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Master's Thesis

INVENTORY OPTIMISATION BY MEANS OF MULTIVARIATE ANALYSIS

Lauri Putkivaara
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ABSTRACT

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The commercial importance of managing inventories is reflected well by an abundance of scientific publications. Most of the models in literature address one or multiple factors that influence inventory levels, e.g. order quantity, lead times and Business Interruption risk, often in a deterministic way. Choosing the right factors can hugely influence the resulting inventory levels suggested by the model, and as a consequence the capital bound in stocks.

In Supply Management, Performance Pricing is a well-established top-down instrument to quantify and address pricing potential by comparing the actual and the statistically calculated price for purchasing items. The calculation of the latter considers a multitude of hard and soft factors by means of multiple regression analysis.

The goal of this thesis is to develop and apply a comprehensive, regression-based assessment method for inventory management, methodically founded on the step model described in VDI 2817. The application is not limited to a single company but facilitates cross-company benchmarking of inventory levels.

The result is a statistically valid inventory optimisation model that uses data from two case companies. The empirical analysis shows that the case companies have inventory reduction potentials in certain material groups. By implementing the findings, the case companies can reduce capital tied to the inventories and improve financial aspects.

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Varastonhallinnan liiketaloudellinen merkitys on hyvin esitetty runsaiden tieteellisten julkaisujen myötä. Suurin osa kirjallisuudessa esitetyistä malleista käsittelee yhtä tai useampaa tekijää, jotka vaikuttavat varastotasoihin, kuten esimerkiksi tilauskokoa, toimitusaikaa ja liiketoiminnan keskeytymisriskiä, usein syy-seuraussuhteen myötä. Oikeiden tekijöiden valinta voi vaikuttaa suuresti mallin laskemiin varastotasoihin, ja sen seurauksena käyttöpääoman kietoutumiseen varastoissa.

Hankintatoimessa Performance Pricing on hyvällä perustalla oleva ylhäältä alaspäin suuntautuva väline hintojen kvantifiointiin ja potentiaalin käsittelyyn ostonimikkeiden aitoja ja tilastollisesti laskettuja hintoja vertailemalla. Tilastolliset laskelmat tarkastelevat useita pehmeitä ja kovia ominaisuuksia regressioanalyysin keinoin.

Tämän pro gradu -tutkielman tavoite on kehittää ja soveltaa kokonaisvaltainen regressiopohjainen arviointimenetelmä varastonhallintaan, jonka menetelmäoppi perustuu VDI 2817:ssä kuvailtuun porrasmalliin. Menetelmän soveltamisen ei ole tarkoitus rajoittua vain yhteen yritykseen, vaan avittaa yritystenvälisten varastotasojen suorituskyvyn vertailua.

Työn tulos on tilastollisesti validi varastonoptimointimalli, joka hyödyntää dataa kahdesta yrityksestä. Empiirinen analyysi osoittaa, että tapaustutkimuksen yrityksillä on varastonvähennyspotentiaalia tietyissä materiaaliryhmissä. Löydösten täytäntöönpanolla yritykset voivat vähentää pääoman sitoutumista varastoihin sekä parantaa taloudellisia aspekteja.

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1 INTRODUCTION

According to a report by PwC (2018), the cheapest way for a company to find funds is to improve the working capital management. The funds available are huge, as 1.3 trillion euros could be released by improving the working capital performance of global listed companies. Companies should spend efforts on working capital management and inventory management practices, in which they could learn best practices from each other. PwC’s study shows that large companies generate better Return On Capital Employed (ROCE), and that they also have better inventory performance measured in Days Inventory Outstanding (DIO), while on the other hand small companies are improving faster in the latter.

Inventory optimisation that leads to reduction of inventories is a way to improve working capital performance. Reducing inventories can positively affect the liquidity of a company by enabling the use of cash for other targets as it is not bound in inventories, but too much reduction can also lead to interruptions in production or sales (Afrifa 2015, 22). Hence, reduction as such is not the objective, but optimisation is. The organisational cost policy associated with holding inventories and the ability to forecast demand facilitates the selection of an inventory management method.

For a long time statistics has been recognized as a powerful tool in inventory management. More than half a century ago, scholars identified that companies with seemingly sound inventory control systems may lack the precise scientific *objectivity* of sophisticated mathematical models that can further improve their inventory management. (Oravec 1960, 40) Interest in scientific inventory control can be dated back to at least the late 1940s (Hadley & Whitin 1963, v).

In an attempt to implement such *objectivity* to inventory management — in a way that would also be applicable across organisations — the concept of the price estimation method *Performance Pricing* could be applied to inventory management. While Oravec (1960, 40) emphasized the importance of recognizing the *factors* influencing inventory, Performance Pricing concept could be used to determine objective weighting *coefficients* for the factors (VDI 2018, 2–3) that are to be called *inventory drivers*. The objectivity can be reached by leaving the calculation of the coefficients to the statistical mechanism built into an analytical software. By doing so the personal subjectivity of individual practitioners influencing them does not arise for debate. Thereby, a mathematical model based on statistics can be created, which can reveal inventory optimisation potentials.

1.1 Background, motivation, research objective and research questions

According to Wensing (2011, 1) individual inventory management methods are generally deemed too complex to allow a single approach to perform well in multiple individual inventories. Comments like this cause the desire to attempt to tackle the challenge of falsifying that claim, and to establish a sophisticated inventory management method that would be applicable across inventories and organisations. To be able to conduct research for that purpose, different types of inventories need to be identified from different organisations and the data collected from these multiple sources.

Research revolves around the new adaptation of Performance Pricing. The objective is to create a multiple regression model representing inventory, where the dependent variable is *pieces* – instead of value – and the independent variables are *inventory drivers* – instead of value drivers. Value and value drivers are used in Performance Pricing, so changing them establishes the adaptation to inventories.

- Research objective: *Create an inventory optimisation model by adapting Performance Pricing as described in VDI 2817. The model shall be statistically valid according to common criteria.*

Two main questions arise from the reseearch objective. The first one considers developing the model, i.e. the empirical part of the study. The second research question considers what can be concluded from the findings as into practical implications. Reduction of inventories would be the ideal findings.

- Research question 1: *What inventory drivers can be used for inventory benchmarking between the two case companies?*

- Research question 2: *What inventory optimisation (reduction) potentials does the model show?*

Additionally, a third research question comes from adapting VDI 2817 from price evaluation and optimisation to inventory level evaluation and optimisation.

- Research question 3: *How to convert VDI 2817 to inventory management?*

1.2 Research definitions and key concepts of the study

Five ways to define and describe the research are depicted in Figure 1. At the core lies the empirical nature, which is common in business research and especially in master's theses, as opposed to a theoretical research. The word empirical comes from Greek word *empeiría*, meaning experience, which reflects the fact that the study deals with information that has been observed from the environment. As such, the research attempts to maximise the practical implications via the results. That is what most businesses need, since by one definition, their job is to generate the maximum profit to their shareholders. Therefore, studies where the results can be turned into cash fast are desirable. Another perspective is that any organisation needs to maximise the relationship of input and output to serve the environment. Shareholder value is then a side product.

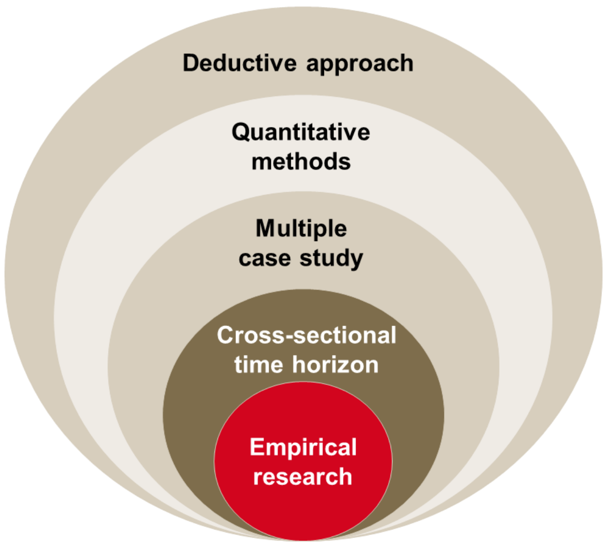

Figure 1. *Research definitions (adapted from Saunders et al. 2016, 124)*

Moving on to the second layer of Figure 1, the time horizon of the data used in the research shall be defined. A cross-sectional time horizon reflects a clear beginning and ending date for applicable data. The idea is that the results represent the span of time as well as possible. Typically, there is a pre-defined reason to study a certain timeframe. In the case of this research recent events are studied in order to understand the current state of business through them, as it can be expected that major changes have not occurred after the ending date. As opposed to a cross-sectional time horizon, another way to conduct the study would be longitudinal. A Longitudinal study may last for years and its purpose could be rather to measure how things change within time.

The third level of Figure 1 and the research considers the strategy. It has a variety of different possibilities for the researcher to choose from, such as survey, experiment, ethnography, archive research or case study to name a few. This master thesis utilizes the case study strategy, which is common for theses that are made specifically for the purposes of a company. In a case study, the goal is to understand the specific case, i.e. the company, as well as possible. As a potential downside, it might not be possible to generalise the results so easily. On the other hand there is potential to reach a greater benefit for the specific company, since it is under a detailed scrutiny. Especially if the company can be described as an outlier or a frontrunner amongst its population, the research findings may not be possible to be generalised yet. Likewise, research results that are too general might lack some newness value or have difficulties to act as the source of a unique competitive advantage. This research is conducted as a multiple case study where the degree of specificity is not bound to a single company only. The results are applicable to the case companies, and towards some generalisability.

Next in the fourth layer of Figure 1, the methodology of research is commonly divided into quantitative and qualitative methods. The division is not that black and white in reality, as there are also mixed and multi-methods where, for example, the two can be used in tandem. This research is conducted with a mathematical method that involves statistics so the analysed data is in a numeral format. Therefore, this study is done with quantitative methods. Chapter 3.4 provides some more insight into the quantitative study.

Lastly, different approaches to theory development are available: deduction, induction and abduction. They vary in logic, generalisability, the use of data and theory aspects. In this research, using general theory from the scientific literature is used to reach specific results for the case company. The premises assumed to be true and therefore the conclusions are also true. Case companies data is collected to test the hypotheses and evaluate propositions. The objective is to provide suggestions for practical implications. The main goal is not to create a completely new scientific theory, but rather to use and verify existing ones in order to reach a change in the practical premises of the case companies. (Saunders, Lewis and Thornhill 2016, 145)

As a study in the school of business and in the specialisation field of (purchasing and) supply management, the key concepts are derived from this school and field. Inventory management is the first key concept as it clearly links to the specialization field. The original idea for the thesis was to deal with inventory optimisation. Therefore, the next key concept is optimisation itself.

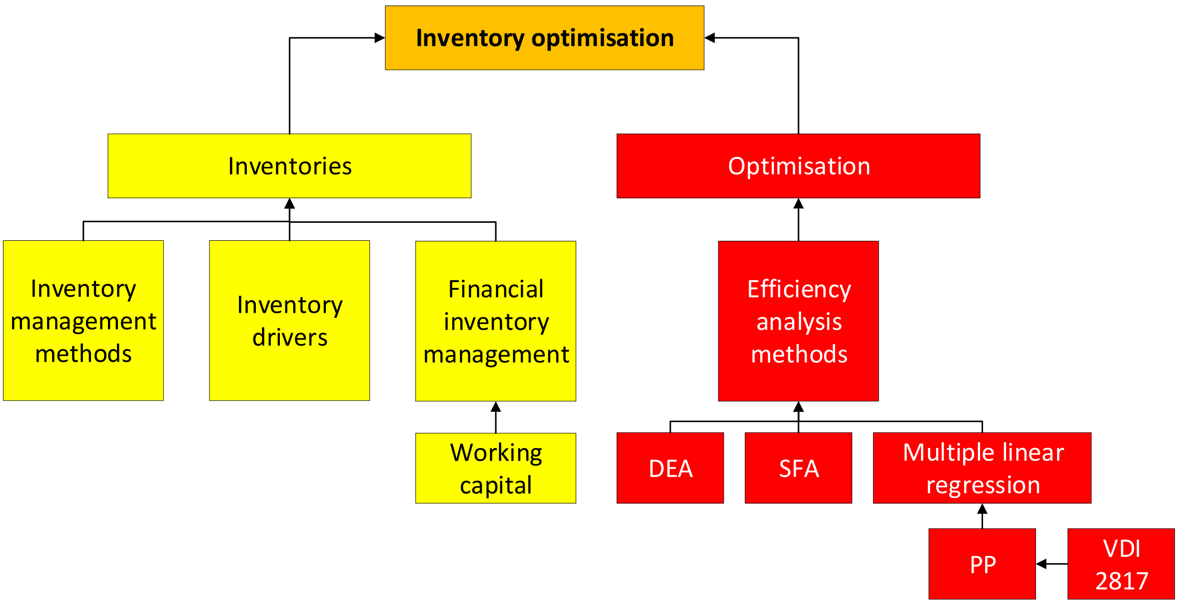

Figure 2. *Key concepts of the study*

In inventory management the sub-concepts considered are management methods, inventory parameters (drivers) and financial perspectives. For optimisation, efficiency is an important term as well as measuring it. Analysis methods for efficiency and optimisation have a big role in this research. Three different types are considered: DEA, SFA and PP, which are reviewed in chapter 2.4.

PP is actually a multiple regression method. It comes from cost optimisation, where the Association of German Engineers, VDI (Verein Deutscher Ingenieure), has established a technical standard VDI 2817 for it. The *“VDI 2817 Part 1 – Performance Pricing (PP) Fundamentals and application”* publication serves as the main source for utilising the multiple regression method. The reason for using this publication is that it provides even rather novice readers a well-written guideline on how to use multiple regression. That allows users to start optimising with relative ease as the publication guides the user on which points to focus. As a mathematical method, it requires a lot of statistical calculations, for which the software Analycess Procurement is helpful, making the use of the method again easier to approach for novice users. Lastly, it must be noted that the VDI 2817 Part 1 is written for cost optimisation. Thus, when implemented in inventory management, the reader must convert the domain of price and cost into the domain of inventories.

1.3 Challenges in data collection and harmonisation

In the modern business setting data of various logistics movements and instances is recorded to IT systems – often even automatically without a human monitoring the process. This creates an abundance of data and accessing it can be just a few mouse-clicks away. However, without having a proper contact to the actual physical process behind the data, it is easy to accidentally make false assumptions of what the data really represents or to miss details. Such mistakes may make the entire analysis futile.

Terminology can be defined to differentiate between processes. When data is stored into an IT system it can be called recording data. When the data is fetched from the system for research or analysis purposes, it can be called data collection. Forasmuch as data recording and collection seems easier due to modern technology, it also involves new challenges and pitfalls to be avoided. The recording processes need to be correctly defined so that the systems and the data in them can be trusted. The ability to easily record and collect data from the system creates the urge to do so in many instances just because it happens to be possible, and as a result it is not uncommon to have low quality data that in the end is not utilized at all. Data quality issues are ever present.

When data collection is based on readily available data recorded into IT systems, perhaps more common than a measurement error is the misunderstanding of the meaning of the data, or how the measurements are being made. For example, in an earlier study at the case company, Musacchia (2019, 129) collected lead time data only to report later that it does not reflect reality. The lead time stored in the ERP system was the one defined in the contract as the maximum time allowed by the supplier without causing any negative consequences for them. Hence, suppliers usually deliver in less days, but this real lead time is not recorded. The era of information and big data comes with its opportunities and problems. However, it is possible to work around the errors if the causes were known.

Furthermore, data collection itself is a task that requires a lot of care and attention to ensure the data quality. All the more so when multiple data sources are involved, as the collection procedure from different sources may require different steps, which adds complexity and factors that can cause an error. Even within an organisation it is not uncommon that different IT systems are used in its different units. In different organisations different IT systems providers are bound to be met, such as SAP, BAAN, IFS and others.

To avoid the errors in data collection, the concepts behind the logistics of each inventory in each organisation need to be understood. This is required because a single term can have different meanings in different organisations. For example, instead of taking for granted that lead time in one organisation is defined the same way as in another, questions such as “What do you mean by lead time?” or “How do you measure lead time” need to be asked.

In complex settings, the data often ends up scattered in different systems that are being used by different people, and so even the existence of useful data may not be known to relevant stakeholders, yet the access to it. In an even earlier study at the case company, Thampi (2018, 38) reported that due to inexperience with the ERP system, data was difficult to find and asking help from different stakeholders was not always fruitful, which *“hindered quite substantially the data collection”.*

Additionally, the data in different sources may not be uniform and so may require pre-processing before being jointly used. Such challenge could be overcome by *integral systems* and *data harmonisation.* In the end, the main message is to not underestimate the challenges with data. Data harmonisation and evaluation measures are addressed in chapter 4.3. Management skills become highly useful in making different stakeholders commit to providing the data and ensuring its quality.

1.4 Structure of the thesis

After the introduction in chapter 1, the reader is presented with the literature review in chapter 2. It gives the theoretical context and the tools found from scientific publications that guided the author towards completing the research. Then in chapter 3, a general look into the concept in VDI 2817, statistical validation and regression analysis is taken. In addition, important definitions regarding inventory, optimisation and model evaluation for the context of this research are made. Chapter 4 is used to move from the general look into the actual methodological part where the VDI 2817 is translated from being a tool for costs into being a tool for inventories. In chapter 5 the reader is briefly familiarized with the case companies, and then presented with the results. In the last chapter, the work is concluded and future research suggested.

2 LITERATURE REVIEW

This section provides the theoretical context of the thesis. It is divided in four subchapters, explained shortly in the following list.

- Inventory management
    - Basic inventory management methods
    - Benefits
    - Different inventory management perspectives
- Benchmarking
    - Basic concept, challenges and success factors
- Optimisation and measuring efficiency
    - Basic concepts of optimisation and efficiency
- Efficiency analysis methods
    - Comparison of competitive methods to Performance Pricing

2.1 Inventory management

Many methods for inventory management are available, such as Economic Order Quantity (EOQ), Economic Production Quantity (EPQ), Joint Economic Lot Sizing (JELS), single-period, and multi-period models (Ziukov 2015). Different models have been created to fit for specific needs and one model may not be suitable for all cases. As an example, the EOQ model focuses on optimising cost based on orders and the EPQ focuses on optimising cost based on production. Similarly, products with short and long product life cycles (PLC) may not be suitable for the same inventory planning method (Ali, Madaan, Chan & Kannan 2013, 3864). Thus, different inventory management methods are required. In addition, comparability and benchmarking of inventory management (methods) is not a simple task. Current models do not account for a high amount of multi-criteria. Therefore, a task to develop a model that can point out reasonable improvements and optimisations across industries and companies no matter the focus point would be ideal.

Inventory item demand is often stochastic so inventory level estimations can be based on historical demand only to a limited extent (Akcay, Biller, & Tayur 2011, 297). For example the newsvendor problem relates to items with uncertain or random demand with apparently infinite variations, thus the order quantity is difficult to decide for profit maximization (Gholami, Sandal, & Ubøe 2016, 2-4).

Inventory can start creeping up to higher levels when new items are introduced, as the material managers may be placing too high orders “just in case” something unexpected happens, as the demand is hard to estimate (Gustavson 1987, 13). As a solution to that, staying on an optimal inventory level could be influenced by penalties being imposed on inefficient material managers or controllers (Fandel & Trockel 2011, 256). In the end, excessive inventories are often reached, which creates need for inventory optimisation. As a consequence, reductions in inventories can occur, which may have a positive or a negative impact profit-wise. For example, removing obsolete items is called *scrapping*, which can amount to significant losses of up to 1% of profit (Cattani & Souza 2003, 217). However, in the end, benefits for good inventory management practice include the following

I. Improved material availability
    - Meeting demand
    - Reducing stockouts
II. Cost savings
    - Reducing ordering costs
    - Reducing expediting costs
    - Reducing warehousing costs

There is a lot of literature about inventory management and controlling inventories spanning across decades. Table 1, presented on the next page, provides some selected publications. Different perspectives, such as financial matters, spare parts, production and planning scheduling, and just plain principles and analysing have been studied by scholars of inventory management. Especially books by Silver et al. (1998) and Tersine (1988) are classics in the field. Publications by Cachon & Marshall, Lee & Billington, Nahmias and Baumol are much-cited. A remark amongst the authors can be made about Arrow, who received the 1972 Nobel Prize in Economic Sciences.

Table 1. *Selected titles in inventory management and control*

Author	Year	Publication
Xiaoying, L., Ma, L., Wang, H., & Yan, H.	2017	*Inventory Management with Alternative Delivery Times*
van Houtum, G.-J., Kranenburg, B.	2015	*Spare Parts Inventory Control under System Availability Constraints*
Curseu, S. A.	2012	*Retail inventory management with lost sales*
Arikan, E.	2011	*Single Period Inventory Control and Pricing*
Bruin, J.	2010	*Inventory control in multi-item production systems*
Muckstadt, J. A., Sapra, A.	2010	*Principles of Inventory Management: When You Are Down to Four, Order More*
Gimpl-Heersink	2009	*Joint Pricing and Inventory Control under Reference Price Effects*
Sethi, P. S., Yan, H., & Zhang H.	2005	*Inventory and supply chain management with forecast updates*
Cachon, G. P., & Marshall, F.	2000	*Supply Chain Inventory Management and the Value of Shared Information*
Silver, E. A., Pyke D. F., & Peterson, R.	1998	*Inventory management and production planning and scheduling*
Verwijmeren, M. A. A. P.	1998	*Networked inventory management by distributed object technology*
Lee, H. L., & Billington C.	1992	*Managing Supply Chain Inventory: Pitfalls and Opportunities*
Tersine, R. J.	1988	*Principles of inventory and materials management*
Nahmias, S.	1982	*Perishable Inventory Theory: A Review*
Hadley, G., & Whithin T.	1963	*Analysis of inventory systems*
Baumol, W. J.	1952	*The transactions demand for cash: An inventory theoretic approach*
Arrow, K. J., Harris, T., & Marschak, J.	1951	*Optimal Inventory Policy*

2.1.1 EOQ – Economic order quantity

The EOQ model is a simple and classic example of an inventory management method. It is more than 100 years old (Harris, 1913) and is thus a very basic principle that every inventory manager should know, and then be able to move to the use of more advanced methods. Figure 3 illustrates how the model fits into an inventory level and time graph.

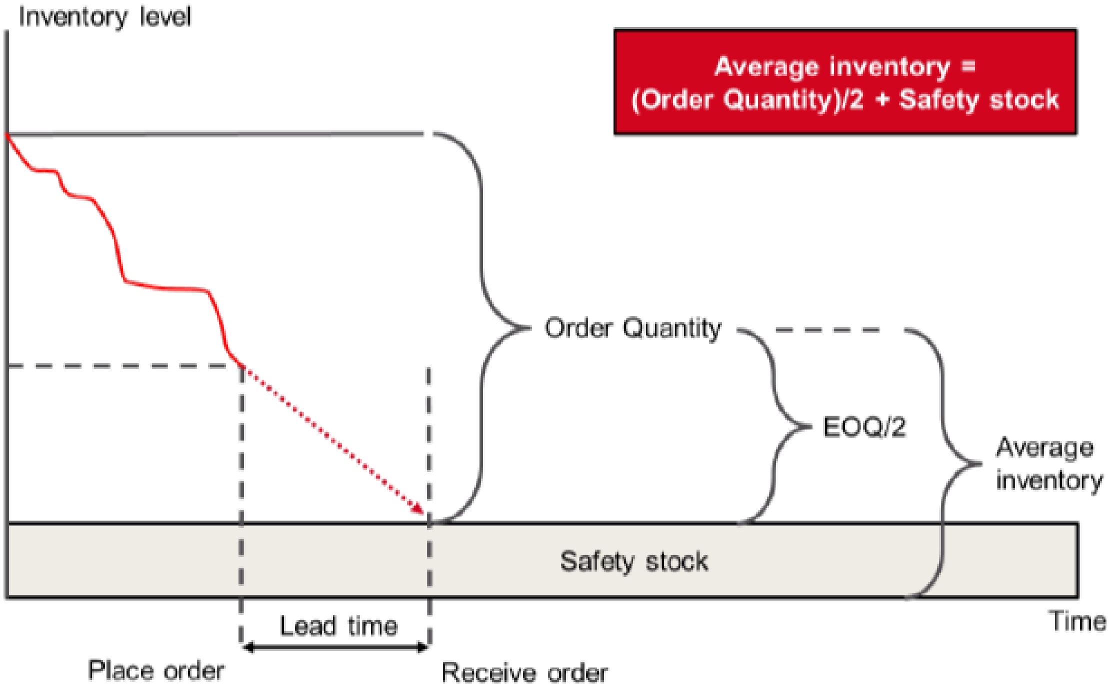

Figure 3. *EOQ model and average inventory*

The basic EOQ model only takes into account the order cost *C*, the holding cost H_t, and the *fixed* rate of consumption D_t per the time unit *t* to calculate the quantity *Q*, as shown in the equation below (Nahmias 2011, 49).

$$Q = \sqrt{\frac{2 \times C \times D_t}{H_t}}$$

The balance between holding costs and reorder costs can be minimized with the EOQ model as illustrated in Figure 4 (Agarwal 2014, 233). It can be assumed that annual ordering costs decrease with increasing lot size, but there is a limit to how low the ordering cost can be. Annual holding costs increase as lot size increases. It is quite common to take a constant as the assumed holding costs per inventory item or a lot size, as it is quite challenging to consider all the factors influencing holding costs. Therefore, the annual holding cost is a straight line going diagonally up.

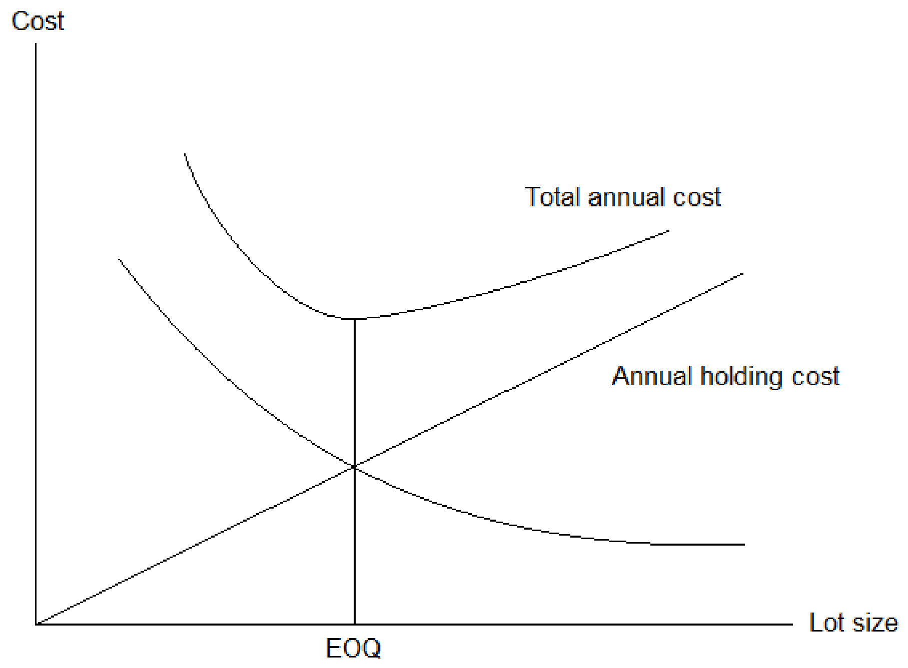

Figure 4. *Economic order quantity is where holding and ordering cost meet and the total cost is at the lowest*

2.1.2 Different stock types and classifications

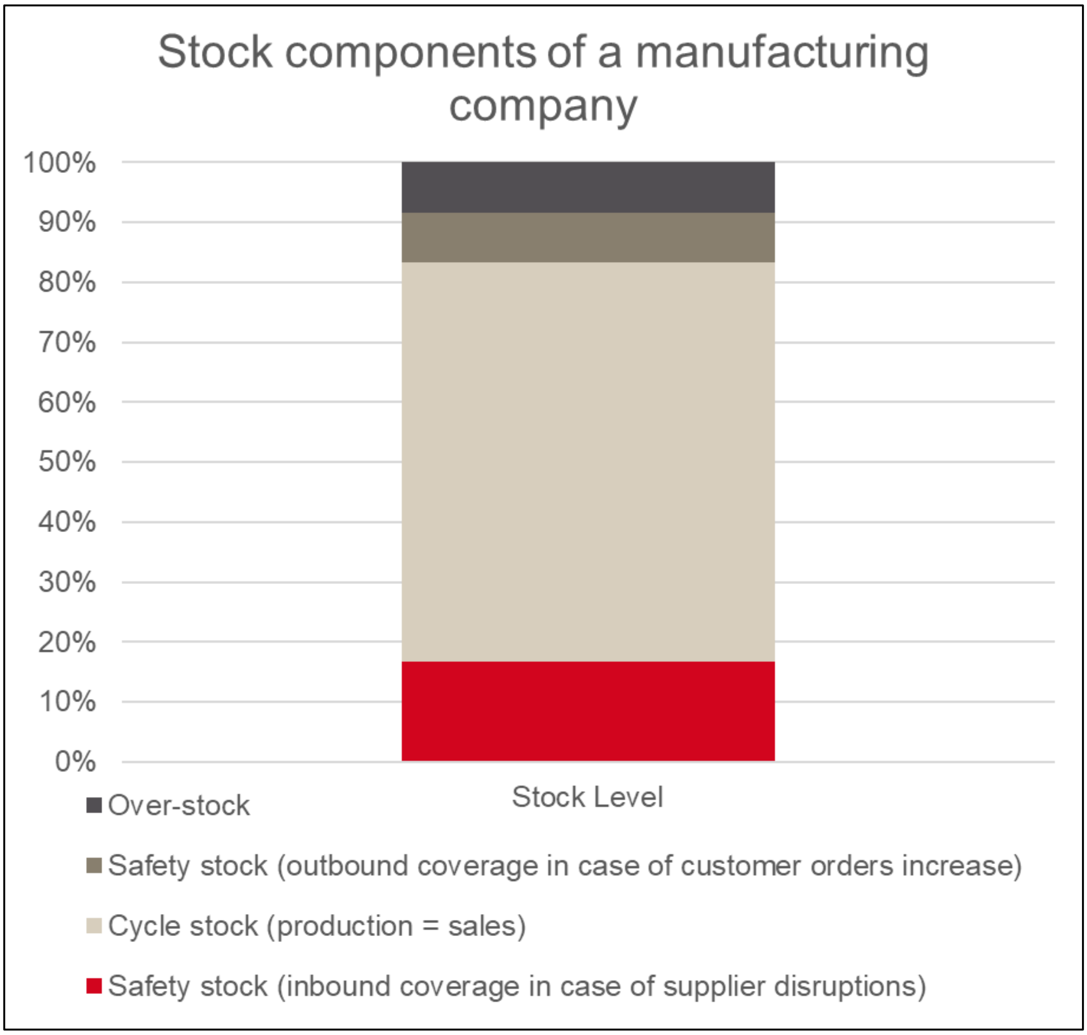

Figure 5. *Item stock components*

In general, stock can be divided into four components. Those components are cycle stock, over stock, safety stock for inbound coverage, and safety stock for outbound coverage. Figure 5 roughly illustrates their shares in an inventory.

The main reason for holding a safety stock is to cope with an unplanned and unforeseen disruption in inbound supply, thus ensuring uninterrupted outbound supply of goods. Unforeseen disruptions that lead to the supplier's inability to deliver to the organization can occur for multiple reasons like labour strikes or natural disasters (Darom, Hishamuddin, Ramli & Nopiah 2018, 1011).

An unexpected increase in customer orders could also tempt an organisation to use its safety stock to increase production to satisfy customer demand, but doing that would not be advisable – the purpose for the safety stock could be mixed between stakeholders. Thus, the definition of safety stock must be clear and adhered to or otherwise problems arise. For this thesis the definition of the safety stock is such that it should only be used if the inbound supply for cycle stock faces a problem. Having this limitation allows better to specifically focus on inbound supply issues.

So for unexpected customer orders, another component of the safety stock should exist, as illustrated in Figure 5. When different components are being used, the safety stock consists of pieces belonging to different stakeholders, thus each one can influence their piece without hindering others, and information about changes do not need to flow to all stakeholders. Production and sales have their own components of safety stock to cope with uncertainty in their daily business. In addition, there exists the possibility of over-stock, which represents the pieces in the warehouse considered excessive, and is the first component of inventory level that should be optimised, that is completely removed. According to Saad, Perez and Alvarado (2017, 42) excessive inventory is a sign of hidden problems.

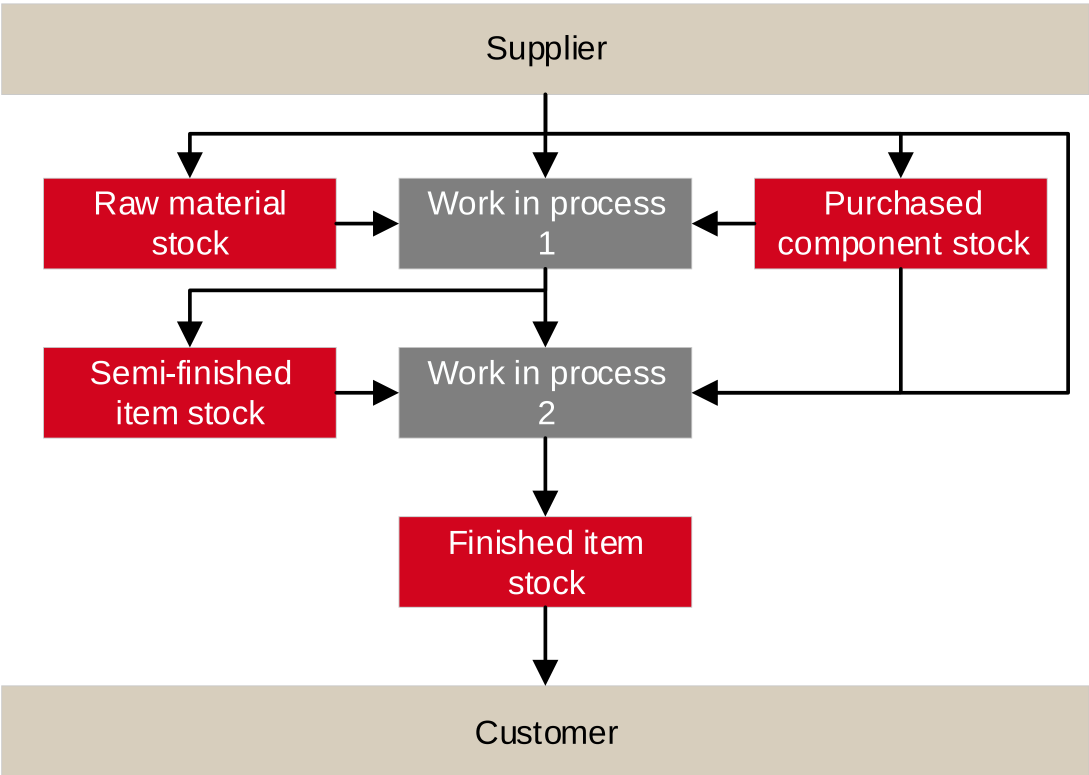

Figure 6. *Internal flow of an item (Jonsson & Mattsson 2009)*

The production stage of an item could be divided into sub-steps, and as the item progresses from one step to another, it becomes more valuable. Therefore, before an item will be considered a finished product within a manufacturing company, it can have multiple *work in process* stages. After each stage a different item is created, and their stock levels could be calculated individually. Figure 6, adapted from Musacchia (2019, 48) who in turn adapted it from Jonsson & Mattsson (2009), provides a simple illustration of an internal flow of an item in a manufacturing company.

Consider the purchased component stock in Figure 6. There is only one path from supplier that leads to it. However, there are three possible paths that the item can go through before becoming a finished item. These paths can be combined to create logistic chains. The possibilities for the chains formed are listed below.

- Chain 1: Supplier → Purchased component stock → Work in process 1 → Work in process 2 → Finished item stock
- Chain 2: Supplier → Purchased component stock → Work in process 1 → Semi-finished item stock → Work in process 2 → Finished item stock
- Chain 3: Supplier → Purchased component stock → Work in process 2 → Finished item stock

To complicate things more, the item in *purchased component stock* goes through two separate *work in process* stages in Chain 1 and Chain 2, but only through one *work in process* stage in Chain 3. Therefore, on one hand, items stocked in *purchased component stock* may end up becoming entirely different finished items: item X can be manufactured through Chain 1 and Chain 2, but item Y can be manufactured only through Chain 3. On the other hand, two individual items in the *purchased component stock* may end up becoming the same finished items, but can go through a different logistic chain, namely Chain 1 or Chain 2. Hence, considering the inventory efficiency of an item in *purchased component stock* may actually require considering the one and same type of an item as three different items based on the logistic chains. Then, a more in-depth understanding of the actual efficiencies of the three items could be calculated.

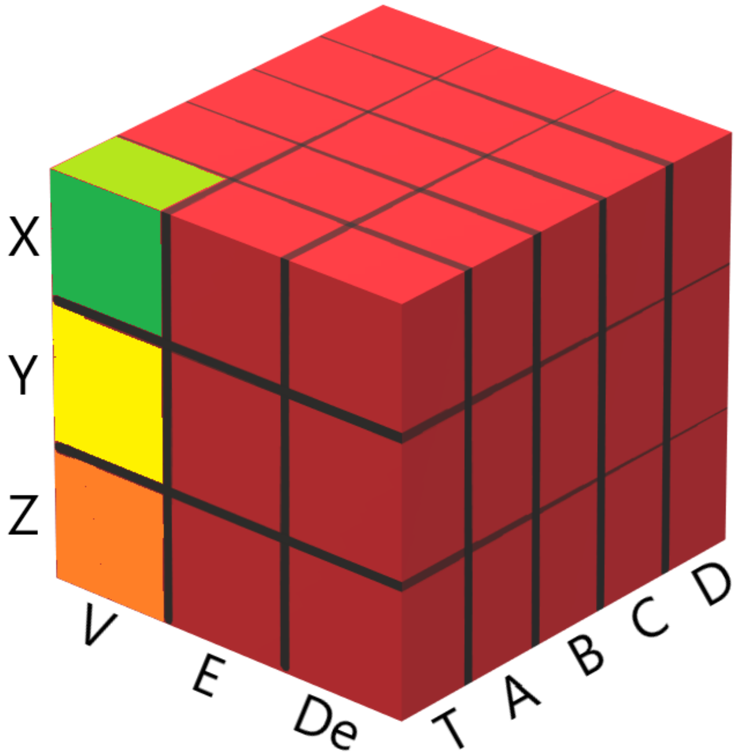

Figure 7. *ABC (TABCD), VED and XYZ cube*

Yu (2011, 3420) stated that ABC analysis should be replaced with multi-criteria classification approaches for more efficient inventory management. Therefore, three classifications types for inventory items are illustrated in Figure 7. The cube structure reflects that with a simultaneous use of all three, it is possible to reach $3x3x5 = 45$ eventual classifications. The TABCD classification is based on volume or spend. The XYZ classification is based on ability to forecast consumption. The VED classification is based on criticality. One definition for criticality could be for example impact on profit in case of business interruption.

TABCD has been implemented in the case company A. However, Schutten (2018, ii) recommended the classification in the company to be reduced by combining the TA into A and CD into C, resulting to ABC-classification. She also mentioned (2018, 66) that the 15 classes resulting from the TABCD-XYZ classification are difficult to manage.

2.1.3 From inbound to outbound supply

Outbound supply chain consists of the logistics of transporting finished items from production plants to sellers (Eskigun, Uzsoy, Preckel, Beaujon, Krishnan & Tew 2005, 182). It is also known as downstream supply. On the other hand, inbound supply is known as upstream supply, and can refer to, e.g. transporting goods to manufacturing plants.

Integral control of goods flow allows a multi-method approach to improve inventory management. Taking stock control as the starting method and integrating planning, production control, job-shop scheduling and forecasting methods into it can create a more comprehensive concept for appropriate stock levels. (Hoekstra & Romme 1992, 1) Especially sales forecasting methods from the outbound supply chain can address the customer-oriented inventory management where inventory levels are optimised for profit and customer satisfaction.

The point where the customer order is initially recognizable in the logistic chain is the Decoupling Point (DP), which needs to be decided as the control point for inventory level analysis (Hoekstra & Romme 1992, 29). It can be considered as the point for “Warehouse outbound stock”, which then is considered as the main stock point. (Hoekstra & Romme 1992, 6) The decoupling point can reach further back towards the starting point of the inbound supply chain based on whether ATS, MTS, ATO, or MTO, respectively, are used as the stocking philosophy, as illustrated in Figure 8 adapted from Hoekstra & Romme (1992, 7).

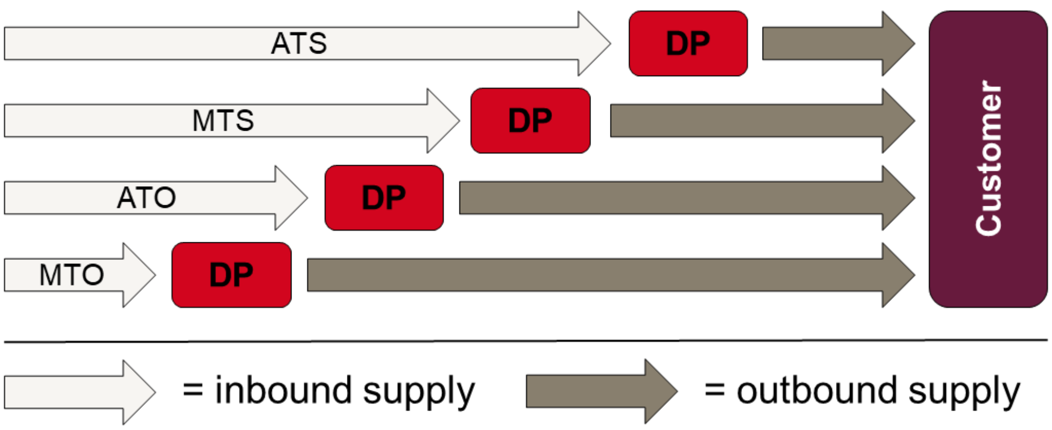

Figure 8. *Different possible positions of the decoupling point (adapted from Hoekstra & Romme 1992, 7)*

2.1.4 Financial perspectives and working capital management

As per the Chartered Institute of Management Accountants, or CIMA, (CIMA 2005, 82) working capital is the capital, which is available for conducting the daily operations of a company. Templar, Hofmann & Findlay (2016, 44-47) emphasize that it is a major issue in business, particularly in supply chain finance (SCF), which is a part of financial supply chain management (FSCM) as duly remarked by Liebl, Hartmann & Feisel (2016, 395).

Typically working capital is calculated as current assets minus current liabilities (CIMA 2005, 82). One definition for what makes the assets and liabilities "current" is that they are realised or settled within a year (CIMA 2005, 62).

$$Working\ capital = current\ assets - current\ liabilities$$

Table 2 presents a simplified version of the components of current assets, with liquidity increasing when going down the table, and the components of current liabilities, adapted from Johal and Vickerstaff (2014, 38) and CIMA (2005, 61). Components that are not specified can be included in the "other" components.

Table 2. *Current assets and current liabilities*

Current assets	Current liabilities
Inventories	Short-term borrowings
Accounts receivable	Accounts payable
Marketable securities	Interests
Cash	Taxes
Other current assets	Other current liabilities

The interesting bit for supply practitioners is that inventories is a part of the current assets and rather illiquid. If a company has excessive (i.e. not needed) inventories, the capital tied up to them has a negative implication on its cash flow, working capital cycle and liquidity (Templar et al. 2016, 50).

Liquidity refers to the company's ability to meet financial obligations when they are due (CIMA 2005, 92). It is essential for a business to have this ability or else they might risk becoming closed down (Johal and Vickerstaff 2014, 168). Liquidity ratios measure this ability.

Current ratio is one liquidity ratio. While working capital is the difference of current assets and current liabilities, current ratio is the ratio of those two figures.

$$Current\ ratio = \frac{current\ assets}{current\ liabilities}$$

Templar et al. (2016, 51) write that, in theory, if current assets are more than current liabilities, a company has enough assets to convert into cash to pay all its credit. In this sense the considered credit is such that it needs to be paid promptly but not hastily.

Quick ratio is another liquidity ratio with the only difference to current ratio being that the inventories are not taken into account. It follows the assumption that the value of the inventory is not realised on disposal (Templar 2016, 51), unlike for other components of the current assets such as marketable securities. In other words, quick ratio takes into account only the most liquid assets, and inventories are not considered as such. The better the ratio, the better a company is able to pay its current liabilities hastily.

$$Quick\ ratio = \frac{(current\ assets - inventory)}{current\ liabilities}$$

Once excessive inventory is sold, it eventually becomes converted to cash as illustrated in Figure 9. Therefore, in the ratio, the decrease in inventory generates an equal increase in the cash component included in the current assets. Hence, reducing excessive inventories has a double effect on improving the quick ratio, since inside the brackets the minuend increases and the subtrahend decreases.

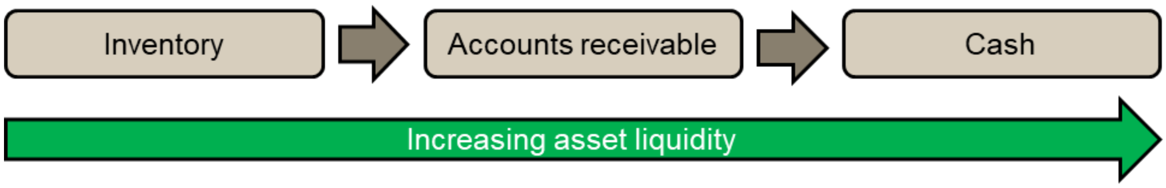

Figure 9. *Selling inventory and turning the current assets to a more liquid degree*

Therefore, from this accounting perspective, the reduction of excessive inventories implies that the resulting increased cash has improved the liquidity of the company by converting its assets to a more liquid degree. Quick availability of funds for any situation has improved.

Optimising inventory levels by converting excess inventories into cash has no impact on the amount of working capital, since the total amount of current assets and current liabilities do not change. However, it has impact on the working capital cycle (WCC), also known as cash conversion cycle (CCC) or cash-to-cash cycle (C2C). As explained by Hofmann and Kotzlab (2010, 308), WCC indicates how long the cash is tied up between procurement and sales. Adapting their definition of WCC, it is the time between (1) the payment of cash for materials and components that are used to produce the finished inventory items, and (2) the receipt of cash for sale of the finished inventory items. The equation for WCC is presented below as expressed by Templar et al. (2016, 53).

$$Working\ capital\ cycle = Inventory\ days + Receivable\ days - Payable\ days$$

While reducing inventories, the company is still producing and selling the same amounts as before. Therefore, paying and receiving cash do not change. Hence, the figure of inventory days decreases, and receivable days and payable days do not change, which can be explained through the formulas of the WCC equation components in Appendix 1. As a result, WCC decreases, and the free cash flow increases (Johal and Vickerstaff 2014, 139).

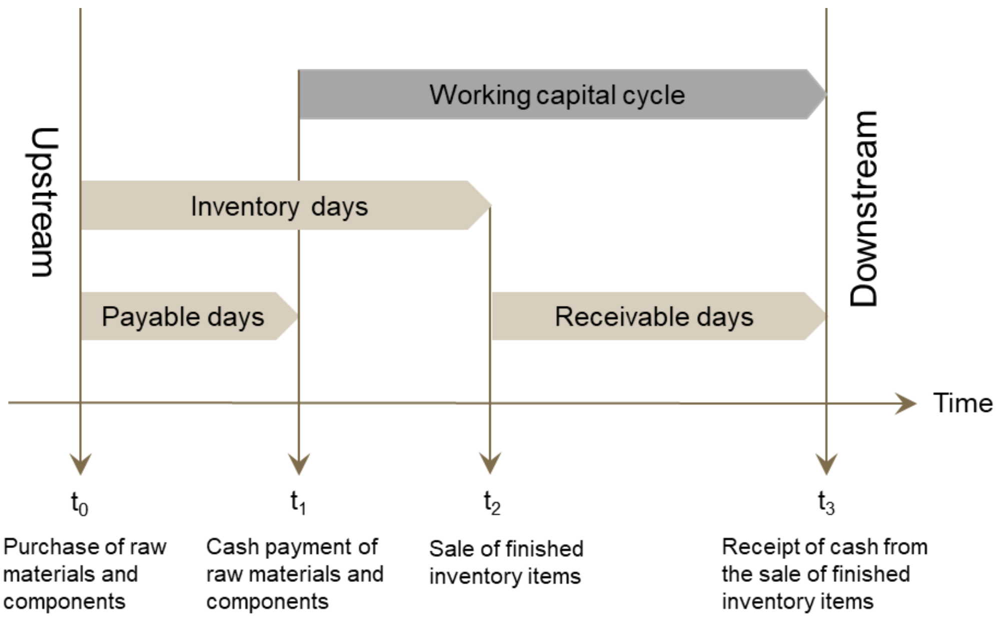

Figure 10. *Working capital cycle (adapted from Hofmann and Kotzlab 2010, 309)*

Figure 10 illustrates WCC as the time between points t_1 and t_3. Another element to consider is production, which can occur anywhere between t_0 or t_2. Then, the purchase price of the raw materials and components is carried into the value of the finished inventory item.

For example, Richards and Laughlin (1980, 36) identified WCC as a more insightful indicator than the current ratio and quick ratio for the amount and timing of funds for a company’s liquidity needs. Since understanding the usefulness of the WCC figure can be traced at least back to the year 1980, it should be well understood by modern day inventory practitioners who desire to display the financial impact of their inventory management activities.

A company should consider also it’s entire supply chain when attempting to improve its liquidity state by WCC management. The impact from it goes deep into the upstream supply network, not only to suppliers but also to sub-suppliers in many tiers beneath. As a consequence, the downstream supply network and customers are also affected. Templar et al. (2016, 68-69) call this network phenomenon the “liquidity domino effect”.

In addition to liquidity ratios, efficiency ratios may be affected by inventories. Efficiency ratios are also known as the activity ratios. Included ratios are the asset turnover, inventory turnover period, accounts payable turnover period and accounts receivable turnover period. (Johal and Vickerstaff 2014, 169)

Especially inventory turnover period is interesting, as it measures the ratio between the inventory level and the cost of goods sold in a given time period. It is also suitable in comparing the inventory performance of companies of different sizes. (Hançerlioğulları, Şen, & Aktunç 2015, 682). In this sense, it could also be used as the starting point for inventory benchmarking activities, where going deeper could expose useful inventory optimisation requirements.

However, the prior definition for inventory turnover is perhaps more suitable to retail and downstream. In a more generic approach, better suitable for upstream supply, inventory turnover can be calculated just as the ratio of how many days inventory is held within a year (Templar et al. 2016, 67). The ratio of the days divided by 365 shows how many times a full set of inventory is replenished in a year.

2.1.5 Inventory drivers

There are many reasons to hold inventories. These reasons contribute together to form the final inventory level of an item. They can be called the reasons that drive the existence of inventories. A single reason or a cause can be called an inventory driver, which can be turned into a variable amongst many others causing inventory levels (Sieben 2020).

Inventory drivers could also be referred to as the inventory parameters which may be considered from perspectives of item characteristics, cost, customer needs or many others (Sharma 2017, 1-3). On the other hand, Ganeshan, Boone and Stenger (2001, 112) identified the key supply chain performance parameters as service level, supply chain cycle time and return on investment. Hence, financial concerns come up among the drivers of both inventories and material flow. Cost-based drivers are also rather central in the domain of FSCM.

Ferrin and Plank (2002, 25) constructed an exhaustive list of total cost of ownership (TCO) drivers including pre-transaction, during transaction, and post-transaction categorisations. Sharma (2016, 128) adapted the list into eight factors for consideration of strategic sourcing decisions. Sharma claims these are applicable to manufacturing companies and used by leading supply chain software companies. The eight factors are listed below.

1) Product design cost
2) Maintenance and downtime cost
3) Operation cost
4) Quality related cost
5) Logistics costs
6) Inventory cost
7) Administrative cost
8) Transaction cost

Out of the eight factors, logistics costs and inventory costs are the two most obviously relevant to consider in this research. Logistics costs are relevant as different logistic chains and chain types can incur different costs. Inventory costs are relevant as the objective in this research is to decrease the inventory cost or release capital tied into inventories. Sharma divides these two factors into further sub-factors.

- Logistics costs
    - Transport costs including freight, packaging, handling, warehousing tariffs, duties and import fees, and outbound costs
- Inventory costs
    - Safety stock cost, out of stock costs

All the sub-factors could be considered as drivers of logistic chains and inventories, but they are limited to cost perspective. The inventory cost factors by Sharma thus only have two sub-factors, but Musacchia (2019, 60-66) on the other hand made an exhaustive review of 28 inventory drivers from different perspectives. In the end he used four inventory drivers in his Hilti-specific (linear) regression model to calculate inventory levels in pieces. The four drivers used were:

1) Demand
2) Lead time
3) Rounding value (a multiple of minimum order quantity, MOQ)
4) Inverted value of an inventory item

Another identified, but not used, inventory driver by Musacchia was the demand variance, expressed as a coefficient of variation. As Sheskin (2000, 39) explains, the values of standard deviation and variance are direct functions of the magnitude of the base values. This means that the standard deviation of demand and the demand variance increase proportionally as demand increases, leading into problems associated with multicollinearity when using any two of the three as an inventory driver in a single model. However, the coefficient of variance of demand does not lead into that problem, which makes it usable alongside demand. It gives a value of the deviation in relation to the demand as a figure that represents the degree of variability rather than absolute variability, which eliminates the problem. It is calculated according to the following equation.

$$Coefficient\ of\ variance\ of\ demand = \frac{Standard\ deviation\ of\ demand}{Demand}$$

In the end, cost in one form or another appears to be an important inventory driver. Typically, as the value of an inventory item increases, its inventory level decreases, so the inverted value of an inventory item is a good inventory driver. Demand is an obvious driver, and derived from that comes the coefficient of variance of demand. So far, that gives three inventory drivers

2.2 Benchmarking

When an organisation has optimised its practices or performance to the highest possible level with the internal knowledge and resources they have, it needs to start looking outside the organisation for improvements. Ways for achieving better performance is to find best practices from other organisations, where benchmarking can be used as a systematic process for identifying and implementing those practices (BPIR 2019).

According to Akinshin (2019, 11-12), performance analysis is a popular target of benchmarking. It can be used for several scenarios:

- Tuning performance parameters
- Measuring the impact of change in performance from the time before the benchmarking compared to the time after the benchmarking
- Prove a concept

In the context of this research, tuning performance parameters would refer to similar inventory items in different organisations having differences in the value of an inventory driver, and the one with the worse value would be tuned based on the better one. Measuring impact of change would refer to measuring the inventory efficiency before the benchmarking and after the benchmarking, and observing the actual change in pieces in stock, in capital tied, in inventory turnaround or other ways. Lastly, proving a concept would refer to this research being able to indicate that the VDI step model is not only applicable to the domain of prices but also to the domain of inventories. Though applying requires adaptation, it does not imply that the step model could not be used in a general way.

According to BPIR (2019) certain challenges in benchmarking exist. A cooperative partner needs to be found, meaning that also their staff including all relevant stakeholders are receptive to the job being done, and have the resources. Also Adewunmi, Omirin and Koleoso (2015, 180) reported that in one developing country resistance to change, not understanding the task, difficulties in data accessibility and collection, data accuracy and validity plus resources constraints were the most severe challenges.

Briscoe, Lee & Fawcett (2004) studied benchmarking challenges to supply chain integration. Finding best practices along the end-to-end supply chain can increase organizational competitiveness, and benchmarking can be used as the tool to serve that purpose. However, challenges arise from physical and institutional distance as it creates inertia to change. Responsibilities are easily bounced back and forth between subsequent tiers in the chain if proper technical support is not provided. (Briscoe et al. 2004, 154-154) Therefore, optimising logistic chain efficiency via cross-company benchmarking requires a lot of effort in managing the different stakeholders along the chain.

The Supply Chain Operations Reference (SCOR) model 7.0 by Supply Chain Council (2005) is a model for applying state-of-the art supply chain management practices. In SCOR best practices regarding management of products and finished goods inventories comparisons to industry benchmarking can be found. The benchmarking can be done comparing the company's own past performance to its current performance, or comparing to other companies in similar or different industries. It is easier to compare a company's own performance, which can lead to steady improvements on strategic targets. In the SCOR model, benchmarking process is defined as "*quantifying the operational performance of similar companies and establishing internal targets based on 'best-in-class' results".* (Supply-Chain Council 2005) A strategic target for a case company in this research would be a high return on capital employed, which could be reached by finding optimisations in inventories through benchmarking.

Kailash & Saha (2017, 1670) state that before moving to cross-organisational benchmarking, it would be advisable to first do internal supply chain management benchmarking. They claim that the internal supply chain management (ICSM) benchmarking practice is vital for improving competitiveness in manufacturing industry. Both Kailash & Saha (2017, 1672) and Briscoe et al. (2004, 153) point out that support from senior management and executives is necessary for fruitful benchmarking. This makes sense as BPIR (2019) and Adewunmi et al. (2015) report unreceptiveness to benchmarking and inertia to change as challenges.

2.3 Optimisation and measuring efficiency

Something that is optimal can be described as being as efficient as possible. The measure of efficiency is the ability to obtain the maximum output from given inputs. Efficiency could also be defined as minimising input to obtain a given output. By considering inputs for production we could formulate a *production function,* which reflects "*the state of technology, including applied technique, organization, knowledge and experience"* as the *factors of production.* (Jarzębowski 2013, 178) The two following formulas are derived from that definition.

$$\eta = \frac{output}{input}$$

Where *η = efficiency*

$$w_1 i_1 \cdot w_2 i_2 \cdot w_3 i_3 \cdot w_4 i_4 = Production$$

Where *w = weight (coefficient)*
i = input variable (factor of production)

When the right-hand side of the equation, i.e. output or production, is known, the different input variables constituting to it can be backwards derived, or at least assumed. The weights for different input variables can be varied and the resulting output iterated to see which composition generates the highest output, which could be measured as a pareto efficiency or as the allocative efficiency. The link to this research is the following: in the linear equation of PP, the weights and inputs appear as the coefficients and the inventory drivers, respectively.

2.4 Efficiency analysis methods

Efficiency can be calculated and evaluated through different methods. In the academic literature, efficiency analysis methods can be divided into two branches of nonparametric and parametric methods (Andor and Hesse 2012, 1). Commonly used methods stemming from these two branches are data envelopment analysis

(DEA) and total factor productivity (TFP) indices, which belong to nonparametric methods, and stochastic frontier analysis (SFA) and least squares econometric production models, which belong to parametric methods (Coelli, Prasada Rao, O'Donnell and Battese 2005, 6-7).

A parameter is a characteristic of a population (Sheskin 2000, 31). In statistical tests the population parameters characterise the distribution that is formed. Using a parametric statistical test or a method requires making a specific assumption of one or more of the population parameters, while a nonparametric test or method does not require such assumptions. (Sheskin 2000, 63)

2.4.1 Data envelopment analysis

For efficiency calculations, in order to optimise the relationship of input and output, a data envelopment analysis (DEA) could be used. (Ji & Lee 2010, 268) Regarding the inventory of a company in manufacturing industry, the concept could be applied roughly with physical or capital input to the inventory and physical or capital output from manufacturing. Physical would refer to the number of components, parts and finished goods, and capital would refer to the investments and profits made.

DEA was introduced in 1978 by Charnes, Cooper and Rhodes as a performance measurement for decision-making units (DMUs). Originally designed to measure efficiency in a situation where all DMUs would operate at their optimal level, giving a constant returns to scale (CRS), the method was later extended to variable returns to scale (VRS). With VRS it is possible to consider breaking the efficiency into technical details and modelling scale efficiency. (Ji & Lee 2010, 268) Scale efficiency refers to size modifications rendering the DMU as less efficient.

Data envelopment analysis can handle multiple performance metrics, that are the inputs and outputs. It classifies the analysed DMUs into a set of efficient DMUs, forming a best-practice frontier, and a set of inefficient DMUs. Once the frontier is created, adding or deleting an inefficient DMU does not alter it nor the efficiencies of the existing DMUs. Therefore, it can be stated that all DMUs are benchmarked against the frontier of efficiency. Two approaches in benchmarking exist, namely “context-dependent” DEA where the evaluation is done against a particular evaluation context, and another approach where the evaluation is done against a set of given benchmarks. (Zhu 2015, 292)

According to Andor and Hesse (2012, 1) DEA is the most important nonparametric efficiency measurement method. They explain that DEA functions without considerations of the statistical noise, which makes it a deterministic method. Furthermore, they state that the lack of noise considerations and statistical measurements is the method’s main disadvantage. Due to that it is not possible to figure out if measurement errors have been made or variables omitted (Andor, Parmeter & Sommer 2018, 6). However, Andor and Hesse (2012, 1) state that the main advantage comes from the nonparametric nature, which increases the flexibility of the method.

2.4.2 Stochastic frontier analysis

Originally stochastic frontier analysis (SFA) was proposed for production estimation by Aigner et al. in 1977 and Meeusen and Van den Broeck in the same year. With the method, a frontier of production can be created, defined by the underlying technology. Fully efficient producers may realize maximum output for given inputs, while inefficient producers fall below the frontier. Hence, SFA is a method that allows technical inefficiency in the estimation of the production function. (Wang 2008, 1) Coelli et al. (2005, 242) wrote that the original stochastic production function proposed by Aigner et al. and Meeusen and van den Broeck took the following form:

$$ln\ q_i = x_i'\beta + v_i - u_i$$

Where *q = the output of the firm i*

x_i *= a vector containing the logarithms of inputs*

β *= a vector of unknown parameters*

v_i *= statistical noise*

u_i *= a random variable for technical inefficiency, greater than or equal to zero*

This means that when calculating the output of the firm, the method accounts for the deterministic part ($x_i'\beta$), noise (v_i) and inefficiency (u_i). The ability to account for the statistical noise is the strength of SFA over DEA (Coelli et al. 2005, 261). Requirement for the noise considerations can act as a cut-off point in method selection process in favor of SFA.

Stochastic frontier analysis is most often applied to estimating production and cost functions (Wang 2008, 3). However, when estimating efficiency using SFA, a distance function, cost frontier, profit frontier or a single-output production frontier can be created. The vast possibilities, and especially the requirement to make many decisions such as regarding the functional form, error distribution, estimation methods and software is the main disadvantage of SFA as a parametric method (Coelli et al. 2005, 288).

2.4.3 Performance pricing

Performance Pricing (PP) is a multiple regression based efficiency measurement method that is originally designed for price optimisation. The method is described in VDI 2817 (2018), which is a technical standard created by The Association of German Engineers (Verein Deutscher Ingenieure). In a nutshell, the method is used to statistically evaluate the price of products, similar to other methods such as true cost analysis (TCA) or total cost of ownership (TCO) (VDI 2018, 2-3). This chapter encompasses a summarisation of the key elements of the PP method explained in VDI 2817 relevant for this thesis.

The price of a product is a sum of multiple factors, or variables, which describe its characteristics. Relevant characteristics to be taken into account can be, among others, weight, color, material, strength or size. These are very general characteristics that can be described for many items found in the market. For analyses of specific items, the characteristics become specific as well, and can be unique to the item, for example thread pitch variance for screws.

Once the most important characteristics for the items to be analysed are decided, they shall be measured for all the items taken into the analysis. The beauty of the

PP method comes from the fact that the analyst does not need to decide the weighting factors, or the coefficients, that describe the importance of different characteristics to the item. The method objectively sets weighing factors for each item based on comparing the items in the sample with each other. That is achieved through a statistical procedure, where software can be used to go through the calculations. Analycess Procurement is designed for that purpose.

Once the data is analysed, the items are given a technical figure that is the target of the analysis. In price optimisation, this is called “technical value”, which is the statistically calculated theoretical price of an item, which the analysis suggests should be its price based on the given variables and the sample. The technical value is then compared to the actual price, and then it is possible to evaluate whether the item is efficiently valued or not, i.e. whether the technical value is above or below the actual price. Once the data is plotted in a “value graph”, the items are distributed above and below a 45-degree line as illustrated in Figure 11. Items exactly at the 45-degree line are deemed correctly valued, as the technical value is indicated to be the same as the real value. Items above the line have a higher actual price than technical value, which suggests that they are overpriced. Items below the line have a higher technical value than actual price, suggesting that these items are favorably priced in comparison to other items in the sample, meaning that based on their characteristics, a higher price could be asked at the market. This favorability counts for the buyer, but on the other hand the seller might conduct the analysis and find out that they are underpricing their technical superior items compared to inferior and more expensive items of the competitors.

The technical value of all items can then for instance be described by a multiple linear regression equation:

$$Y = \alpha_1 x_1 * \alpha_2 x_2 * \alpha_3 x_3 \dots \alpha_n x_n + \varepsilon,$$

Where α resembles a weighting coefficient of a variable, x resembles a value of a variable and ε resembles the residual, i.e. the difference from the real value. Graphically the results look like Figure 11, where the black dots resemble individual items.

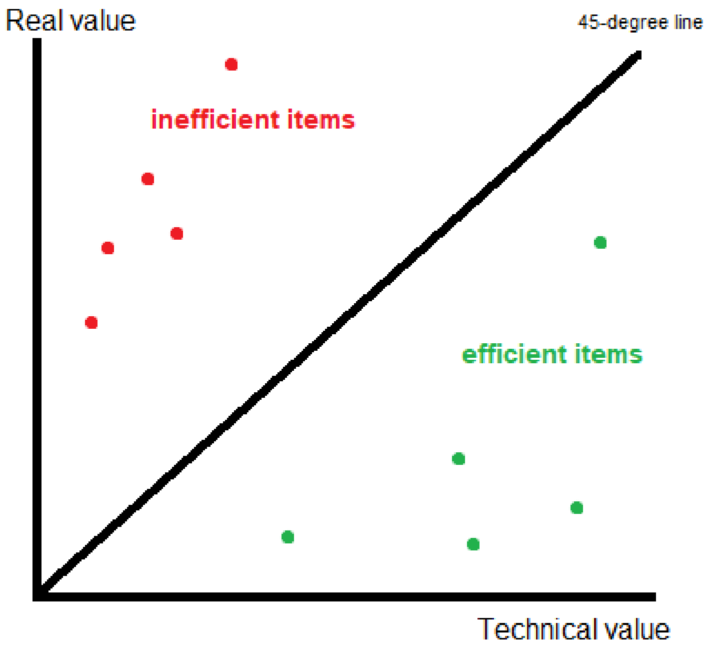

Figure 11. *Value graph*

2.4.4 Methodological comparison

There are many reasons that influence the reasons why a certain method is to be chosen for an analysis. A few examples are capabilities of the personnel, IT infrastructure, available systems and software, and nature of the observations and the data. Lastly, Bauer et al. (1998, 111) point out that the results drawn from the different approaches should reflect reality, which is the main concern in deciding which method to choose.

To compare the methods and their suitability for the way this inventory optimisation is wanted to be done, seven criteria deemed important were selected and evaluated in Table 3. Common use cases of the two other methods, SFA and DEA, were reviewed in Table 4 to see where they are best suitable, and if projects with many similarities than this research have been carried out using them.

In the process of gathering information for the two tables, the author discovered a major doubt appearing multiple times in the literature compromising the two methods, as illustrated in Table 5. Information gathered to build the three tables are compiled in Appendix 2.

Table 3. *Comparison of SFA, DEA and PP*

	Criteria	SFA	DEA	PP
A	Sensitivity to outliers	●	○	●
B	Sensitivity to measurement errors	◕	○	●
C	Selection of drivers / Robustness	◕	◔	●
D	Required function knowledge	◔	●	●
E	Statistically measurable	●	○	●
F	Required computational demands	◔	◕	◕
G	Simplicity	◔	◔	◕

	Harvey Ball	Explanation
1	●	Easiest, most suitable, or of highest quality
2	◕	Easy, suitable, or of high quality
3	◔	Difficult, less suitable, or of worse quality
4	○	Most difficult, least/not suitable, or of worst quality

In Table 3, a full Harvey ball is the best score while an empty one is the worst. PP and SFA score fully in criterion A, which is fundamental for quick identification of optimisation potentials. Criterion B refers to data quality issues and C to the choices made in approach, where PP is the most flexible in handling errors.

A very important criterion is E, statistical measurability, which is a “simple” way to indicate scientific “goodness” of a model. Various statistical tests can be performed with PP but DEA is completely out of the picture in this criterion. Besides this major drawback, DEA is only equal to or worse than PP in all criteria. In addition, it beats SFA only in criterion F by being less computationally (time) demanding, and in it’s only *real* strength, criterion D.

With the selected criteria, PP is overall the best choice followed by SFA, and DEA is the worst choice being far behind the other two. SFA is relatively near to PP but its main drawbacks are criteria D and G, which make it mathematically too complicated for many organisations, and more challenging to widespread adaptation by practitioners within, respectively. PP on the other hand is rather simple to jump into.

Table 4. *Some application domains of SFA and DEA*

Application domain of SFA and DEA	Source
Technical efficiency of 240 crop farms in Bangladesh	Theodoridis & Anwar 2011
Operating efficiency for 27 international container ports	Lin & Tseng 2005
Hospital units' efficiency	Katharakis et al. 2014
Technical and scale efficiency of fresh fruits farms in Greece	Karagiannis & Sarris 2004
200 Meat processing companies in Poland between 2006-2011	Jarzębowski 2013
NHS Hospitals' (Trusts) efficiency	Jacobs 2001
Productivity and efficiency of Bangladeshi rice	Hossain et al. 2012
Relative operating efficiencies of cattle feedlot farms in Iran	Ghorbani et al. 2010
The cost efficiency of German banks	Fiorentino et al. 2006
Mean technical efficiency in microfinance	Fall et al. 2018

After a review of use cases of SFA and DEA, illustrated in Table 4 with 10 examples, it is clear that the methods can be applied to a multitude of different domains, ranging from the efficiency analysis of farms to hospitals, banks and more. In contrast, Performance Pricing has been well accepted in cost engineering, supply management and controlling circles where value drivers are defined and measured. Some of those drivers may be or fall near to being inventory drivers, and therefore using the method in inventory management is a natural next stepping stone to be considered.

Recommendations to use both SFA and DEA also exist in the literature. In addition, combination methods of the two, like “Three-Stage DEA” and “StoNED” (Näf 2015) are available for analyses. Table 5 refers to the recommendations and combination methods.

Table 5. *Recommendations to use both SFA and DEA in an analysis*

Quote	Source
"Given the limitations of frontier techniques, it may be that they are best employed in tandem, when possible"	Katharakis et al. 2014, 355
"Due to the infirmities of the deterministic methods (in the context of the validation of the obtained results), the efficiency measurement basing on integrated use of the SFA and DEA method was applied"	Jarzębowski 2013, 173
"Given their different strengths and weaknesses, several studies […] have compared efficiency estimates obtained from these two approaches. The results […] from DEA and SFA often yield quite different distributions of measured efficiency."	Karagiannis & Sarris 2004, 151
"Choice of modelling approach does affect the results"	Jacobs 2001, 105
"The parametric and non-parametric methods are not generally mutually consistent"	Bauer et al. 1998, 110
"The use of multiple techniques and specifications is likely to be helpful"	Bauer et al. 1998, 111

In the literature, it is easy to find authors that express their doubts about the validity of SFA and DEA. The doubts have pertained for decades as can be seen in Table 5. There is no clear consensus on which modelling method is the better one, if that kind of a question would even be applicable due to the different fundamental natures of the methods. In any case, such dispute may always leave an analysis performed by either method questionable. Not that Performance Pricing is safe from doubts either, but to aggravate things more, SFA and DEA may also be carried out by different efficiency techniques, which use different equations that yield yet again differentiating results. This leads to the often-occurring recommendation to use the two methods in tandem to be able to figure out the real efficiency. Using both SFA and DEA signals three negative implications:

1. Double work required for the analysis.
2. A flaw in either or both methods.
3. In many cases it is not possible to use both SFA and DEA.

With these deficiencies, it is just simpler to choose Performance Pricing. The technical standard status it has reflects the consensual scientific trust in the method.

3 METHODOLOGY

3.1 Concept and adaptation

Performance pricing is a price estimation method with cross-organisational application, and technical standard status in Germany (VDI 2018). Based on multiple regression, it can be used to evaluate also other variables than price.

The method does not have a strong empirical background of its suitability to inventory management. It could become a multi-criterion inventory management method that provides new approaches and insights to inventory optimisation. As of 2020, inventory optimisation potential by the method may be undiscovered, and a new context-flexible inventory management method could be established with it.

The technical standard's applicability to inventory management needs to be improved. Adapting the concept from VDI 2817 to inventories follows the same seven step model as described for cost optimisation, with the difference that step one considers inventory items and step two considers inventory drivers. Figure 12 shows the adapted steps.

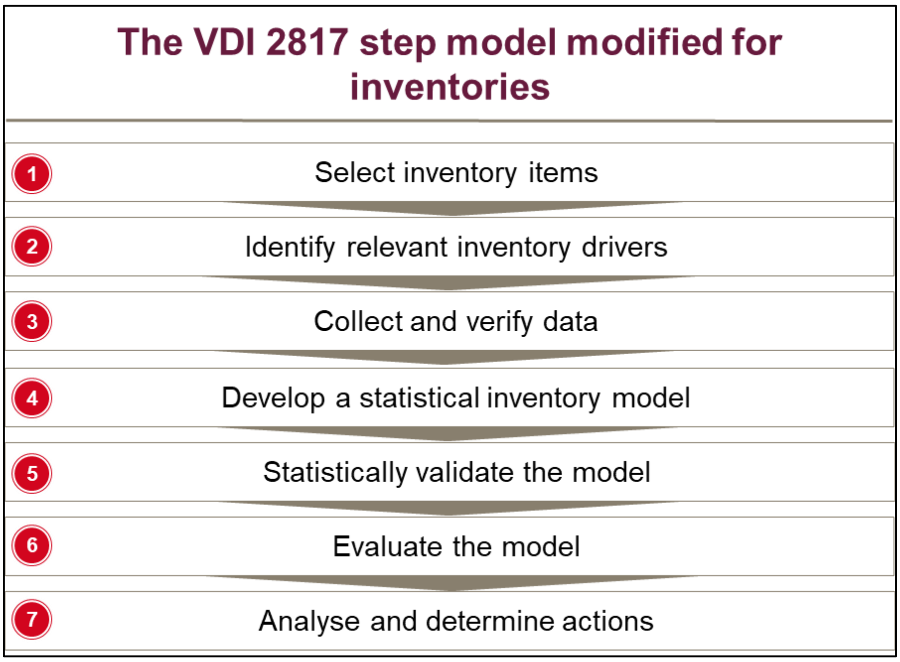

Figure 12. *The VDI 2817 step model adapted for inventories*

The results obtained with the analysis then do not show technical value, but instead technical inventory level, i.e. the statistically calculated inventory levels. Likewise, the real value is the actual inventory level. This can be seen in Figure 13 where the abscissa and ordinate are named accordingly. Hypothetically, a benchmarking line could be found by the graphical analysis. If a benchmarking line was not deemed reasonable, the inventory optimisation would be done according to the average line.

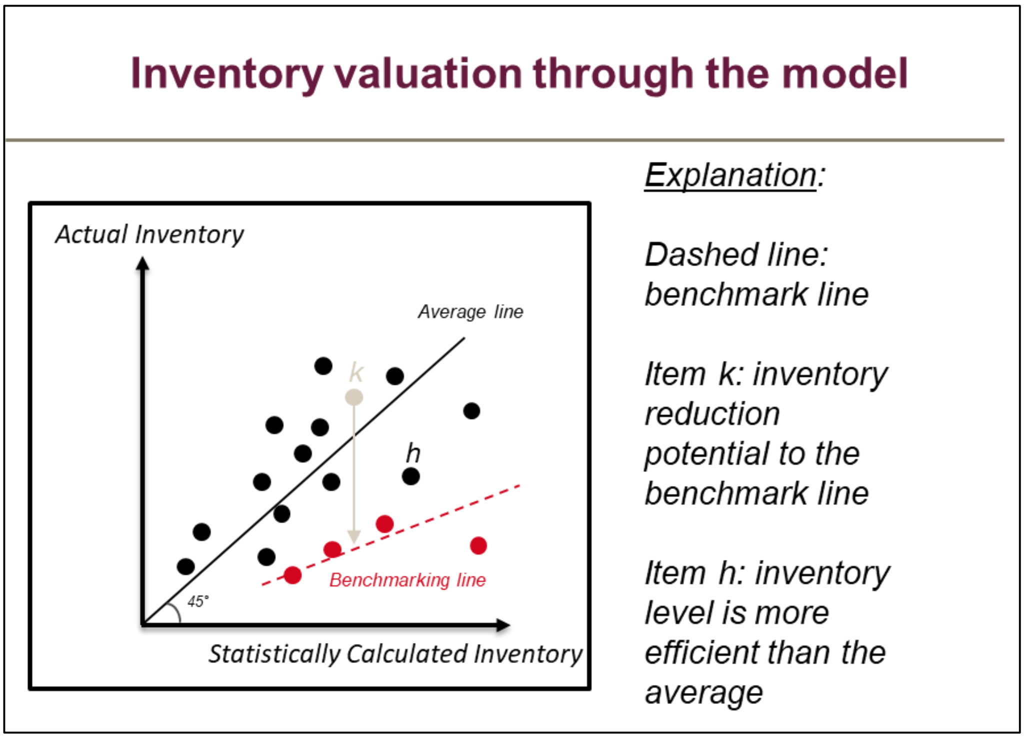

Figure 13. *Inventory valuation through the model*

3.2 Multiple regression

A simple regression model can be written as

$$Y = \alpha + \beta X + \varepsilon$$

Where *Y = dependent variable*

α = constant

β = coefficient of the independent variable

X = independent variable

ε = error term

On one hand, a simple regression model is used to model the relationship of two variables, and use the model to predict the value of the dependent variable based on the independent variable (Lee, Lee, Chang & Tai 2016, 447). On the other hand, a multiple regression model can be written as

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ \dots\ + \beta_k X_k + \varepsilon$$

The relationship of more than two variables examined with regression analysis is called multiple regression analysis. It contains one dependent variable and more than one independent variables (Lee et al. 2016, 513). Multicollinearity is one potential problem of the method, and refers to how the independent variables are correlated with each other. In an ideal model the selected independent variables do not correlate with each other, but usually some degree of correlation is present. (Lee et al. 2016, 545-546)

3.3 Formal methods

There are various ways to analyse the statistical validity of a model. The software Analycess Procurement reports a few purposefully selected figures to the user for the analysis. Illowsky and Dean (2013, 690-691) explain the following evaluation measures.

- **r**, the coefficient of correlation
    - Indicates the *strength* and *direction* of the linear relationship of the dependent and independent variable. Can have a value between -1 and 1. Interpretation of this value is expressed in Table 6.
- **r^2**, the coefficient of determination
    - Square of the coefficient of correlation. Indicates how much of the variation in the dependent variable can be explained due to the variation in the independent variable.

- **adjusted r^2**, the adjusted coefficient of determination
  - Modification of r^2. Takes the data points and independent variables into consideration. Value increases only if a newly added independent variable improves the model more than would be expected by chance. (Processbench 2014)

According to Saunders Lewis and Thronhill (2016, 545) the correlation coefficient can be interpreted according to the following way presented in Table 6. It is just a general orientation because in reality interpreting r-values is a relative matter depending on the reasons it has been computed and what it is used for (Guilford 1942, 219).

Table 6. *Interpretation of r-value*

r-value	Interpretation
(-1.00)	Perfect negative relationship
(-0.99) – (-0.80)	Very strong negative relationship
(-0.80) – (-0.60)	Strong negative relationship
(-0.60) – (-0.35)	Moderate negative relationship
(-0.35) – (-0.20)	Weak negative relationship
(-0.20) – 0.20	No relationship
0.20 – 0.35	Weak positive relationship
0.35 – 0.60	Moderate positive relationship
0.60 – 0.80	Strong positive relationship
0.80 – 0.99	Very strong positive relationship
1.00	Perfect positive relationship

- **Q^2**, the Stone-Geisser criterion
  - Indicates stability of the model. In general, it shows how single data points influence the statistical model. Possible values range between $-\infty$ and 1. Negative values indicate an unstable and untrustworthy model, and values close to 1 indicate a stable model. (Processbench 2014)

- **F test**,
  - Tests the validity and predictive capability of the model beyond the considered sample. Calculated as the proportion of explained variance of Y to unexplained variance of Y. The larger the F value, the more likely the right independent variables have been chosen, and the regression function is more realistic. (Processbench 2014; VDI 2018, 22)
- **F critical** (also known as **F statistic**),
  - States the F value for a given probability level that deviations in the input data lead to a higher F value. Probability level of 0.3% is used in Analycess Procurement. (Processbench 2014) Null hypothesis can be rejected if the value of F critical is smaller than the value of F test (Lee et al. 2016, 519).
- **signif F**,
  - Probability value related to F test, telling whether the model has statistically significant predictive capability. Lower values indicate higher likelihood to reject the hypothesis that all coefficients are 0. Value should be lower than 0.05 for 95% confidence level. (Processbench 2014)

By using these criteria, the validity can be evaluated by many perspectives. It is always important to validate a theory, procedure and a result. It can be done in multiple ways such as consulting practitioners who can validate through experience. However, statistical validation, on the premise that the indicators are evaluated correctly, gives a validation through nature.

3.4 Quantitative study

The key characteristics of quantitative research are that it includes numerically measured data, which is used to examine the relationships of the variables. Ample statistical and graphical techniques are available for analysis. Then, it is possible to utilise a single or multiple data collection techniques and analytical procedures in research. (Saunders et al. 2016, 166)

In favor of multiple quantitative analytical procedures, Bryman (2006, 111) states that such an approach can lead to new understandings. It is reasonable to assume that multiple procedures provide more information from different perspectives. However, Wilkinson and the Task Force on Statistical Inference (1999, 598) recommend *“choosing a minimally sufficient analysis”* to find answers to questions. Indeed, even when more and more could be learned by multiple analyses, simplicity and a single purposeful procedure with the final objective in mind might be the better choice to obtain a sufficient result in time.

A single simple procedure is elegant at its best. Linear regression is simple since it expresses either a direct or inverse relationship of two variables. Multiple linear regression is a combination of multiple such simple relationships. Even though this constructs a simple premise for the procedure, it requires the researcher to go deeper in many aspects before being able to present the rather simple and easily understandable graphical regression plot. The start and the finish are simple, but the complexity of the detailed work between them is not to be underestimated.

Another perspective to quantitative data can be addressed by comparing its nature to the nature of qualitative data. Quantitative data can be expressed by exact numbers, which have universally an exact one meaning. Qualitative data is not exact but rather characterising or approximating the observations and leaving room for interpretation. In this sense, it could be said that the availability of quantitative data means that the variables or phenomena being studied are understood better, to the extent that they can be represented with universal language of numbers, mathematics and statistics. For example, if it is known how to break down a single qualitative variable into multiple variables that can be pinpointed with quantitative numbers.

4 MODEL DEVELOPMENT

4.1 Choosing inventory items and attributable inventory

To maintain relevance in the entire analysis, it is important to consider the reasons how inventory items are selected. Choosing items is the first step in the seven step model of VDI 2817 so it serves as the starting point for the model development, and therefore influences the rest of the six steps by creating limitations.

Multiple possible approaches for the selection procedure exist. There are thousands of unique inventory items for both case companies alone, so the population of potentially usable items is in the thousands as well, or even above ten thousand depending on how uniqueness is defined. When the final sample of items is in tens or hundreds, it would be large enough for generalisations to be done, yet limited enough to keep the scope of the analysis within reasonable extent. Therefore, aiming at 50-1000 items in the final analysis would be justified to a certain extent.

In the end choosing the items follows some kind of categorisation-based approach. Companies have their own ways to categorise, classify and group items, some of which may be their in-house-developed methods or more generally accepted universal categories. The latter is better, as it allows for an easier way to do inter-firm comparisons of items. For example, Hilti is beginning to implement the UNSPSC (United Nations Standard Products and Services Code) in its material group taxonomy to categorise items using a general categorisation procedure. However, at the time of this thesis, Hilti-specific categorisation system was still in use. In the case of Finder, similarly, a categorisation system developed by themselves for their own purposes was in use. Therefore, the categorisation methods were different but specifically developed by the companies' employees to best serve their inventory items.

In addition to categorisations, the actual warehouse where the items are stored plays a role. Items are often found in multiple warehouses in multiple locations, and not only in one warehouse. Figure 14 illustrates how a logistic chain can include multiple storage locations and an item can be stored as an individual part or included in a manufactured tool. Which position of the item is considered to the attributable inventory has to be decided. In Figure 14, HC stands for “Hilti Center” where customer buy the end product and CW stands for central warehouse. The red lightnings show the many possibilities where a disruption in the logistic chain could occur. As there are many of them, it reflects that each inventory may play an important role in ensuring continuous business operations.

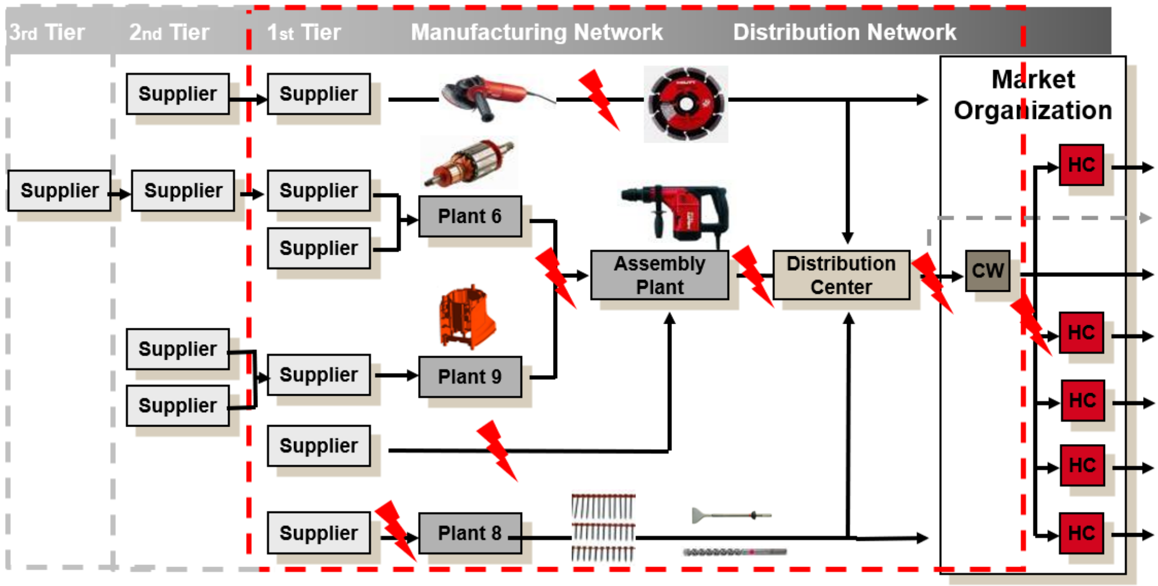

Figure 14. *Example of logistic chain complexity influencing the measuring of attributable inventory (Hilti AG 2019, internal source)*

Therefore, to avoid complexities, single warehouse for each case company was chosen. For Hilti it was the warehouse of an assembly plant in Austria. Finder it was a single warehouse in Germany, in the same building with the regional head office and assembly. Therefore, both warehouses include items that go into production and are assembled into finished items together with other inventory items, but also finished or *pure* items that for example come from suppliers and are branded as the case companies’ items. In the latter case the warehouse only serves as a sort of interim storage for the items along their logistic chain.

Since the items and how they are categorized in the companies are defined differently, the same item selection procedure cannot be applied to both companies exactly the same way. Therefore, attempting to compare items of same or similar categories is challenging. Some differences in the details could be hard to spot, yet not recognizing them could impact the actual reliability a lot.

Items from Hilti side were chosen from a pre-collected, ABC analysed dataset. The reasoning behind this was that those items were analysed with the Performance Pricing method against each other in an intra-company case. To generate more information about the optimal inventory levels of those items, the next step would be to analyse them from another perspective, where the benchmarking in this thesis comes into use. With that being said, choosing those items into this analysis allows Hilti to advance in understanding the optimal inventory levels of those items.

Finder items were chosen based on uniqueness. Finder catalogue of items includes different types of items, which are put into 12 groups. These 12 groups then include different categorisations for the items, which are called *series*. Some groups have many series, but four groups have only one series. These four groups with four series were chosen for the analysis with item category uniqueness in mind. In addition to them, two other groups that include two and four series, were chosen. In total, six groups were chosen, and all serieses from each group were taken to the analysis.

Once the selections were made for both case companies, a further selection procedure was applied to the entire dataset. The final selection procedure limited the items to the ones that have between 300 and 7000 pieces as the average inventory level. This was done to put the items in the same scope in terms of pieces stocked. 300 was chosen as below that there were only Finder items, and 7000 as above that was mostly Hilti items. Therefore, the 300-7000 limitation took a cross-section of the possible inventory levels of the item groups, such that both companies would be evenly and fairly represented.

Ideally, the method works with any items and whether similar or different items have been chosen. In the end the selection procedure for the analysis in this thesis combines items with similarities, differences and uniqueness, therefore creating a sample that can again be used in further analyses for example by delimiting it to only items similar with each other.

4.2 Defining and justifying the chosen inventory drivers

The available data from the case companies included many parameters that could be considered as inventory drivers, as listed in Table 7. Case A had 13 drivers and Case B 10 drivers to be potentially used in modelling. Some of them, are not entirely independent figures but derived from another driver. For example, both demand variance or lifetime consumption have a clear relationship with demand. Therefore, they can be achieved only by performing a calculation to the demand figure. For case B, lifetime consumption was readily available in the ERP system, but to obtain demand variance, a programming code needed to be run through the data. Actually, to obtain demand as an average of 12 months for case B, even in that case a programming code was required to run the calculations converting demand from transactional demand to the average demand.

In addition, some of the drivers had too low data quality. For example, the value of MOQ saved in the ERP system of case B could not be confirmed to be accurate, and therefore not used in the analysis. On the other hand, the inventory driver weight did not improve the model, but rather deteriorated it and therefore was not used. Lastly, the inventory drivers used in the model had to be available in both companies. This kind of reasons lead to the final selection of inventory drivers.

Table 7. *Potential inventory drivers per case company*

Case A – inventory drivers	Case B – inventory drivers
Demand	Demand
Demand variance	Demand variance
Price	Price
MOQ	MOQ
Material group	Material group
Supplier	Supplier
Weight	Weight
BI Risk	Lifetime consumption
Material manager	Price group
Product availability	Statistical group
Rounding value	
Lead time	
Lead time variance	

Three main inventory drivers could be considered for the final model: demand, inverse coefficient of the variance of demand (reflecting demand variance), and inverse price (reflecting item price). The first of them, demand, is very simple since inventories – as an interim storage location for items – have to exist somehow if, for example, production items are not sold to customers with an extreme just-in-time manner like directly from the production line. With stable demand, it is expected that inventory levels reflect the wished inventory turnover rate.

However, demand is often stochastic and difficult to forecast, but history can tell how much variance there has been in demand of different times. Variance, or standard deviation, or even a coefficient value of “standard deviation over demand” can be used to represent the changing demand figure. The variance should be a smaller influencer than the actual demand itself, and could be expected to increase inventory levels by a bit to cover for times when higher than average demand occurs. On the other hand when lower than average demand occurs, demand variance factor taken into account in calculating inventory levels could add up to extra high levels of inventory in some cases. Justification for that would still be that it is more important to cover stock-outs for the high demand times.

It makes sense to consider the price of an item, as the more expensive the item the more capital it binds to the inventory. Therefore, in inventory analyses the ABC analysis is often one of the simplest methods used to focus on the expensive items. To keep cash available, expensive items should be kept with as low inventory levels as possible. Opposite to that, it makes sense to have large stockpiles of inexpensive items as it may decrease the effort and time used in the management of their inventory levels and also purchasing by conducting activities only occasionally in this regard.

4.3 Data standardization and harmonization

In benchmarking it is crucial that the data collected from different companies is uniform or can be harmonized effortlessly (VDI 4400, 2-3), since it grants validity to the indicators, i.e. the variables, and makes comparisons possible.

Items could first be categorised in slow moving and fast moving items, as these have a different behavior. A slow moving item is kept in the warehouse for more than a year without movement, and a fast moving item has movement each year. One year time period was chosen for the analysis, therefore rendering items that move slower than that inapplicable. The reason for that is the fact that collecting data for some variables requires transactions during the considered time frame. For variables that are time dependent, one month was used as the factor of time. This means that for example in case of average inventory, demand, and demand variance, one value for each month during the year was taken into consideration. In the end 12 monthly averages for inventory, demand, and demand variance were obtained.

Since data from different organisations was used, pre-processing the data before conducting the analysis became one crucial element of the work in order to have standardised data. It is not surprising that larger enterprises, such as case company A, have more data in many ways, such as the amount of collected raw data, older data collected longer time ago, more types of data and variables collected, more observed phenomena and physical elements, and more readily pre-processed figures made out of those. The processing of calculations might be integrated as an automatic function in the system, which then makes analyzing information faster and could lead it to becoming a routine activity. In large enterprises the need to monitor and maintain the established systems and keep up with the vast amounts of information exchanging every minute creates the need to have automatic processing, as otherwise the paths to access certain information would be too complicated and time-consuming, hindering progress in the enterprise.

On the other hand, for case company B the matter is different as they are a smaller enterprise. The data collection processes have been established but not to as sophisticated or well-maintained level. For the analysis purposes in this thesis, a file containing transactional data for inventory items was provided. Consisting of all transactions of all items in the considered inventory during the chosen one year time frame, the master file had over 250 000 transaction lines, each with almost 30 variables, leading up to a total of roughly 7 million data points. During the research, actually two similar files were made available with the difference of coming from different one year periods. The one with the more recent timeframe was chosen in the end to give as contemporary information as possible.

With such a large amount of data, clearly filtering, pre-selecting and pre-processing of data was necessary. To cope with the massive amount of information, programming activities were included in the process. Originally working with plain Excel functions and Pivot tables were used, but processing the data with them was deemed too limited and wanted figures were not possible to obtain conveniently for the mass. Different programming languages to be used were considered such as Python, VBA and R, which is a good programming language for statistical purposes as is the nature of this thesis.

In the end VBA was chosen due to the easy access to it as it is readily available in Excel. VBA stands for Visual Basic for Applications and was introduced by Microsoft in Excel version 5.0 in 1993 (Clough 2017, 40). It is a programming language, where the code is often referred to as macro code (Morgado 2016, 1).

Given the nature and scope of the research, the programming task was given to an external programmer. This required again additional stakeholder management skills and multiple rounds in discussions with the programmer. The discussions revolved around explaining the purpose of the task, the mathematical calculations, explaining the format of the master file, and the required outcomes. In the process of programming, interim checks of the results were made and finding errors and mistakes both in the instructions and the code were found, and so corrections were made as they were noticed.

4.4 Analycess Procurement

The software used to conduct a large part of the processing and analysis of the empirical data in this thesis is called Analycess Procurement. For the most part it is a tool that helps the user in the multiple regression analysis by performing mathematical calculations required to create and visualise the desired model. The software also reports many additional features about the data and the model such as various statistical indicators among other graphs and figures.

Analycess Procurement is the core product of the software company Processbench, which began as a spin-off of the Fraunhofer Institute for Material Flow and Logistics. Founded in 2006 with German-Dutch roots, Processbench GmbH has been managed by the German company Institut für angewandtes Mechanismus Design since 2013. (Processbench 2020) In addition to Hilti, companies listed in DAX stock market index are among the users of the software (IFAMD 2019).

Originally designed to analyse the value of products or services (Processbench 2014), the software can be adopted into analysing other things as well via the regression mechanism programmed in it. With a few changes and a bit of an effort, also inventory levels can be analysed. Figure 15 shows just a few of the many features of the software's user cockpit, such as the graphical representation of the linear regression model, the user-friendly indication of model validity and the actual values of various statistical indicators.

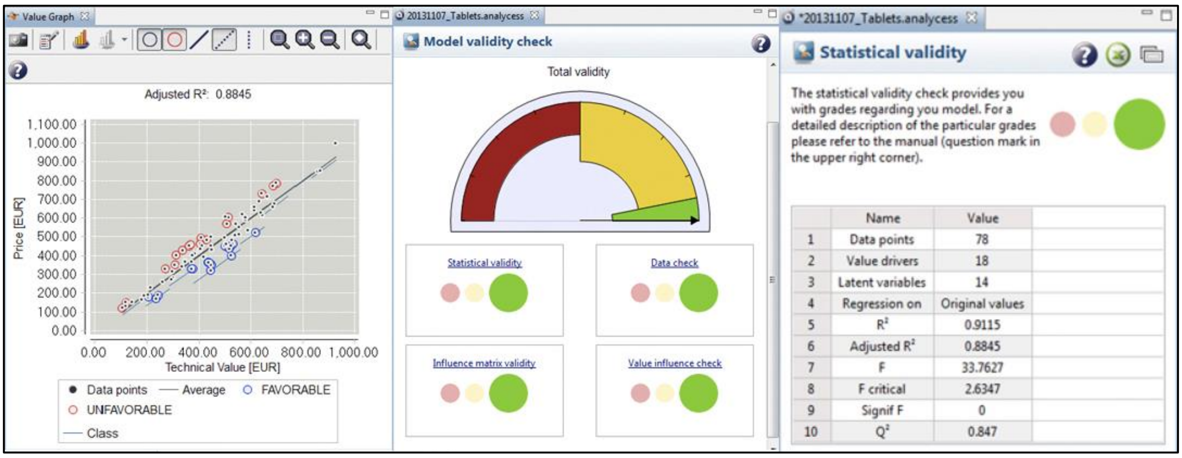

Figure 15. *Screenshot of Analycess Procurement user cockpit*

4.5 Outliers

An outlier is an observation, which deviates from the sample by such a large magnitude that it should be further assessed to make sure it is applicable for the analysis. Figure 16 illustrates outliers. It is possible that an outlier has been generated different than other observations, but it may also reveal useful abnormalities in the system, and in this research something abnormal in the drivers, influencing the results (Aggarwal 2015, 17).

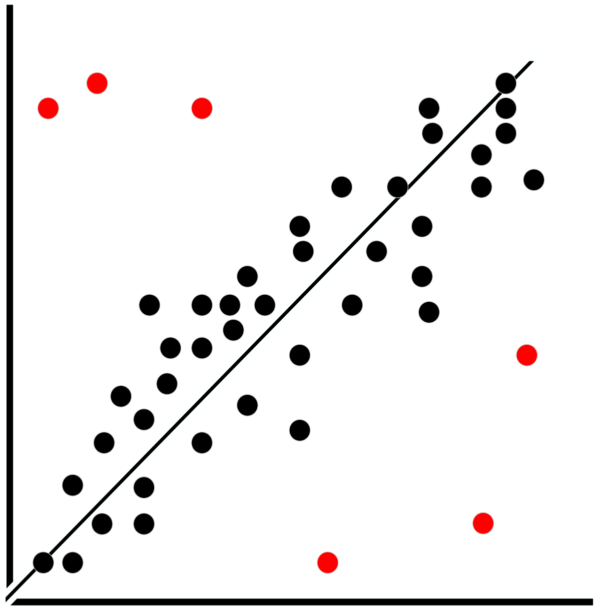

Figure 16. *Outliers in a regression graph colored in red*

It is important to evaluate whether an outlier should be disregarded from the results as an inapplicable component disrupting the model, or if it is an exceptional observation that shows a useful discrepancy that could be applied to other observations. To help in this task, firstly, the outliers can be categorized in upper outliers and lower outliers. Secondly, those categories can be divided into two. Upper outliers can be divided into random noise and true effects, and according to Akinshin (2019, 193), they can be described in the following way:

- Random noise
    - Unwanted outliers.
    - Cannot be completely removed from the data, but some of them can be manually cleared.

    - Do not provide useful information.
    - Hinder analysis accuracy.
- True effects
    - Wanted outliers.
    - Shows the extreme boundaries of the potential of real performance.

Lower outliers can be divided into errors and fast paths. The terms come from software and network environment, and mostly refer to how data behaves in information systems. Their concepts translate well into this research and data collection, in line with Akinshin (2019, 193-194):

- Errors
    - Basically, a data collection failure, usually leading into a zero value. The person conducting the analysis and investigating the data set needs to be informed if the real value is actually zero, or if the data was not available or not possible to collect.
    - Instead of zero, could also be any other false figure, but likely to be an extreme low or extreme high.
- Fast paths
    - The process has been improved leading to a better value for the data point. However, the process description of how the data is collected is not up to date. This means that the new process is being used without the information of the change having been shared. Therefore, the person analysing the outliers would unnecessarily need to examine the outlier to find out where its wrongly reported better performance is coming from.

Despite their names, in the context of this research, upper and lower outliers can both appear above and below the regression line. Upper outliers need to be manually removed or identified as observations with the highest or lowest real performance. Lower outliers refer to systematic errors in the data collection, can be overcome by information exchange, and always need to be removed. Lastly, purely for obtaining better model results, the inclusion or exclusion of outliers would be unethical data manipulation.

4.6 Evaluation and optimisation measures

The technical standard VDI 2817 describes price-analysis centered measures to evaluate prices by composing multiple regression models. It also describes price optimisation measures. Therefore, known measures exist and the technical standard can be used as a good source. However, the measures are indeed described for a different purpose than inventory management, hence adapting the concept of performance pricing in VDI 2817 from prices to stocks is not unequivocally a straightforward process. Pricing of items and stocking of items are two different domains that may have a different kind of behavior in some relevant aspects. The measures or methods may not be fully suitable for inventory models. Lastly, in the act of the eventual evaluation and optimisation, these measures can be used, but are not absolutely necessary as there are also other ways to evaluate and optimize.

The chapters 4.6.1 and 4.6.2 are translated directly from the VDI 2817 technical standard where price-related terms are converted for inventory domain. Therefore, a lot of similarities and same wordings can be found as the basis for the instruments and measures come from how they were defined in VDI 2817. Since the concept in inventory domain is still based on multiple regression, which is strictly bound to the mathematical and statistical rules, some parts for the instructions of evaluation instruments are directly interchanged from price domain described in VDI 2817 to inventory domain.

4.6.1 Evaluation instruments

Inconsistent inventory levels with respect to manufacturing volumes

For particular products whose manufacture is characterised by significant scaling effects (e.g. stamping and/or injection molding parts), a first assessment of the statistical inventory level model generated can be conducted through analysis of the manufacturing volume, usually a filter. Figure 17 depicts it graphically.

Inventory items with larger lot sizes should be found in the upper section of the inventory level graph, whereas more expensive items and hence a positioning in the region below the inventory level graph can be expected for increasing manufacturing volumes. The latter occurs also because of the threat of large bound of capital into inventories with high amount of expensive items. Items that constitute a large part of the purchasing volume often receive closer attention, for example through an ABC analysis, and are the focus of optimisation. Moreover, the manufacture of more expensive items should be postponed as much as possible, leading to a smaller average real inventory level.

The influence can be checked by selecting the manufacturing volume as a statistical inventory driver and checking the recalculated inventory level model by means of the technical level equation. In this analysis, it is relevant whether the regression has been improved by this selection with respect to the statistical evaluation parameters.

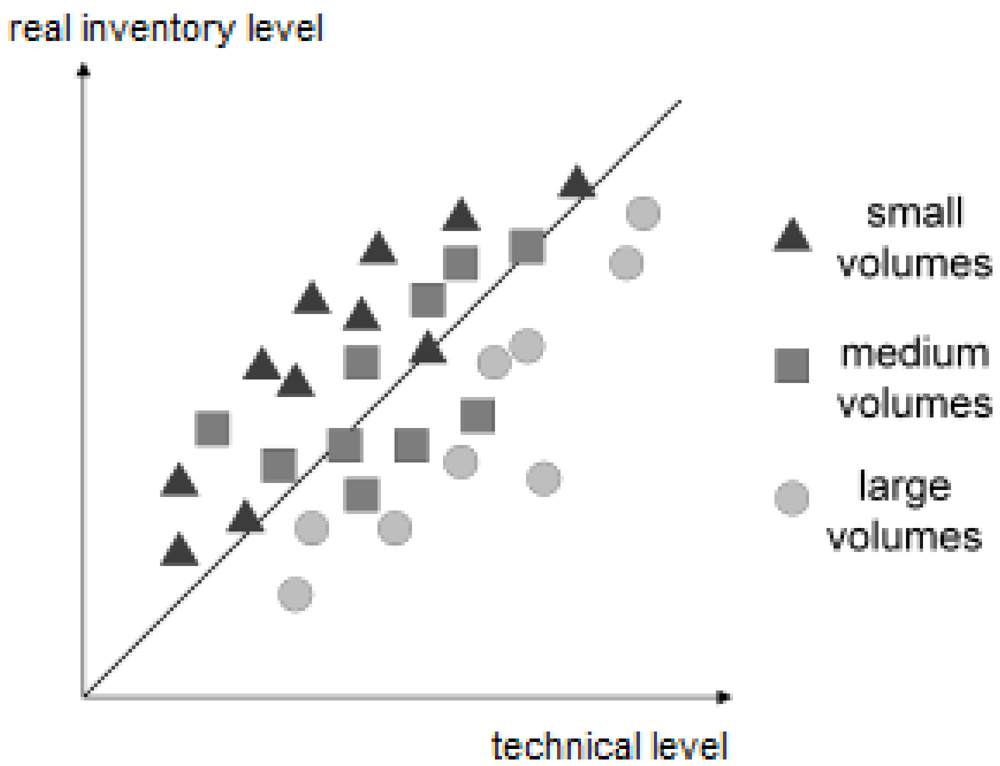

Figure 17. *Inconsistency due to manufacturing volumes (adapted from VDI 2018)*

Check against simulated daily inventory levels and stock-out days

The results obtained can be validated by means of component-related item cost comparison. As explained in section 4.4.6. of VDI 2817, the difference with regard to the calculated technical level and the stated level is checked for correctness based on stock-outs.

Stock outs can be checked by simulating actual daily inventory levels (in the end of each day) by subtracting from them the difference of the real inventory level and the technical level (also converted to a daily figure, if average technical level is calculated for a timeframe of a month). If previously stock-out days did not exist for the item, and they appear with the new inventory level, it reflects service level deterioration. If previously stock-out days existed, and they increase, the verdict is the same. In such a situation another evaluation needs to be done on whether many optimised days of inventory levels is worth the increased stock out days.

4.6.2 Optimisation measures

It is possible to choose two items in the analysis and compare them as pairs. The idea is to take one item that the model indicates being efficient, and another item that the model indicates being inefficient. When the all the variables used in the analysis of the two items are compared to each other, it can be observed which variable causes the difference in efficiency. Turning this into actual measure means learning from the efficient item and converting the practices around it or its performance to the inefficient item and improving one or more variables influencing its efficiency. For example, if the efficient item has lower lead time it might be possible to use the information behind that to decrease the lead time of the inefficient pair.

Inventory level reduction

If a so-called “data pair comparison” reveals inventory items with similar technical level but different actual inventory levels, this commercial inventory level differential shall be verified in a detailed analysis. Further data obtained from, e.g., an EOQ model analysis, can help substantiate the potential. This shall be addressed in a negotiation for the purpose of inventory level reduction.

Vertical patterns, such as those shown in Figure 18, are often termed “commercial levers”. Their main practical application lies in purchasing. A further possible course of action for inventory management development is to initiate a possible portfolio adjustment in the case of inventory items with identical technical level but excessive real inventory level.

Supply chain or inventory management enhancement

Horizontal patterns can help determine whether inventory items which offer a higher technical level at nearly the same inventory level can be substituted (i.e., in Figure 18 Supply chain or inventory management enhancement, inventory item 1 instead of inventory item 2).

This could be achieved by switching to a supplier with shorter lead time, reducing the amount of stopping points between origin and destination, streamlining transportations routes etc.

Increase in inventory turnover

Diagonal patterns occur when data pairs compared lie parallel to the average line. As shown in Figure 18 “Increase in inventory turnover”, it is possible to increase inventory turnover of an inventory item by reducing lead time, reducing minimum order quantity, reducing manufacturing cycle time etc. Conditions for this procedure are logistic feasibility and that the service level is perceived as equivalent by the customer.

As a rule, a more favorable inventory turnover can be negotiated based on smaller purchasing volumes. Diagonal patterns are thus used in manufacturing and purchasing.

It is possible to replace items with higher inventory level (and low inventory turnover) by fast moving items (and higher inventory turnover) of smaller lead time or minimum order quantity, or reducing manufacturing cycle time etc.

Strategic procurement development

The analysis of existing data patterns can reveal an inventory management or an inventory manager's strategy. For instance, items of lower demand can be purchased with efficient order quantities, but items of higher demand with inefficient order quantities, see Figure 18 “Strategic purchasing development”. It is advisable to embark on an alternative purchasing strategy. For instance, it can be worthwhile to develop demand forecasting for items with corresponding (high) technical level in order to achieve inventory level reduction. On the other hand, it might be useful to increase order quantities for items with low technical level to achieve cost reductions in purchasing.

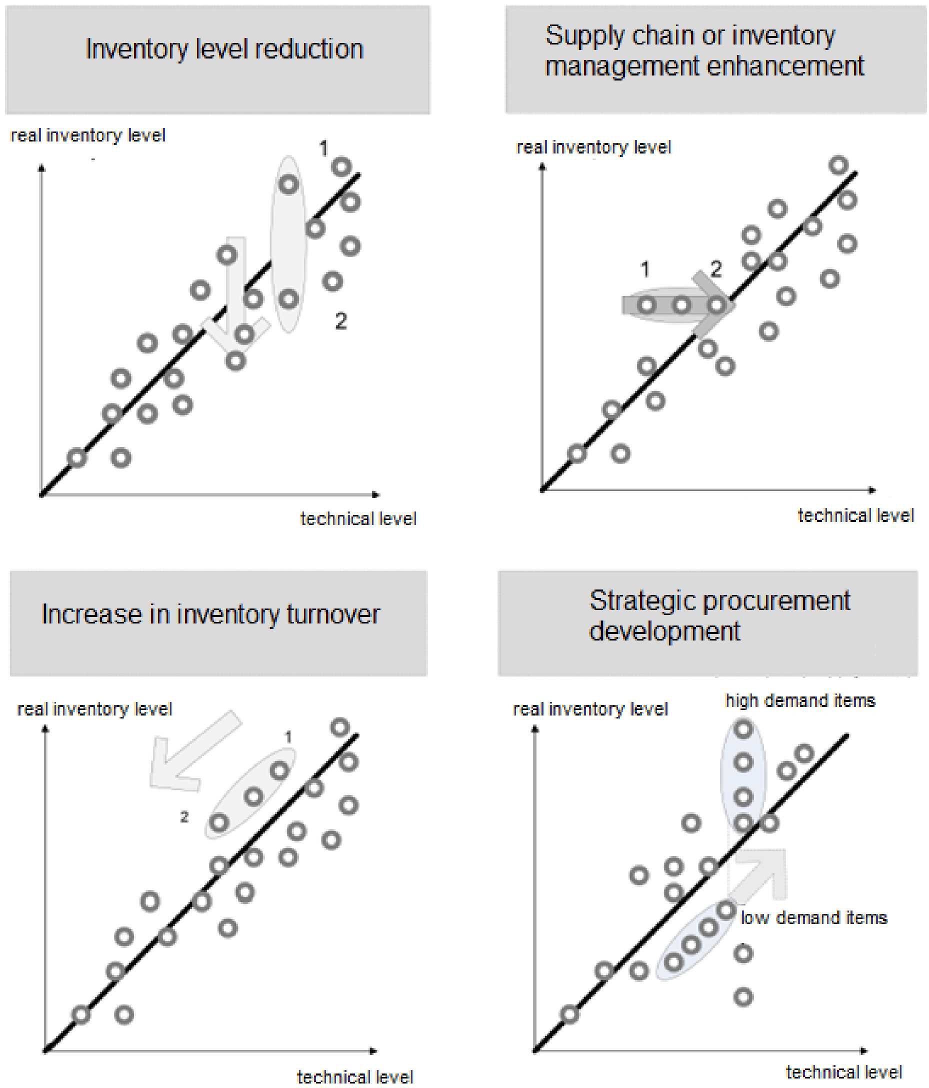

Figure 18. *Graphical analysis for determination of actions (adapted from VDI 2018)*

5 MULTIPLE CASE STUDY

Investigating a phenomenon in a real-life situation is called a case study (Karlsson 2016, 7). It can help in building understanding of real-life phenomenon in different fields including business. In a case study, and especially in a multiple case study, the cases studied must have a spatial or temporal relation to each other. (Karlsson 2016, 1) The case companies in this research have activities in manufacturing and assembly, which gives them a spatial relation due to similar aspects in their businesses. The analysed data from the companies comes from the same timeframe, which gives the case study subjects a temporal relation.

There are problems with the case study definitions and understandings, and sometimes researchers may avoid naming their studies as case studies to appear more credible (Karlsson 2016, 2). A case study does not allow for general support of the hypothesis in nature, but only within the case subjects. Therefore, there is no statistical representativeness in general, but it does not take away the statistical validity of the results of the case study itself. However, considering what an individual business wants, an in-depth and specific knowledge and results of its particular case might be more useful to it, than a general and less specific knowledge and results (Karlsson 2016, 2).

Conducting a multiple case study is the next step from proof of concept towards an empirical model. Table 8 presents some of the key figures of the case companies.

Table 8. *Overview of the case companies' figures*

	Hilti AG	Finder S.p.A.
Revenue	5 900 MCHF	200 MEUR
Employees	30 000	1300
Industry	Construction	Electronics

As a reminder, benchmarking is the act where one company is being compared to other companies (VDI 2001, 2). It provides a way to develop effectiveness and competitiveness. However, the characteristics of the companies benchmarked against each other may not easily have a relevant fit for comparisons. (Farahani, Asgari & Davarzani 2009, 272). Thus, it is important to choose suitable companies, or otherwise meaningful conclusions cannot be reached from the results.

5.1 Case company A (Hilti AG)

Figure 19. *Hilti logo*

Hilti operates in the construction industry by providing products, systems, software and services. The company is based in Schaan, Principality of Liechtenstein, where it was founded in 1941 by brothers Martin and Eugen Hilti. In 2020 the company is fully owned by Martin Hilti Family Trust.

The company stands for quality, innovation and direct customer relationship. This allows a lot of ideas and improvements to be developed directly at the construction site, as Hilti creates solutions to the on-site challenges together with its customers. Core values of the Hilti group are integrity, courage, teamwork and commitment. By demonstrating them in its interactions with every stakeholder, the company is able to uniformly act towards its strategic objective of sustainable value creation through market leadership and differentiation. (Hilti AG 2020b, 4-5)

Since 2015, the company has had a steady increase of its net sales from 4 400 MCHF to 5 900 MCHF, its operating result from 550 MCHF to 780 MCHF and its net income from 410 MCHF to 590 MCHF. Likewise, the amount of employees has increased from 23 000 to 30 000 in the same time. (Hilti AG 2020b, 4-5) The figures indicate that the company has been in growth and expansion trend. Therefore, a lot of inventories have had to be established to get things running. The obvious next step is to optimise the inventories and reduce excessive levels. Hence, Hilti is a good case company for the topic of this research, and also due to the fact that they spend about 6% of their revenue on research and development.

Production locations are in Liechtenstein, Austria, Germany, Hungary, Mexico, China, USA and India, with most of the production workforce in the European countries (Hilti AG 2020a). Hilti is therefore very centrally positioned in Europe, but also operating in the Americas already for decades, as well as having a steady foothold in Asia.

Nine different business areas are under the scope of Hilti, as shown in Figure 20 (Hilti AG 2020c). Therefore, the company has a wide product range to offers to its customers. In the past, Hilti made some of its most important breakthroughs with direct fastening, while power tools and accessories is the largest business unit as of 2020.

Figure 20. *Hilti business areas*

Direct sales is included in the Hilti business model (Hilti 2019), meaning that the company not only manufactures products, but it sells them to the end customer, contrary to the usual manufacturing business that sells to wholesalers or retailers. This gives the company more control and responsibility of the outbound supply chain. It should also allow better service level of the forward supply chain, but on the contrary, it requires more effort due to complexity when dealing with the flow of materials in the entire chain under its own responsibility.

PwC (2018) reported that during 2013-2017 both industrial manufacturing, and construction and engineering industry, improved their working capital days. This raises the question whether Hilti is at the forefront of its industry, and what has been the development of their inventories and its impact on the working capital figures.

Hilti inventories from different years are illustrated in Table 9. As the inventories are over 100 MCHF every year, they can be considered significant. Fluctuations in the total figure are due to provisions for inventories according to Hilti AG (2018; 2016; 2015), meaning for example write-offs of obsolete and damaged inventory. Such statements may indeed reflect excessive inventories, which gives reason to inventory optimisation at the company.

Table 9. *Hilti inventories between 2014 and 2018 (Hilti AG 2018; 2016; 2015)*

	2018	2017	2016	2015	2014
Raw materials	20.4 MCHF	19.1 MCHF	18.3 MCHF	20.4 MCHF	23.8 MCHF
Consumables	8.9 MCHF	8.5 MCHF	8.5 MCHF	8.7 MCHF	9.5 MCHF
Production in progress	6.1 MCHF	6.1 MCHF	5.8 MCHF	6.2 MCHF	6.6 MCHF
Finished products and goods held for resale	138.8 MCHF	92.5 MCHF	79.8 MCHF	93.6 MCHF	142.1 MCHF
Total	**174.2 MCHF**	**126.2 MCHF**	**112.4 MCHF**	**128.9 MCHF**	**182.0 MCHF**

5.2 Case company B (Finder S.p.A.)

Figure 21. *Finder logo*

Finder S.p.A. was founded in 1954 in Italy and is mainly known for its manufacture of relays for residential, commercial and industrial applications (Finder S.p.A. 2019). In total, the product portfolio includes 12 500 different products for electrical and automation purposes such as relays, timers, solid state relays, sockets, thermostats, power supplies, contactors, fans, heaters and monitoring relays. As the largest relay socket producer in Europe, Finder has 20 000 square meters of production facilities. Factories located in Italy, France, and Spain reach a daily output of 400 000 units. (Finder S.p.A. 2020a)

The company, employing 1300 people, is independent and privately owned. The global headquarters of the company is located in Almese, Italy, and they have also 26 subsidiaries worldwide. 1980s included the establishment of two abroad subsidiaries, 1990s seven, 2000s nine, and 2010s seven. The sales turnover has increased from 26 million euros in 1993 to 192 million euros in 2017. These figures show that the company has been expanding steadily in its international nature and revenue growth.

Finder GmbH, which is in the focus of this thesis, was founded in 1983 as the first abroad subsidiary of the mother company (Finder S.p.A. 2020b). It shows how the German market is one of the most important for the company, and that Finder GmbH is a well established subsidiary with almost 40 years of operation. In addition to being a logistics center, new business development and cost optimisation activities take place at Finder GmbH. They are located in Astheim, Trebur, in the state of Hessen in Germany. A visit to the Finder GmbH's facility where both warehousing and assembly takes place was made during the project. During the visit, the operation of the facility was introduced to the researcher.

5.3 Results

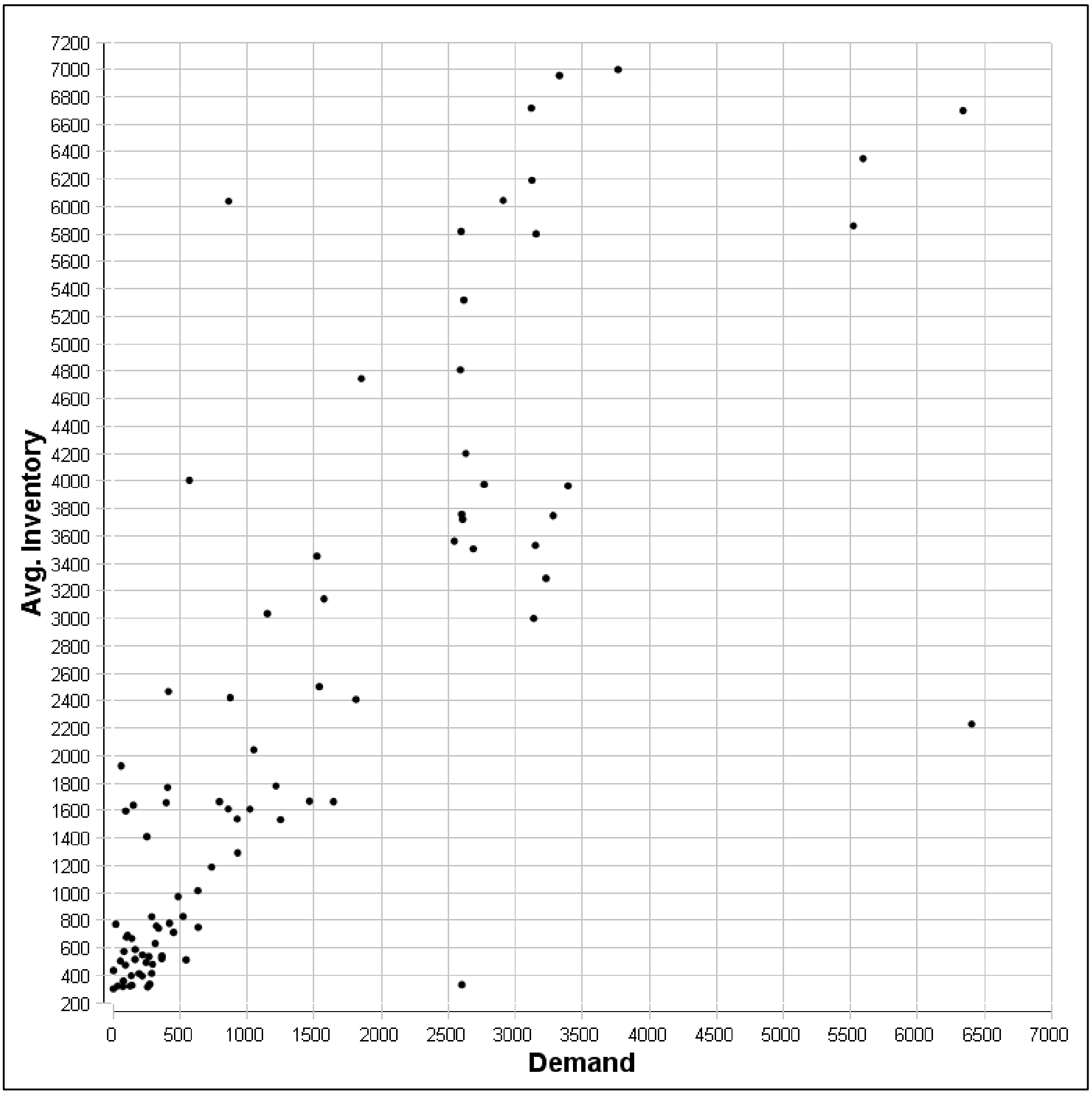

Figure 22. *Scatter plot of inventory items with demand versus average inventory*

Demand has a strong positive correlation with average inventory levels as Figure 22 illustrates, with the correlation coefficient resulting as 0.62. It is an expected result, since inventories are kept to be able to meet demand, therefore demand is the main reason for inventory levels. With many other tested item samples as well, demand had a strong or very strong relationship against inventory levels, and it was often the dominant variable to explain inventory levels in multivariate models.

The graph shows that there are a few items as individual outliers, especially at demand levels of around 800, 2600 and 6400. Also, a large amount of items lie below demand of 500 and inventory level of 800, forming sort of a group.

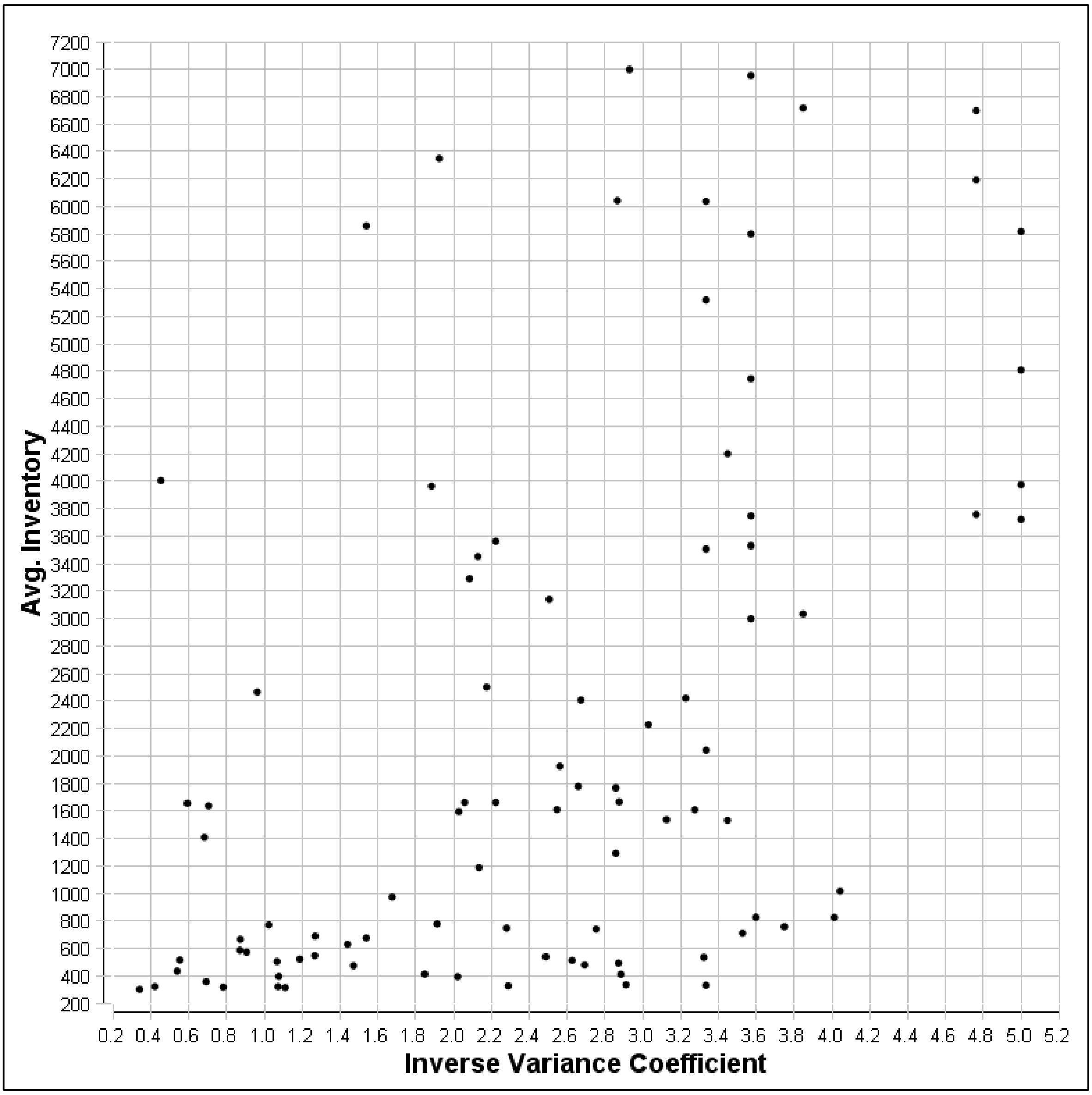

Figure 23. *Scatter plot of inventory items with inverse variance coefficient versus average inventory*

Demand variance, converted to variance coefficient and then inverted to make the variable suitable for regression analysis, has a correlation coefficient of 0.25 against average inventory, indicating a weak relationship. Graphical representation of the inventory items' inverse variance coefficient against average inventory is illustrated in Figure 23.

The group of items below inventory level of 800 pieces discovered in Figure 22 now spread largely in terms of inverse variance coefficient, with values ranging from 0.3 to about 4.0. Highly lonely outliers are not present as much as in Figure 22 but the items are scattered more evenly all across the graph.

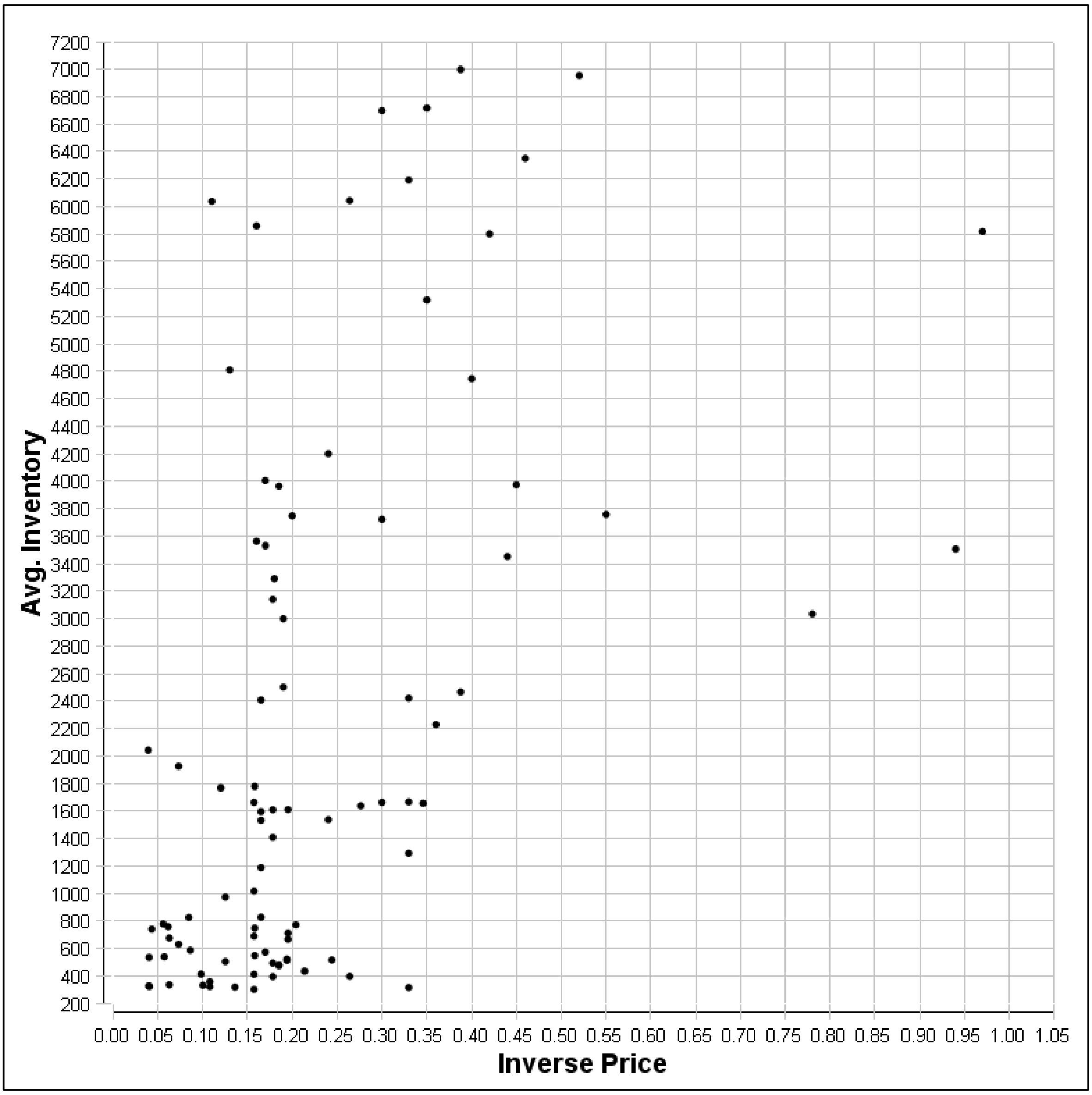

Figure 24. *Scatter plot of inventory items with inverse price versus average inventory*

Price, turned to inverse price to make it suitable for linear regression, is graphically illustrated against average inventory on Figure 24. The correlation coefficient is 0.27 indicating a weak relationship. Three distinct outliers can be noted, all on the right side of the graph with the highest values of inverse price (i.e. lowest actual price) and two in the vertical mid-point of the ordinate and one among the highest inventory levels. The rest of the items fall below or at inverse price of 0.55.

Scatter plots with the variables variance coefficient and price before inversion was done are shown in Appendix 3 and 4, respectively. In those two graphs a clear non-linear relationship can be observed, justifying the inversion.

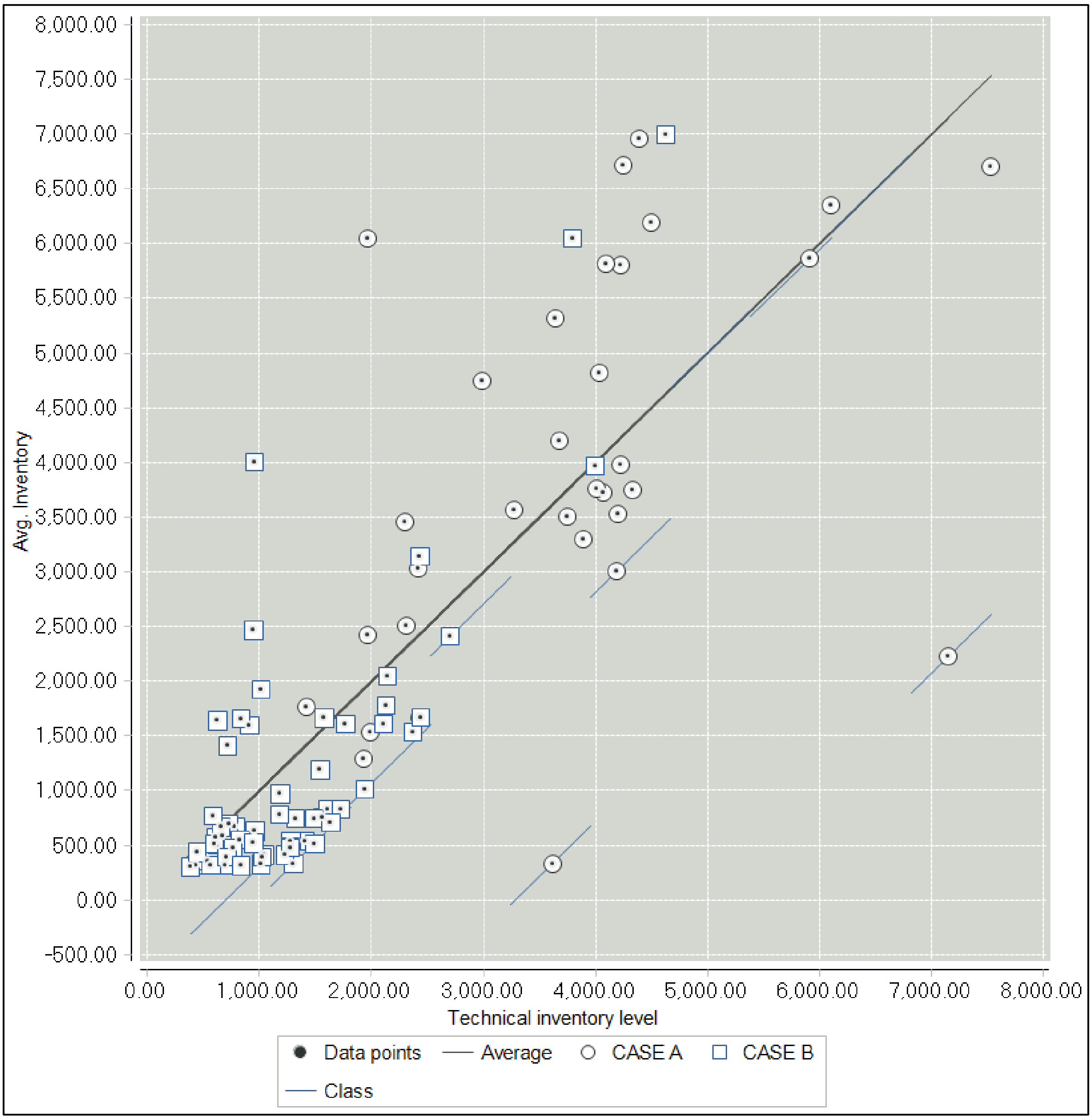

Figure 25. *Inventory graph with case company as a filter*

Inventory items of the case company A and B are illustrated in Figure 25, where A's items are represented as circles and B's items are represented as squares. The abscissa represents the technical inventory level, that the model suggests for the items. Best-in-class lines can also be noted. R^2 value is 0.63.

The lower left corner of the graph is dominated by case company B's items, while case company A's items are represented somewhat more all across the graph but also with higher spread. The most distinctive outliers are items of case company A, and caused mostly by their value of demand, as in Figure 22, where the outliers are located more or less in the same place.

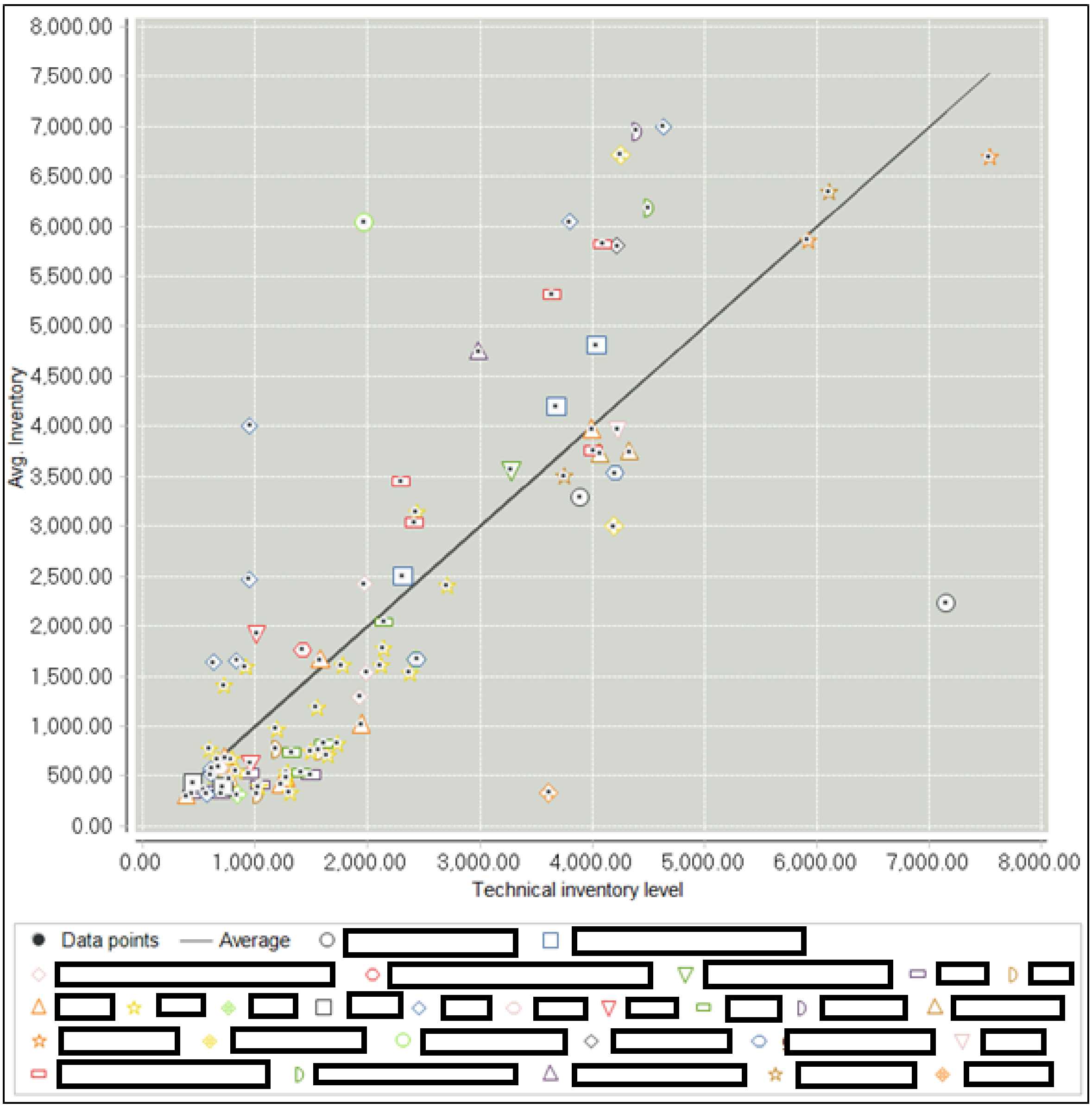

Figure 26. *Inventory graph with material groups as a filter*

With the material group as a filter, it is possible to observe how the item groups are spread out or grouped in the inventory graph as illustrated in Figure 26. The actual names of the material groups are hidden from the legend.

The material group indicated by a yellow star is M04, which is strongly represented in the lower left corner of the image. The material group therefore has many items with small reduction potentials on an absolute scale. The largest outlier can be spotted in M16, which is represented by a grey circle at the technical inventory level of about 7100 as opposed to its actual average inventory level of 2250 pieces. The item with a green circle at technical inventory level of 2000 and actual average inventory level of 6000 belongs to M08, offering the largest reduction potential.

	Name	Value
1	Data points	91
2	Value drivers	3
3	Latent variables	2
4	Regression on	Original values
5	R^2	0.65
6	Adjusted R^2	0.63
7	F	53.08
8	F critical	5.09
9	Signif F	0
10	Q^2	0.62

Figure 27. *Statistical validity of the model*

A screenshot of the statistical validity info screen of the software Analycess Procurement can be seen in Figure 27. With 91 data points and the three inventory drivers (written as value drivers in the software due to its terminology referring to costs instead of inventories), the model receives good statistical validity.

The value of R^2 is 0.65 and Adjusted R^2 is 0.63, both of which indicate a strong positive relationship between the independent variables and the dependent variable. Therefore, inventory levels correlate well with demand, inverse price and inverse variance coefficient. Moreover, Figure 28 shows the regression coefficient, standardised coefficient and the regression significance of each of the three inventory drivers. As such the inventory level can be calculated with the following formula.

$$Technical\ inventory\ level =$$
$$288.83 + 0.95 * (Demand) + 259.27 * (Inverse\ Variance\ Coefficient) + 57.2 * (Inverse\ Price)$$

	Name	Regression coefficient	Std. coefficient	Regression significance
0	y-intercept	288.83	0	-
1	Demand	0.95	0.71	88.6 %
2	Inverse Variance Coefficient	259.27	0.16	39.96 %
3	Inverse Price	57.2	0	67.73 %

Figure 28. *Calculated weighting factors of the model*

The other statistical indicators in Figure 27 receive good values as well. F test is 53.08, and F critical is smaller than that, so the hull hypothesis can be rejected. Signif F is zero so the confidence level is above 95% that the model has a statistically significant predictive capability and we can reject the hypothesis that all inventory driver coefficients would actually be zero. Lastly, the Q^2 is 0.62 which is close to 1, indicating a stable model. Even if single data points would be added or removed, the results would not change much.

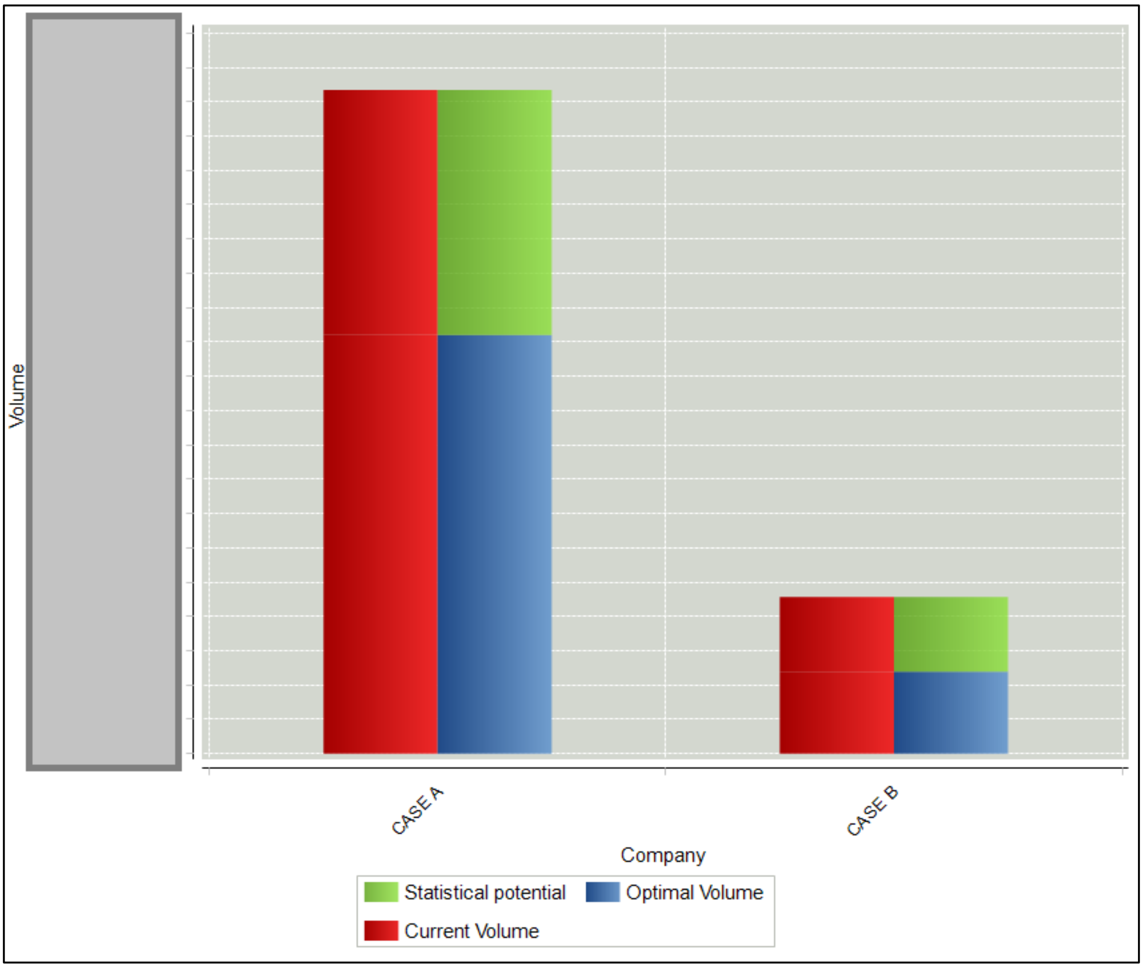

Figure 29. *Statistical potentials based on case company*

Regarding the amount of pieces that could be reduced from the inventories, Figure 29 shows the potentials as a bar chart. Actual volumes are hidden from the figure. Table 10 shows the percentages of the reduction potential from the current volume to the optimal volume. Case A has 37% potential and Case B 48% potential. It is somewhat expected that Case B, as a smaller company, has its inventories on a less optimal level, and therefore more relative reduction potential. The reason is likely that Case A is utilising more sophisticated and complex calculations for their current inventory levels.

Table 10. *Statistical potentials as percentages based on case company*

Case company	Potential
Case A	36,92%
Case B	47,60%

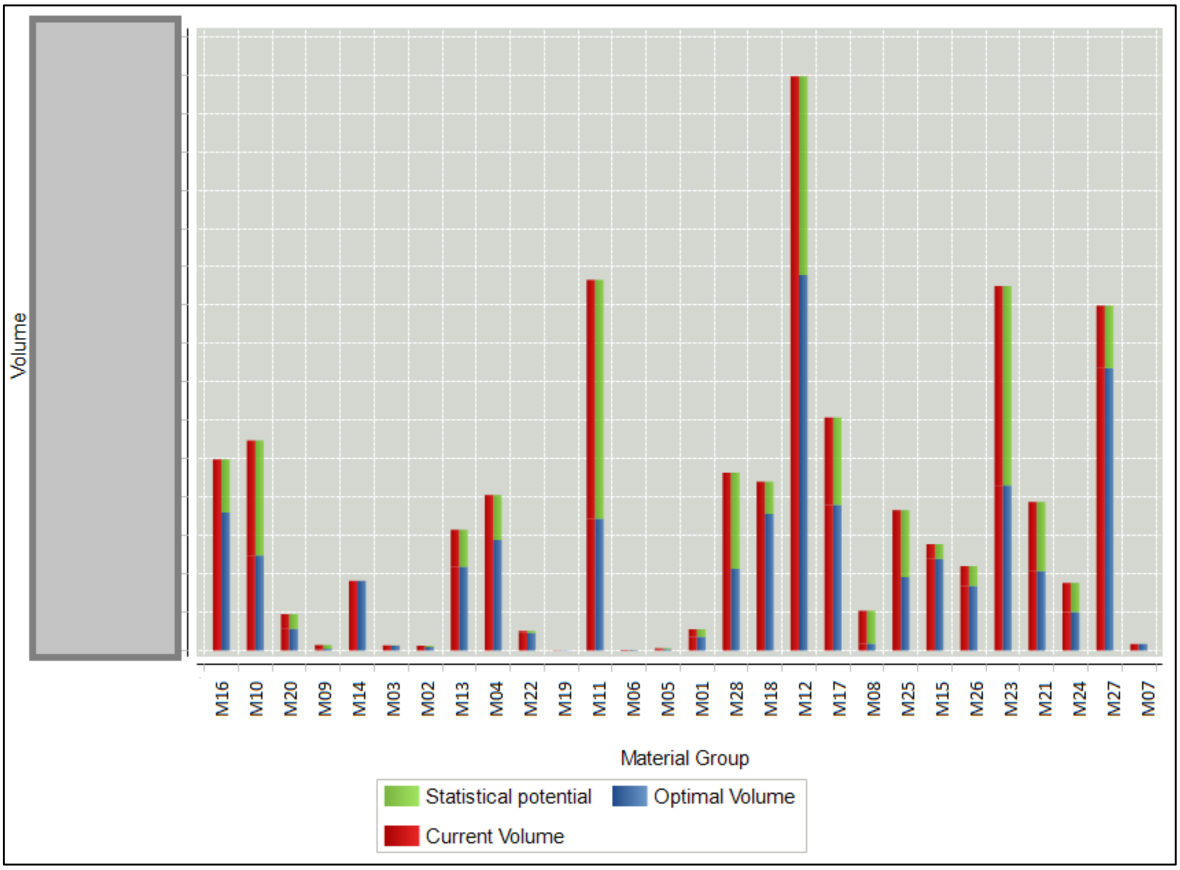

Figure 30. *Statistical potentials based on material group*

In terms of material groups, the reduction potential can be seen in Figure 30. Material groups M12, M11, M23, M27 have considerably largest current volumes. Table 11 shows the relative statistical potential that can be reduced from the volumes of each material group. M08, M09, M11 and M23 offer the highest statistical potential, while in addition to them M10, M28 and M05 are in the class of material groups which have over 50% potential. M14, M06 and M07 are calculated to have no reduction potential at all.

Combining the consideration of the current volume and the percentage shares of the statistical potential, the optimisation effort should be focused on the factor of those two figures. This is shown as the green bar in Figure 30. Material groups M11, M12 and M23 offer the largest absolute inventory level reduction potential. They have the highest current volumes and high or fairly high percentage share of the reduction potential. Therefore, focusing on M11, M12 and M23 would allow the highest potential for the amount of capital to be released from the inventories.

The material group M11 belongs to Case B, while the material groups M12 and M23 belong to Case A. Material groups M07 and M14 which had zero reduction potential, belong to Case A. The third material group with no reduction potential, M06, belongs to Case B. Therefore, both case companies have extremities on both ends of optimisation.

Table 11. *Statistical potentials as percentages based on material group*

Material Group	Potential		Material Group	Potential
M08	82,69%		M13	30,64%
M09	70,92%		M02	30,49%
M11	64,48%		M04	28,97%
M23	54,74%		M16	27,79%
M10	54,70%		M26	23,63%
M28	54,00%		M18	19,15%
M05	52,26%		M27	18,11%
M25	47,79%		M19	15,82%
M21	46,64%		M15	13,69%
M24	43,26%		M22	9,14%
M20	40,51%		M03	6,99%
M17	37,55%		M14	0,00%
M01	36,41%		M06	0,00%
M12	34,62%		M07	0,00%

6 CONCLUSION

First, to conclude this master thesis, the research objective and two research questions shall be evaluated. How well was the objective reached and how did the research answer to the questions posed in the beginning?

- Research objective: *Create an inventory optimisation model by adapting Performance Pricing as described in VDI 2817. The model shall be statistically valid according to selected criteria.*

The objective was reached. A multiple linear regression model was created with three independent variables. The development of the model was done mainly according to the guidelines in the technical standard VDI 2817. The technical standard proved useful as it includes well-written instructions for supply management practitioners on how to create a multiple linear regression model. The instructions include various points that need to be worked out as the requirement for a model to be of high quality. The adaptation from price estimation and value as the dependent variable, to inventory optimisation and pieces as the dependent variable was successful.

The statistical validity of the model was evaluated according to the six statistical indicators: R^2, adjusted R^2, F test, F critical, signif F, and Q^2. The indicators show statistical validity of the model, with strong correlation coefficients and proofs that the null hypothesis can be rejected.

- Research question 1: *What inventory drivers can be used for inventory benchmarking between the two case companies?*

Many parameters were considered and tested in construction of the model. The two case companies had interesting sets of parameters in the datasets used in this research. However, the data was not uniform, which constituted a major constraint for the research. Working out the data quality and other data issues added a lot of workload for the study. Data standardisation was required in order to allow the use of certain parameters in the eventual model. To reach standardised data, a VBA programming code was implemented to calculate and convert figures to a suitable format. Three parameters were standardised.

The parameters – known as inventory drivers – used were demand, inverse coefficient of variance of demand, and inverse price. These inventory drivers were possible to obtain from the datasets of both case companies. Therefore, the benchmarking between the inventories of the companies was done based on their values. Even though the overall model had a strong positive correlation to inventory level, the inventory drivers inverse coefficient of variance of demand and inverse price had a weak positive correlation only, when individually considered.

- Research question 2: *What inventory optimisation (reduction) potentials does the model show?*

The model shows various aspects when used in the software Analycess Procurement. First, case company B items in the sample have relatively more inventory reduction potential, namely 47,60% of the current volume calculated as pieces in inventory. Case company A has a higher volume of inventory and therefore more absolute reduction potential although with a smaller total percentage of 36,92%. Material groups M11, M12 and M23 offer the greatest reduction potential by total volume. It must be noted that these potentials are theoretical potentials of the selected sample.

- Research question 3: *How to convert VDI 2817 to inventory management?*

The case study reflects that VDI 2817 can be converted to inventory management. Chapter 4.6 with evaluation instruments and optimisation measures show translations of selected sections of the technical standard from price domain to inventory domain. The converted instructions can serve in optimising inventory levels and improving performance in related fields in supply chain and procurement as well.

Overall, with the obtained findings from this research, the case companies can optimise inventory levels for various items in different material groups. When optimising the inventories which are excessive, the companies can reduce the inventory levels and thereby release capital tied into them. That in turn would increase the liquidity of their assets as inventories turn into cash. As a consequence, the working capital cycle would also be improved.

A quick source for cash is therefore available for the companies. Financial ratios and the entire financial situation can be improved with the optimisation. More efficient use of capital also sends a positive signal to current and potential creditors, ensuring that cash is available for expected payments. Credit rating is very important for Hilti AG, which has a “High A stable” as the latest rating (Hilti AG, 2020d), which is to be maintained to keep the company as a trusted partner in trading.

6.1 Managerial contributions

This research provides a unique approach to inventory benchmarking. In the past, some master theses have been made where PP has been implemented to inventory management based on VDI 2817. However, they have been limited to a smaller context, mainly into one item category in a single company, or to multiple item categories in a single company. Therefore, considerations of multiple case companies in a single inventory analysis has not been made with the method. With that regard, this research shows another way how to approach inventory optimisation by utilising the VDI 2817 technical standard.

The main benefit of the thesis for managers is that it presents a method for optimising inventory levels based on benchmarking information from other companies. It allows managers to evaluate stock levels in order to reduce the risk of stockouts and business interruption, as well as reduce the invested capital into inventories. As the conclusions are driven from benchmarking, it allows managers to consider how well they are managing inventories compared to other businesses.

As a side product, the research shows that companies should pay better attention to their data management. Much of the data that companies collect is not maintained, therefore leading to bad data quality. Documentation of the data collection processes should be kept easily available and updated regularly, or otherwise as time goes on information needed for accurate analysis to be made from the data becomes buried on the hard drives in multiple locations. Likewise, when employees who work on development projects leave the company, the information about the procedures that they created around the data and the IT systems also leaves. To ensure problems arising from this companies should focus on passing on the information from leaving employees to the new employees, and in complex cases that requires many months of time. Once companies grow, archives become more filled with hard-to-find scattered documentation. To cope with the problem, retention of employees that can serve as process experts becomes useful.

Lastly, with the potential of the PP method and VDI 2817 in many different contexts – like cost evaluations and optimisations, for which it has been originally designed, and inventory optimisation that this research addresses – it would make sense for companies to take the method and technical standard into use. The reasoning behind this suggestion is that the same method can be used for multiple different objectives with some modifications. As there is an easy-to-use software, Analycess Procurement, for the multiple regression analysis, managers should consider taking it as one of the standard softwares of the company. Practice at Hilti and Finder has shown that users tend to get quickly familiar with the software, and be able to conduct analyses and understand different phenomena quantitatively by using it. A multi-purpose and user-friendly software would be an investment with a good return.

6.2 Further research

The topic of adapting VDI 2817 step model to inventory optimisation and inventory benchmarking can be further studied. Firstly, benchmarking between different warehouses of one company would be a good starting point. This could be done using warehouses in different countries to maximise spatial difference. Same items could be used and the same inventory drivers should be easily available. Of course, a large company with multiple warehousing locations is required.

Different timeframe for the same inventory could be used, for example comparing the latest inventory data with data from 5 years ago. With this method it could be possible to rather quickly notice if the inventory management practice has improved or worsened with time. Even smaller companies could be used as a case company.

Benchmarking with more companies, with similarities or differences in size, industry, nationality and other variables could be considered. It is recommended to analyse the potential companies to be taken into comparison thoroughly beforehand. By so fitting partners with similarities that make the analysis possible can be pre-selected, or the fit could come from the fact that they conduct inventory management practices based on different philosophies, which could then be “objectively” compared by a method independent from the methods used by the case companies.

Instead of inventory drivers, logistic chain drivers could be defined for the items in study. By this the researcher would have to consider the items with a larger perspective, and study what happens in the logistic chain during the material flow. It could be especially interesting in items that have converging and diverging chains, meaning that one item could actually flow through different chains. The differences could be due to production facilities, destination, or if the item is used in the manufacture of multiple different products.

Figure 6 in this thesis gives a rough idea of how the logistic chains can differ. Items could be separated as production items and directly sellable items, which might be a simple starting point for logistic chain differences. Taking logistic chains into account would add much complexity to the analysis, so clear feasibility study and setting of limitations before beginning with the research is recommended.

Regarding item selection procedure, it could be interesting to choose such companies for benchmarking that already have implemented UNSPSC material group taxonomy for their inventories. Using the same universal item categorisation methodology would make the item selection process rather simple and items from the different companies should have a significant relevance amongst each other. Moreover, since UNSPSC has existed for only roughly 20 years, the cross-company comparisons of the same category could show some room for improvement for one of the companies or the UNSPSC itself. After all, people define the UNSPSC categories that exist, and employees of companies influence how items receive a classification in the end so human errors may take place and it could be possible to find out improvements for the categorisation. Lastly, the VDI 2817 Part 2, at the time of this thesis still unpublished, describes certain items in UNSPSC categories and the most common value drivers for them. That links the VDI 2817 Part 1

Performance Pricing method and UNSPSC together, and so the Part 2 would also require conversion to inventory management and inventory drivers, which would well constitute another separate research.

Regarding the multiple regression nature, the VDI 2817 could be converted to use for other dependent variables than inventory level. Ideas for that include using lead time as the dependent variable, and utilising the seven step model for lead time modelling. By multiple independent variables, which the research should identify, a statistically valid lead time optimisation model could be created that could result for businesses ability to address problematic factors that could lead into receiving deliveries in less time.

Price as an independent variable could be taken into consideration from a different perspective. The cost of an item can be broken down to a few commonly important components in terms of inventory. Examples are the item cost itself, holding costs, ordering costs and shortage costs. Holding cost could be relevant to consider as a separate independent variable. It should have inverse relationship to inventory levels, the magnitude of which could be modelled by multiple regression analysis.

Lastly, service levels are important in managing inventories and especially when considering reductions of inventory levels. Therefore, it is suggested to evaluate the calculated potentials according to different service levels. If the items can meet a high service level with the reduced inventory level as suggested by the model, then the argumentation for the reduction can be made stronger.

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APPENDICES

Appendix 1. Formulas for the individual components of the WCC equation from Templar et al. (2016, 53-54).

$$\boldsymbol{Inventory\ days}\ \begin{pmatrix} \boldsymbol{a.k.a.DIH, Days\ Inventory\ Held;} \\ \boldsymbol{a.k.a.DIO, Days\ Inventory\ Outstanding} \end{pmatrix}$$

$$= \frac{Average\ Inventory}{Average\ daily\ cost\ of\ sales\ in\ period}$$

$$\boldsymbol{Receivable\ days}\ (\boldsymbol{a.k.a.DSO, Days\ Sales\ Outstanding})$$

$$= \frac{Average\ Accounts\ Receivable}{Average\ daily\ revenue\ on\ credit\ terms}$$

$$\boldsymbol{Payable\ days}\ (\boldsymbol{a.k.a.DPO, Days\ Payables\ Outstanding})$$

$$= \frac{Average\ Accounts\ Payable}{Average\ daily\ purchases\ on\ credit\ terms}$$

Appendix 2. SFA, DEA, and PP table.

<table>
<tr><th>Criterion</th><th>SFA (parametric)</th><th>DEA (non-parametric)</th><th>PP</th></tr>
<tr><td rowspan="2">Sensitivity to outliers</td><td></td><td>• "Frontier position and efficiency scores may be strongly influenced by outliers" (Bezat 2009, 27)
• Largely sensitive to outliers (Burger 2008, 59)
• Outliers are more complicated to find: they may require additional methods to be used and high computational power (Khezrimotlagh 2013)
• "When the newly added DMU is an outlier, it could affect the efficiency measurement" (Lin & Tseng 2005, 598)</td><td rowspan="2">• The goal is to find the outliers
• It is possible to create a model including the outliers to apply for the entire population, or to create a model without the outliers to apply for a specific cluster</td></tr>
<tr><td colspan="2">• Might be sensitive to outliers (Jacobs 2001, 105)</td></tr>
<tr><td>Sensitivity to measurement errors</td><td>• Compared to DEA, less suspectible to measurement errors (Burger 2008, 59)
• Can cope with severe measurement error (Katharakis et al. 2014, 342)
• "Assume a particular error distribution" (Jacobs 2001, 105)</td><td>• "Does not allow for estimation or measurement error" (Bezat 2009, 26)
• "Frontier position and efficiency scores may be strongly influenced by outliers" (Bezat 2009, 27)
• Largely sensitive to measurement errors (Burger 2008, 59)
• Must assume no measurement error or random fluctuations (Jacobs 2001, 105)
• "Does not allow for stochastic factors and measurement errors" (RIC 2005, 21)</td><td></td></tr>
<tr><td>Selection of drivers / Robustness</td><td colspan="2">• "Both methods may be vulnerable to measurement and misspecification error with dangers of omitting significant variables, the inclusion of irrelevant variables, or endogenity bias" (Jacobs 2001, 105)
• "Robust with respect to upper and bottom ranking of mean efficiency" (Karagiannis & Sarris 2004, 152)
• "Each of the mehtods does have unique strengths and weaknesses and potentially measures slightly different aspects of efficiency" (Jacobs 2001, 113)</td><td>• Models can be created with a variety of different drivers.
• Applicable across organisations (VDI 2817 2018, 4)</td></tr>
<tr><td>Required function knowledge</td><td>• "An assumption regarding to a specific functional form of stochastic frontier is required a priori" (Bezat 2009, 27)
• "Assumptions of the efficiency line required" (Burger 2008, 59)
• "The estimates of the extent of (in)efficiencies do depend on the production function (envelop)" (Theodoridis & Anwar 2011)
• "It needs to assume functional form and distribution type in advance" (Lin & Tseng 2005, 598)
• "Requires assuming a specific functional form that determines the input(s)-output relation a priori" (Jarzębowski 2013, 174)</td><td>• "Sensitive to the choice of input and output variables" (RIC 2005, 21)
• No need of prior knowledge (Burger 2008, 59)
• "Does not need to assume function type and distribution type" (Lin & Tseng 2005, 598)</td><td>• No function knowledge is needed</td></tr>
</table>

Criterion	SFA (parametric)	DEA (non-parametric)	PP
Statistically measurable	• Statistical hypothesis tests can be done (Burger 2008, 59) • "Statistical errors in theory, but does not convert into practice" (Burger 2008, 59) • "Allows conducting the statistical analysis of the significance of the obtained results"	• *"Since DEA is a nonparametric technique, statistical hypothesis tests are difficult"* (Bezat 2009, 26) • "No diagnostic tools with which to choose the best model specification" (Jacobs 2001, 108)	• Various statistical checks can be done such as: R^2, F-test, Q^2
Computational demands	• SFA is more computationally demanding than DEA (Coelli et al. 2005, 209)		
Simplicity	Worse. Functional form should be chosen. Worse. Functional form can be complex. • To find out the functional form, different options should be tested against each other (Jarzębowski 2013, 174). Various options exist, so having to have to measure which one is the best creates additional complexity (before the real analysis can be started).		
In tandem use / Similar or different results with each other?	• "Given the limitations of frontier techniques, it may be that they are best employed in tandem, when possible" (Katharakis et al. 2014, 355) • "Given their different strengths and weaknesses, several studies […] have compared efficiency estimates obtained from these two approaches. The results […] from DEA and SFA often yield quite different distributions of measured efficiency." (Karagiannis & Sarris 2004, 151) • *"Due to the infirmities of the deterministic methods (in the context of the validation of the obtained results), the efficiency measurement basing on integrated use of the SFA and DEA method was applied"* (Jarzębowski 2013, 173) • "*Choice of modelling approach does affect the results"* (Jacobs 2001, 105) • *"The use of multiple techniques and specifications is likely to be helpful"* (Bauer et al. 1998, 111) • *"The parametric and non-parametric methods are not generally mutually consistent"* (Bauer et al. 1998, 110) The often occurring recommendation to use both DEA and SFA means 1) double work required for the analysis, and may intend that there is 2) a flaw in either of the analysis methods. Lastly the 3) differentiating results obtained in efficiency results may also intend a flaw in either of the methods. Moreover 4) in many cases it is not possible to use both DEA and SFA.		
Application domain examples	Technical efficiency of 240 crop farms in Bangladesh (Theodoridis & Anwar 2011) Operating efficiency for 27 international container ports (Lin & Tseng 2005) Hospital units' efficiency (Katharakis et al. 2014) Technical and scale efficiency of fresh fruits farms in Greece (Karagiannis & Sarris 2004) 200 Meat processing companies in Poland between 2006-2011 (Jarzębowski 2013) NHS Hospitals' (Trusts) efficiency (Jacobs 2001) Productivity and efficiency of Bangladeshi rice (Hossain et al. 2012) Relative operating efficiencies of cattle feedlot farms in Iran (Ghorbani et al. 2010) The cost efficiency of German banks (Fiorentino et al. 2006) Mean technical efficiency in microfinance (Fall et al. 2018) "Performance of profit organizations" (Lin & Tseng 2005, 598)	"Performance of non-profit organizations or branches of firm" (Lin & Tseng 2005, 598)	

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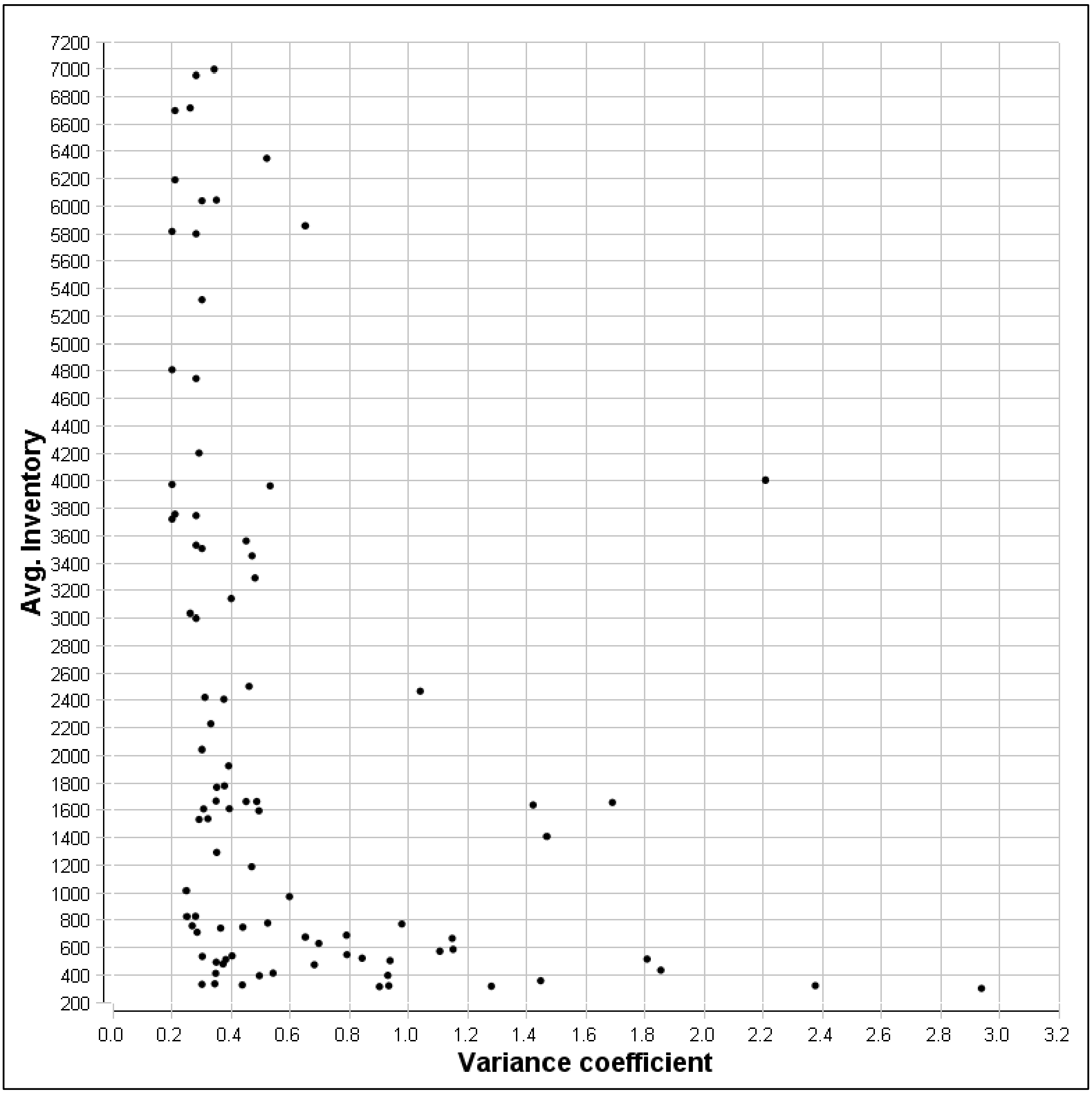
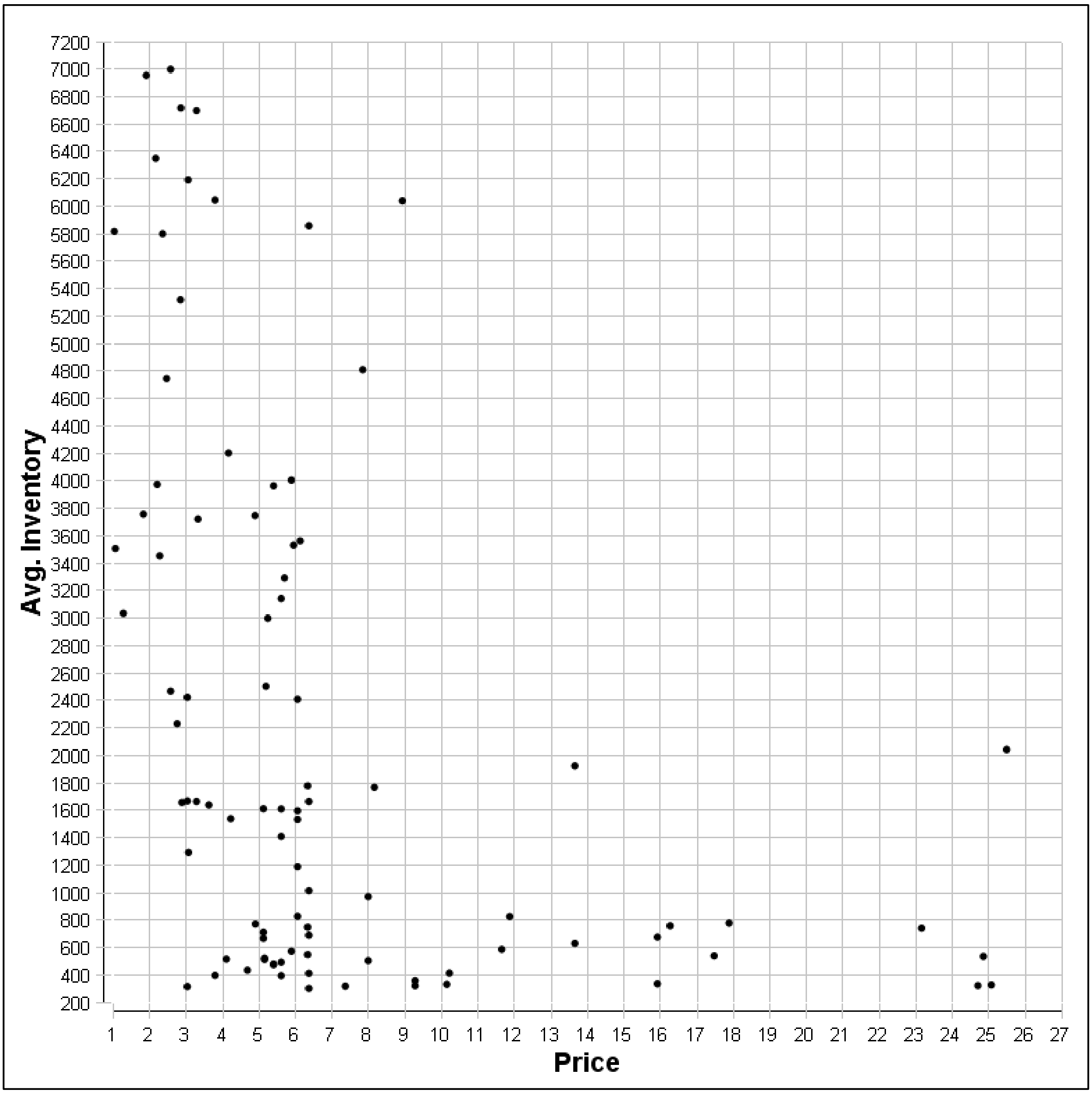
Appendix 3. Avg. inventory and variance coefficient.



Appendix 4. Avg. inventory and price.



Appendix 5. Raw data.

Article number	Material Group	Avg. Inventory	Demand	Standard deviation of demand	Variance coefficient	Inverse Variance Coefficient	Price	Inverse Price	Company
A01	M01	2041.52	1048.67	314.52	0.30	3.33	25.49	0.039	CASE B
A02	M02	325.44	140.50	61.39	0.44	2.29	25.07	0.040	CASE B
A03	M01	534.00	265.42	79.91	0.30	3.32	24.85	0.040	CASE B
A04	M03	320.19	33.08	78.57	2.37	0.42	24.7	0.040	CASE B
A05	M01	740.65	338.92	123.13	0.36	2.75	23.15	0.043	CASE B
A06	M02	778.24	419.67	219.57	0.52	1.91	17.88	0.056	CASE B
A07	M04	537.98	363.08	146.00	0.40	2.49	17.47	0.057	CASE B
A08	M02	758.03	321.50	85.78	0.27	3.75	16.26	0.062	CASE B
A09	M04	675.29	98.42	63.98	0.65	1.54	15.92	0.063	CASE B
A10	M04	333.94	271.83	93.36	0.34	2.91	15.92	0.063	CASE B
A11	M05	1924.12	58.58	22.88	0.39	2.56	13.65	0.073	CASE B
A12	M05	629.23	313.17	217.67	0.70	1.44	13.65	0.073	CASE B
A13	M01	825.50	287.08	71.56	0.25	4.01	11.87	0.084	CASE B
A14	M06	585.65	164.17	188.73	1.15	0.87	11.65	0.086	CASE B
A15	M03	411.81	286.50	155.11	0.54	1.85	10.21	0.098	CASE B
A16	M07	329.58	2600.67	780.20	0.30	3.33	10.14	0.100	CASE A
A17	M03	356.18	76.08	110.10	1.45	0.69	9.28	0.108	CASE B
A18	M03	319.44	125.00	116.59	0.93	1.07	9.28	0.108	CASE B
A19	M08	6038.95	860.75	258.23	0.30	3.33	8.93	0.110	CASE A
A20	M09	1767.32	405.67	141.98	0.35	2.86	8.16	0.120	CASE A
A21	M04	971.13	484.17	289.06	0.60	1.67	7.99	0.125	CASE B
A22	M04	503.08	53.08	49.75	0.94	1.07	7.99	0.125	CASE B
A23	M10	4810.35	2590.49	518.10	0.20	5.00	7.84	0.130	CASE A
A24	M11	316.24	72.58	92.87	1.28	0.78	7.36	0.136	CASE B
A25	M12	5859.45	5522.26	3589.47	0.65	1.54	6.36	0.160	CASE A
A26	M13	1663.33	792.75	385.25	0.49	2.06	6.36	0.157	CASE B
A27	M13	1014.66	630.92	156.08	0.25	4.04	6.36	0.157	CASE B
A28	M13	689.05	107.17	84.57	0.79	1.27	6.36	0.157	CASE B
A29	M13	410.18	192.00	66.57	0.35	2.88	6.36	0.157	CASE B
A30	M13	300.06	0.75	2.20	2.94	0.34	6.36	0.157	CASE B
A31	M04	1777.90	1213.83	456.71	0.38	2.66	6.33	0.158	CASE B
A32	M04	748.00	633.58	277.88	0.44	2.28	6.33	0.158	CASE B
A33	M04	546.82	217.92	172.28	0.79	1.26	6.33	0.158	CASE B
A34	M14	3562.07	2544.75	1145.14	0.45	2.22	6.13	0.160	CASE A
A35	M04	2408.10	1810.83	677.79	0.37	2.67	6.06	0.165	CASE B
A36	M04	1595.36	92.83	45.81	0.49	2.03	6.06	0.165	CASE B
A37	M04	1532.21	1248.83	362.29	0.29	3.45	6.06	0.165	CASE B
A38	M04	1186.54	733.75	343.87	0.47	2.13	6.06	0.165	CASE B
A39	M04	827.09	521.33	144.91	0.28	3.60	6.06	0.165	CASE B
A40	M15	3530.8	3149.14	881.76	0.28	3.57	5.95	0.170	CASE A

A41	M11	4005.30	568.42	1254.67	2.21	0.45	5.89	0.170	CASE B
A42	M11	571.99	80.42	88.82	1.10	0.91	5.89	0.170	CASE B
A43	M16	3291.21	3228.63	1549.74	0.48	2.08	5.7	0.180	CASE A
A44	M04	3140.67	1572.25	627.73	0.40	2.50	5.61	0.178	CASE B
A45	M04	1609.23	1020.17	311.65	0.31	3.27	5.61	0.178	CASE B
A46	M04	1407.86	251.58	369.09	1.47	0.68	5.61	0.178	CASE B
A47	M04	491.76	245.92	85.65	0.35	2.87	5.61	0.178	CASE B
A48	M04	393.05	217.42	107.60	0.49	2.02	5.61	0.178	CASE B
A49	M13	3964.75	3393.58	1803.32	0.53	1.88	5.4	0.185	CASE B
A50	M13	478.65	293.92	109.19	0.37	2.69	5.4	0.185	CASE B
A51	M13	473.25	90.58	61.60	0.68	1.47	5.4	0.185	CASE B
A52	M17	2998.94	3136.67	878.27	0.28	3.57	5.24	0.190	CASE A
A53	M10	2502.08	1537.13	707.08	0.46	2.17	5.19	0.190	CASE A
A54	M03	521.08	362.17	304.99	0.84	1.19	5.15	0.194	CASE B
A55	M03	511.36	543.25	206.91	0.38	2.63	5.15	0.194	CASE B
A56	M04	1610.56	857.67	337.03	0.39	2.54	5.12	0.195	CASE B
A57	M04	710.71	449.92	127.56	0.28	3.53	5.12	0.195	CASE B
A58	M04	666.15	139.25	159.67	1.15	0.87	5.12	0.195	CASE B
A59	M04	771.03	18.92	18.48	0.98	1.02	4.9	0.204	CASE B
A60	M18	3747.4	3281.84	918.92	0.28	3.57	4.89	0.200	CASE A
A61	M19	433.23	1.75	3.24	1.85	0.54	4.68	0.214	CASE B
A62	M20	1537.05	925.28	296.09	0.32	3.13	4.22	0.240	CASE A
A63	M10	4201.63	2630.5	762.85	0.29	3.45	4.16	0.240	CASE A
A64	M11	514.65	163.33	295.11	1.81	0.55	4.1	0.244	CASE B
A65	M11	6044.35	2909.50	1015.46	0.35	2.87	3.79	0.264	CASE B
A66	M19	395.30	134.58	125.09	0.93	1.08	3.79	0.264	CASE B
A67	M11	1637.88	150.42	213.80	1.42	0.70	3.62	0.276	CASE B
A68	M18	3721.81	2606.47	521.29	0.20	5.00	3.32	0.300	CASE A
A69	M12	6698.76	6339.59	1331.31	0.21	4.76	3.28	0.300	CASE A
A70	M15	1663.3	1643.4	739.53	0.45	2.22	3.28	0.300	CASE A
A71	M20	1291.28	928.73	325.06	0.35	2.86	3.06	0.330	CASE A
A72	M21	6191.94	3124.65	656.18	0.21	4.76	3.05	0.330	CASE A
A73	M20	2421.94	872.88	270.59	0.31	3.23	3.03	0.330	CASE A
A74	M22	1666.87	1464.25	509.28	0.35	2.88	3.03	0.330	CASE B
A75	M22	313.26	257.25	231.80	0.90	1.11	3.03	0.330	CASE B
A76	M11	1656.34	395.50	667.98	1.69	0.59	2.89	0.346	CASE B
A77	M17	6717.88	3119.6	811.10	0.26	3.85	2.86	0.350	CASE A
A78	M23	5318.83	2615.39	784.62	0.30	3.33	2.85	0.350	CASE A
A79	M16	2228.5	6404.7	2113.55	0.33	3.03	2.76	0.360	CASE A
A80	M11	6998.04	3766.50	1285.64	0.34	2.93	2.58	0.388	CASE B
A81	M11	2466.55	412.00	428.32	1.04	0.96	2.58	0.388	CASE B
A82	M24	4745.8	1850.83	518.23	0.28	3.57	2.47	0.400	CASE A
A83	M25	5801.07	3154.33	883.21	0.28	3.57	2.36	0.420	CASE A
A84	M23	3452.9	1519.51	714.17	0.47	2.13	2.28	0.440	CASE A

A85	M26	3974.85	2767.67	553.53	0.20	5.00	2.21	0.450	CASE A
A86	M27	6349.64	5594.78	2909.29	0.52	1.92	2.17	0.460	CASE A
A87	M28	6954.97	3328.5	931.98	0.28	3.57	1.91	0.520	CASE A
A88	M23	3757.83	2599.86	545.97	0.21	4.76	1.83	0.550	CASE A
A89	M23	3033.73	1149.95	298.99	0.26	3.85	1.28	0.780	CASE A
A90	M27	3506.37	2686.5	805.95	0.30	3.33	1.06	0.940	CASE A
A91	M23	5818.64	2595.54	519.11	0.20	5.00	1.03	0.970	CASE A