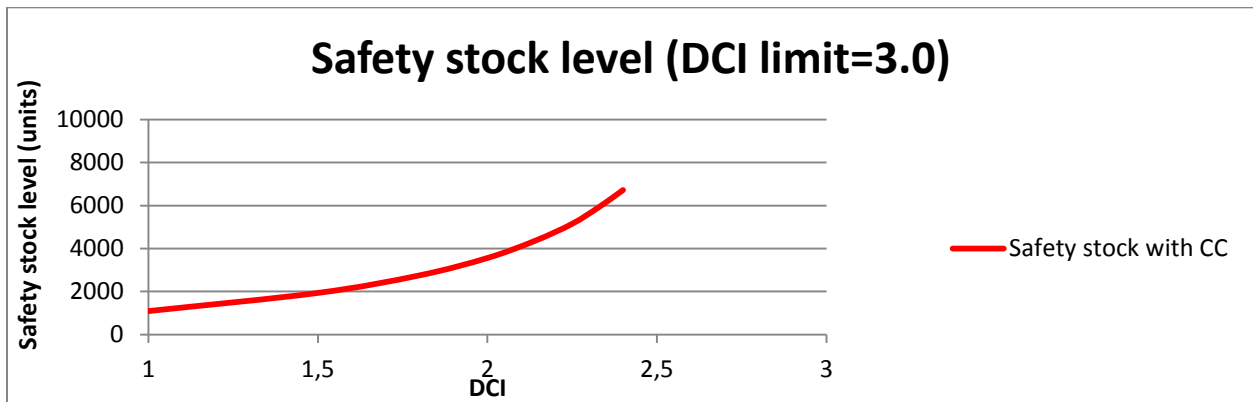
$$\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \rightarrow etc.$$

$$DCI = \frac{4j}{j+3}$$

Safety stock level (DCI limit=4.0)

Safety stock with CC

Safety stock level (CV=0.5)

Safety stock level (CV=1.0)

Safety stock level (CV=2.0)

Inventory level (POCC) CV=0.5

Inventory level (POCC) CV=1.0

Inventory level (POCC) CV=2.0

Cash position with CC (DCI)

Cash position without CC (DCI)

Cash position with CC (POCC)

Cash position without CC (POCC)