MASTER

Designing a holistic segmentation concept

a case study of redesigning the segmentation concept and applying a segmented approach on safety stock optimization

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Designing a holistic segmentation concept: A case study of redesigning the segmentation concept and applying a segmented approach on safety stock optimization

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Abstract

This study covers the design of a holistic segmentation concept for inventory control and a segmented approach for single-echelon safety stock methods. The design of the holistic segmentation concept is based on a case study for a warehouse where items are characterized with; slow-moving high valued items and fast-moving low-valued items, order quantities varying from one to 1000 units. The objective of the design of segmentation concept is to reduce inventory costs while achieving the same or a higher service level to the customer. First, different quantitative segmentation techniques are analysed and compared to each in terms of inventory costs and service level targets. For the best performing segmentation technique, a sensitivity analysis is conducted on the class sizes. Subsequently, the quantitative technique is included in a qualitative Hierarchical Process in order to create a holistic design. The objective of the segmented approach for the safety stock is also reducing inventory costs and achieving equal or higher performance to the customers. First, a segmented approach according to holistic segmentation design is compared with an unsegmented approach for safety stock methods and currently existing guidelines in the case study object, Hilti AG. Second, For the analysis a distribution system set-up is used with one central warehouse and two local warehouses in order to observe differences between short and long lead time markets. Second, special attention is given to a seasonal demand pattern. Hence, a seasonal approach for calculating the safety stock is compared to a non-seasonal approach. Conclusively, a decision framework is presented for selecting the most suitable safety stock for a certain condition.

Management summary

A general rule in supply chain management is "one size does not fit all", therefore, one has to segment their product categories and use different strategies per segment in order to reduce inventory cost and increase the service to the customers. This master thesis develops a holistic segmentation concept based on a case study. Subsequently, a segmented approach based on the holistic segmentation concept regarding single-echelon safety stock methods is analysed. Again, Hilti AG is used as a case study.

Problem statement

Currently Hilti is struggling with different individual segmentation concepts with regards to inventory management in the end-to-end supply chain. On a high level, an extension of the classical ABC analysis is used for creating segments. However, guidelines based on the ABC analysis for e.g., safety stocks, service level settings, and inventory positioning are missing. Subsequently, warehouses are struggling with high on-hand inventories. Furthermore, different single-echelon safety stock methods are used in the whole supply chain. Guidelines for these safety stock methods are available, however, they are not decisive enough and are not linked to the ABC analysis. Furthermore, an approach for seasonal demand patterns is missing. Hence, the main problems are:

1. There is no holistic segmentation concept for the end-to-end supply chain with regards to inventory management
2. Clear guidelines for the current existing safety stock methods are missing.

Based on these main causes the following two main objectives are formulated:

1. *Develop a holistic segmentation concept on a high level with its advantages and principles.*
2. *Optimize Hilti's safety stock methods considering a segmented approach.*

Scope

For our case study regarding designing a holistic segmentation concept we limit the numerical analysis by using one warehouse where more than 90% of all SKUs are available and is located in an important market. Furthermore, the monthly S&OP structure is used to identify current individual segmentation concepts and how they can be implemented in the holistic design. Regarding the safety stock analysis, a distribution system is used with one central warehouse that supplies two local warehouses. Where one local warehouse has a short lead time (± 6 days), and one has a long lead time (± 47 days).

Analysis

The analysis for designing the holistic segmentation concept can be divided into three parts:

1. A numerical analysis between different quantitative segmentation techniques (e.g., ABC analysis, and FSN analysis) based on a dataset which is a subset of the total SKUs in the considered warehouse. In this analysis inventory holding costs and service level to the customer are evaluated.
2. A validation analysis with another randomly selected dataset in order to validate the findings from the first numerical analysis.
3. A sensitivity analysis on the class sizes of the best performing quantitative segmentation technique.

Resulting from the numerical analysis we can conclude that it is important to include the order frequency (divided in three classes) in the quantitative segmentation technique. In combination with the ABC analysis (within Hilti denoted as TABCD), it is the best performing segmentation technique.

Hence, when using the order frequency in combination with the ABC analysis it results in nine segments (i.e., a 3-by-3 matrix). Due to the TABCD structure within Hilti, it results in 15 segments. Since, such an amount of segments is more difficult to manage, five cluster groups (CGs) are introduced for better manageability (Figure 1). By using these CGs, one is able to focus better on the inexpensive and fast-moving items (CG1), and on the expensive slow-moving items (CG5). Furthermore, according to the sensitivity analysis on the class sizes, it is recommended to keep the T/A class relatively small (± 9% of the total SKUs in Hilti's case), otherwise inexpensive and fast-moving items are classified expensive items. As a result, it is more difficult to achieve a high service level to the customer and, hence, for backorders will occur. For the fast-moving class (i.e., the X-class) it is important as well to consider the class size. When this class is too small, fast-moving items are classified as slow-moving items which have a lower service level target. Hence, in such case the risk arises of more backorders for relatively cheap items. On the contrary when the class of fast-moving items is too huge, expensive slow-moving items are classified as fast-moving items with a higher service level. Hence, resulting in higher inventory costs.

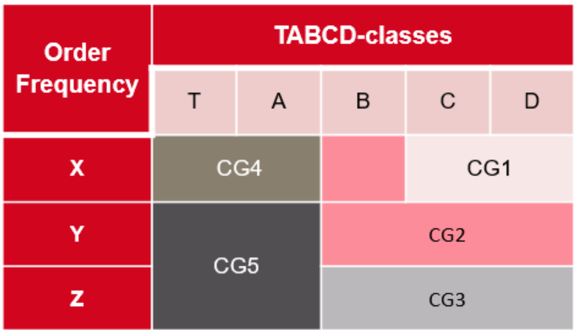

Figure 1 - Best performing quantitative segmentation technique based on the case study.

Regarding the segmented approach for the single-echelon safety stock methods, it is advised to apply a segmented approach when more safety stock methods are available within a company. It is important to apply a segmented approach when one is dealing with long lead times. One should also differentiate between central warehouses and local warehouses, considering that the central warehouse is the most upstream located warehouse in the supply chain and storing too much inventory in the factories is not allowed due to storage space. Furthermore, it is recommended to apply a different safety stock calculation when dealing with a seasonal demand pattern which follows the seasonal demand pattern in a better way and decreases the backorders in the season with high demand.

Solution design

Since the quantitative segmentation technique in Figure 1 does not result in a holistic approach (e.g., it neglects the product life cycle), the CGs are used in a Hierarchical Process. In this qualitative method other segmentation criteria as, Product Life Cycle and Lead time are included, which results in the holistic segmentation design depicted in Figure 2.

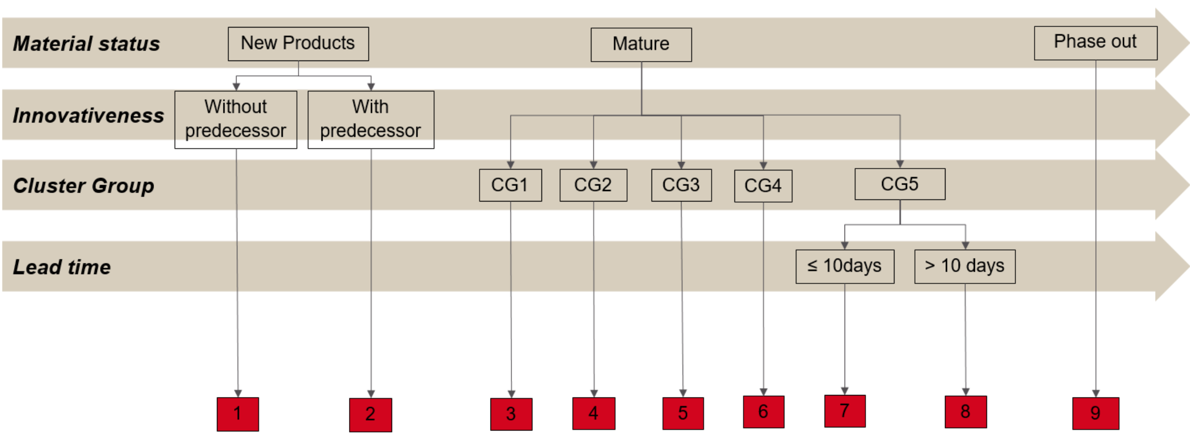

Figure 2 - Holistic segmentation concept

Including the product life cycle is important, because for New products a different strategy is needed since there is no sales data available. Hence a quantitative segmentation technique as the ABC analysis for instance is not applicable.

For a segmented approach in the safety stock methods a decision framework is designed for selecting the correct safety stock method (Figure 3). The main message from this decision framework is that it is important to differentiate between the type of warehouse (closer to customer or closer to factory) because a warehouse close to the factory needs to keep more safety stock due to (re-)supplying warehouses downstream in the supply chain. As mentioned earlier, the second most important decision criterion is the lead time (either short or long). When one is dealing with short lead times it is (depending on the CG) better to keep no safety stock in a warehouse downstream in a supply chain in order to reduce holding costs. Furthermore, for each safety stock method in Figure 3 a seasonal approach is applicable when an item has a seasonal demand pattern.

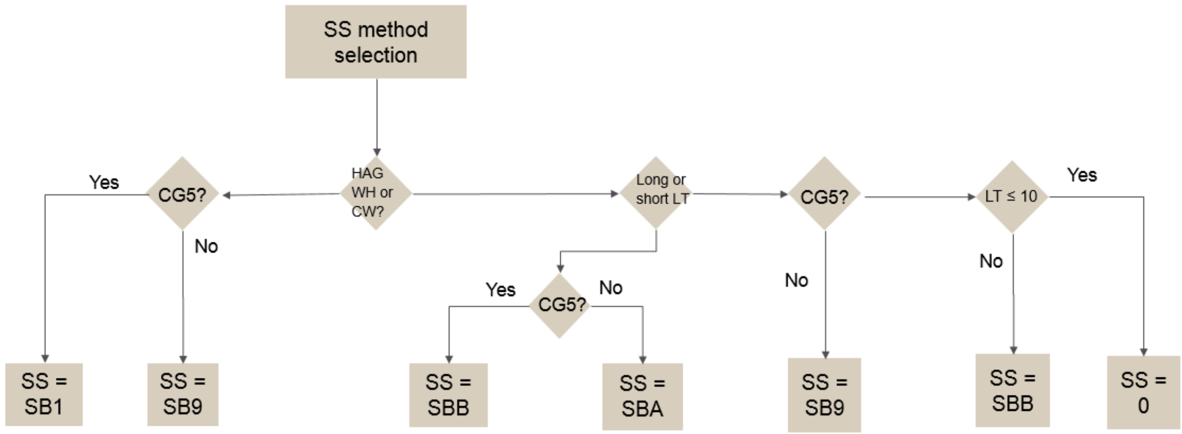

Figure 3 - Decision framework safety stock methods

To conclude, the main findings from this research are:

- Order frequency cannot be neglected in a quantitative segmentation technique
- Cluster groups are recommended when a quantitative segmentation technique consists of more than six classes. By defining cluster groups, the manageability of a segmentation technique is improved.
- Using a Hierarchical Process helps to design a holistic segmentation approach, also in combination with a quantitative segmentation technique.
- A segmented approach for the safety stock methods is recommended when a company has different safety stock methods.
- In case of a seasonal demand pattern, the safety stock should be calculated according to the seasonal demand pattern.

Preface

This study presents my master thesis which is conducted at Hilti in the principality of Liechtenstein. Completing this master thesis means that I have finalized my master's degree in Operations Management and Logistics at the University of Technology in Eindhoven. Simultaneously, it means the end of my fantastic student life. After finishing my bachelor's in Mechanical Engineering in Utrecht, The Netherlands, I am glad that I made the choice to follow a master's program in Industrial Engineering. For instance, it has enriched my knowledge and it has offered the possibility to study abroad for a year.

One of these possibilities was writing my master thesis at Hilti, for which I have to thank Roeland Baaijens and Rüdiger Kübler for giving me this opportunity. I really enjoyed my time at GLMM in Nendeln. Of course, this was also due to the nice team in which I was located. I'm grateful that they were helpful and cooperative if I had any questions. I also want to give special thanks to my company supervisor Federico Scotti-di-Uccio for his feedback and guidance during the master thesis. Furthermore, I also want to thank Ralph Gut and Sindri Fridriksson for their support.

Besides the colleagues of Hilti, I also would like to thank my first supervisor from the university, Tarkan Tan. I am grateful for your valuable feedback and support during the whole master thesis project. After every meeting I felt confident on how to proceed. I also would like to thank Shaunak Dabadghao, my second supervisor from the university, for his input and feedback during joint meetings with Tarkan. I found it helpful that you were involved from the beginning such that we were all heading in the same direction. It is evident that you were involved in the beginning, because part of this master thesis is jointly written with Nika Schutten. Therefore, I would like to thank Nika in particular for working together on this master thesis. Although, there were some ups and downs during the whole project, I found it always pleasant to work with you and I really appreciate your focus on details. Finally, I would like to thank my fellow students for working together in group assignments and for having a great time during my pre-master's and master's program. Especially I would like to thank Filip Obers for the great and somewhat sarcastic discussions and the delicious coffee moments at Julia's in the mornings. Also, I would like to give special thanks to Ruben Wegmann. It was always delightful to make a cycling trip after work or during the weekend. The beautiful areas and amazing views on our cycling routes in Austria and Switzerland helped me to destress during this period.

In the end I would like to thank my family, in particular my parents Marcel and Lidy for supporting me while I was abroad. Though I know you did not like it that I was abroad again for a period of 7 months after Milan, I really appreciated that you were supporting me during this period.

Luc Sonneville

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Abbreviations

AHP	Analytical Hierarchy Process
ATS	Availability to Standard
BA	Business Area
BU	Business Unit
CG	Cluster Group
CODP	Customer Order Decoupling Point
CSL	Cycle Service Level
CW	Central Warehouse
DC	Distribution Centre
DFU	Demand Forecasting Unit
EB	Executive Board
EMT	Executive Management Team
EOQ	Economic Order Quantity
GL	Global Logistics
GLC	Global Logistics Controlling
GLD	Global Logistics Distribution
GLM	Global Logistics Materials
GLS	Global Logistics Services
HAG WH	Hilti Headquarters Warehouse
HC	Hilti Centres
HIP	Hilti Integrated Planning
HNA	Hilti North America
INP	Introduction New Product
LCN	Logistics Centre Nendeln
MDQ	Minimal Delivery Quantity
MM	Materials Management
MO	Market Organization
MOQ	Minimum Order Quantity
MRP	Materials Requirement Planning
MTO	Make to Order
MTS	Make to Stock
OFR	Order line fill rate
OL	Orderline
PTO	Purchase to Order
RDC	Regional Distribution Centre
ROP	Reorder Point
S&OP	Sales and Operations Planning
SAP APO	SAP Advanced Planner Optimizer
SKU	Stock Keeping Unit
SS	Safety Stock
TM	Transport Management
VED	Vital Essential Desirable
WM	Warehouse Management

1. Introduction

A popular and classical way to segment products is the ABC method or Pareto analysis whereby around 20% of the total items is accounting for 80% of the sales revenue. Hence, in practice one is aiming for a high service level to customers for SKUs in class A. This is also examined in Armstrong (1985), and Stock and Lambert (2001). However, Sherbrooke (1986) argues that such an approach would lead to sub-optimal inventory costs. Therefore, one should aim for a service level for less expensive items with a high order frequency in order to reduce inventory costs. Recent studies (Teunter, Babai, & Syntetos, 2010; van Wingerden, Tan, & van Houtum, 2018) showed a similar approach where they showed that keeping on stock low valued with high order frequency results in lower inventory costs. Simultaneously, the number of classes and class sizes had an impact as well.

A further segmented approach is observed in the calculation of safety stocks. For instance, there exists a different calculation strategy for seasonal products in a single-echelon environment (Herrin, 2005). Also, in practice one uses different ways to calculate the safety stock in a single echelon environment, however, there is not much literature that covers a segmented approach for calculating the safety stock. Hence, this master thesis contributes to inventory classification techniques by using a case study wherein different segmentation techniques are compared to each other. Furthermore, this master thesis contributes to single-echelon safety stock calculations by considering a segmented approach for using a certain safety stock calculation method.

This master thesis is conducted at Hilti. Within Hilti, an extension of the ABC classification technique is used. In addition, they use two more classes which results in the TACBD classification. Furthermore, three additional classes (XYZ) are used for denoting the order frequency on order line level which results eventually in 15 classes. Besides the TABCD-XYZ classification Hilti is using several safety stock calculation methods. However, there no clear guidelines when to use a certain safety stock method. Hence, the aim of this research is two-fold. First a new segmentation concept is designed with proper service level targets per class and guidelines with regards to inventory management. Second, the current safety stock methods are investigated in order to see whether a segmented approach is applicable while considering the new developed segmentation concept.

This thesis is organised as follows: it starts with a general introduction of the company where the thesis is conducted. Thereafter, the root-cause analysis is discussed accompanied by the research question and scope of the master thesis project. In chapter 4, key literature for designing segmentation concepts and safety stock optimization in a single-echelon environment is briefly discussed. Chapter 5 gives an overview of the current segmentation concepts used within Hilti and compares it to findings in literature. Subsequently, the new designed segmentation concept for Hilti is presented in chapter 6. In chapter 7, an overview is given about the current safety stock methods used within Hilti. Similarly, it provides solutions to use a segmented approach for safety stock methods within Hilti. At last, the conclusions and limitations of this master thesis project is given in chapter 9. Directions for further research are presented as well in this chapter.

2. Company Description

To understand the general context of this master thesis it is important to address where this master thesis project will be conducted. This chapter gives this insight. At first, general information about the company will be discussed which gives an insight in Hilti's business model and strategy. Thereafter, more insight is given in Hilti's corporate structure in order to see where in Hilti's organization the master thesis will be conducted. Then Hilti's supply chain will be elaborated followed by the role of the department Materials Management in the supply chain.

2.1. General information

The Hilti Group (hereafter Hilti) was founded in 1941 by Martin Hilti. Nowadays Hilti is still a family company where all the shares are in possession by the Martin Hilti Family Trust and its headquarters is in Schaan in the Principality of Liechtenstein. Hilti excels in developing and manufacturing products, software, systems and services for construction and energy industries. Moreover, Hilti offers an extensive after-sales service for her customers to keep the customers enthusiastic. Keeping customers enthusiastic is part of Hilti's goal, "passionately create enthusiastic customers and build a better future.

At this moment Hilti is operating in more than 120 countries and has around 27,000 employees worldwide. Two -thirds of the employees work in sales organizations and engineering which means that there are more than 200,000 customer contacts every day. Moreover, Hilti has its own production plants and R&D-centres located in Europe, Asia and Latin America.

Over the last year Hilti exceeded all its targets significantly compared to the year 2016. For instance, Net sales, Net income, and Return on sales rose to 5133 MCHF, 530 MCHF, and 13.5% respectively (i.e. an increase of 11%, 10%, and 4% respectively compared to 2016). However, some countries had more impact on these figures than others, as depicted in Figure 4. Europe and North America are the biggest markets for Hilti in both years.

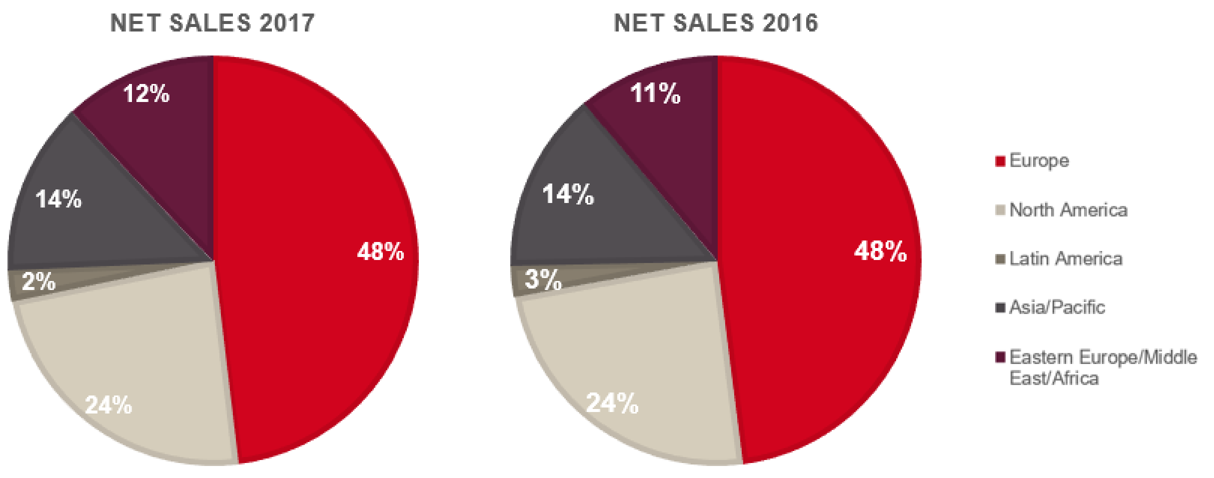

Figure 4 - Net sales per region in 2016 and 2017

The guidance for the results presented in Figure 4 are the result from Hilti Business Model (Figure 5). The business model clarifies *why* Hilti exists and *how* the core values are enacted. Hilti's goal (purpose and value) is to create enthusiastic customers for long the long term by satisfying all stakeholders. Before stating the strategy, Hilti makes clear that the employees are making the difference in the daily operation and therefore are key figures in achieving the goal.

Figure 5 - Hilti Business Model

2.2. Global Logistics

Global Logistics (GL) manages three areas, namely Warehouse Management (WM), Transport Management (TM), and Materials Management (MM). The description of these areas is elaborated in Table 1. GL is responsible for supply chain planning and control on a tactical level for every MO or region. GL is involved in designing processes on a global and regional level in the three areas from Table 1. Hence, in cooperation with the MO's and regions it designs regional and central warehouses; sets safety stocks policies; makes forecasts and makes decisions on the order size and when to replenish all SKU's.

Table 1 - Description of main areas GL

Area	Description
WM	- Designing of distribution networks - Managing processes and standards in warehouses - Warehouse capacity management - Third party logistics management
TM	- Designing transport network - Route optimization - Carrier management - Tendering
MM	- Inventory management - Sales planning and forecasting - Order process management - Export and customs

Besides being responsible for supply chain planning and control for the MO's, GL provides recommendations for setting up inventory and replenishment policies to the BU's as well. At the same time, GL is accountable, together with the MO's and BU's, for achieving targets with respect to customer satisfaction, service level and inventory level. Therefore, GL can be considered as an independent organization which is at the same time an integrated business partner, instead of a pure service provider.

2.2.1. Global Logistics Strategy

The strategy for GL is derived from the company's strategy. Hereby the targets for GL are to achieve a high product availability (more than or equal to 98%) and a reliable order execution (more than or equal to 97.5%) by minimum inventory levels (less than 90 days on hand) and against the lowest costs.

In order to create sustainable value creation, GL will focus on three main areas. First, the focus is on offering advanced services. Hereby, Hilti can strengthen its competitive position as a high-quality service provider by offering highly reliable, more advanced and segmented services. Second, Hilti pursues its strong operational foundations by using lean processes, an optimized supply chain network, and a new integrated sales and operations planning. Therefore, Hilti is able to continue providing high quality service levels, reduce inventory, improve productivity, and support global growth. At last, GL will act as an entrepreneurial business partner within Hilti. This implies that GL is closely integrated into the local organizations such that better local decisions are made and are faster implemented. Simultaneously, GL uses the strength of its independent global set-up.

2.3. Hilti's supply chain

Since the master thesis is going to address Supply Chain topics, it is important to get better overview of Hilti's supply chain. Currently, Hilti has 380 suppliers of raw materials which are supplying the plants. Whereas, 900 suppliers are allied suppliers of finished goods and ship directly to the Hilti AG Warehouses (HAG WH's), central warehouses (CW) or distribution centres (DC). The plants are controlled by the BU's and are dispersed globally. Finished products from the plant are then distributed either to the HAG WH's or to the CW's or DC's. Subsequently the repair centres, Hilti Centres (HC's) and repair vans are resupplied. Although, this structure differs among regions. For instance, in Hilti North America (HNA) products from HAG WH's are consolidated in two national DC's which, subsequently, distribute the products to Regional Distributions Centres (RDC).

Another exception is when order volumes are too low to ship them directly from CW's to DC's, these orders will be shipped to a transhipping hub to consolidate the order and from there on distributed to the different MO's.

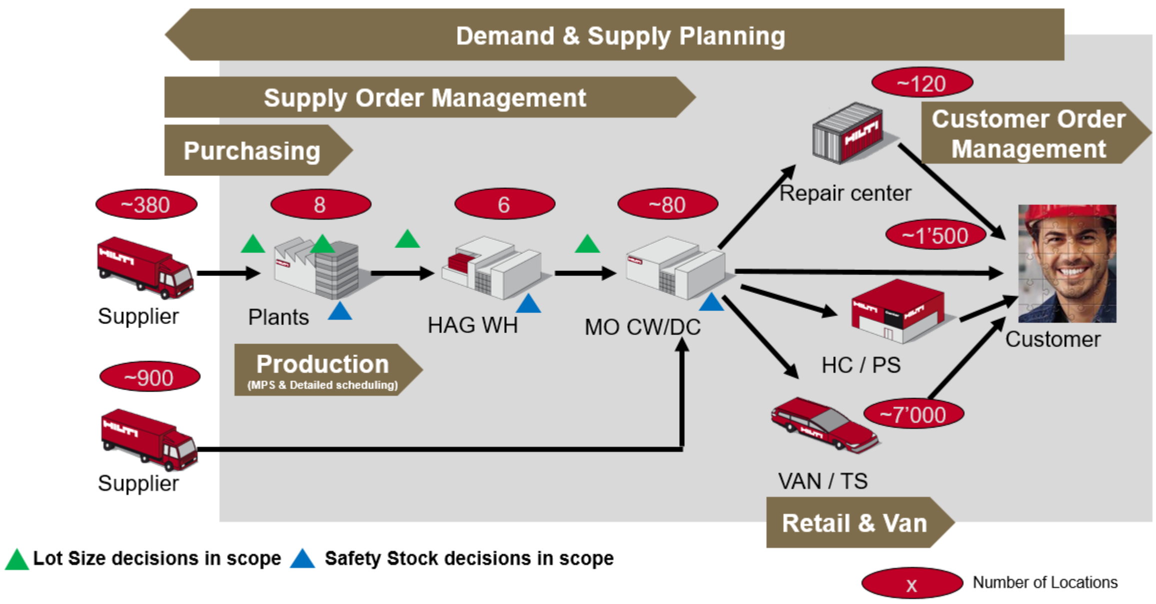

Figure 6 - General overview Hilti's supply chain

Eventually the customer order management is at the HC's, repair centres, and repair vans. Hence, customers can order new products at the HC's or via the internet or can bring their Hilti products to the HC’s for repair. The repair centres and repair vans are only for maintenance issues. However, when a customer has a large order or orders from the internet, then the customer’s will be delivered directly from the CW or DC.

Hence, it can be concluded that Hilti’s supply chain is quite complex. Moreover, Hilti’s supply chain is quite unique, because Hilti controls almost the entire supply chain from end-to-end (from to producing to selling to the customer).

2.4. Hilti Integrated Planning (HIP)

To match customer’s expectations with supply chain and production planning, Hilti is implementing a Sales and Operations Planning framework, i.e., Hilti Integrated Planning (HIP). The goal for implementing HIP is to achieve a higher maturity level in S&OP and, therefore, achieve better alignment between customer’s demand and Hilti’s supply chain.

The HIP can be divided into two main processes namely, Sales Planning (Figure 7) and Operations/Supply Planning. Each main process consists of sub processes. The first process in Sales Planning is performing the statistical forecast for the products which have sufficient historical data. Thereafter, the forecasts will be reviewed, and market intelligence is incorporated. This implies for instance, whether new products will be launched, or a new project starts. Moreover, it becomes clear which products are going to be promoted in the markets.

After the demand review the sales forecasts are integrated with the BU’s. In this process, an alignment takes place between marketing & sales and the BU’s, which implies that marketing intelligence is managed on product family or item level. The resulting plans are then communicated with the MO’s. In the MO, these plans are discussed then discussed with different market segments (in Hilti called ‘trades’) and regions.

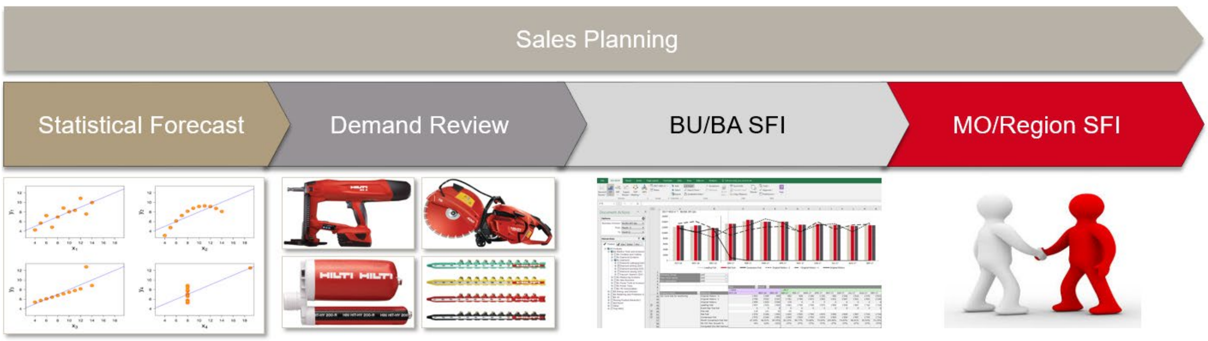

Figure 7 - Sales planning Hilti

With the Sales Planning completed, the Operations Planning starts. First, a capacity preview is done in order to check if Hilti’s plants have enough capacity to satisfy the forecasts. The capacity preview is done for 3 or 4 months ahead and gives insight in the maximum capacity for Hilti’s plants. Based on the Supply Planning and the capacity preview, decisions are made on how to increase capacity (when needed) in Hilti plants (e.g., increase number of shifts or workforce on shorter term, or invest in new machines on the longer term).

Figure 8 - Operations Planning

Thereafter, the master production planning (MPS) takes place. In this process, the supply plan is disaggregated in weeks instead of months. By dividing the supply plan in weeks, a production schedule is made in such way that set-up times are minimized, and the production pattern is optimized. At last a distribution planning is made to deploy the produced goods to the warehouses and MO's. When the demanded production volume cannot be met, the produced units are fairly shared among the warehouses and MO's.

3. Problem Description

This chapter discusses the problem Hilti deals with. Practically, it provides an answer for why this research is important. First, the root causes and corresponding symptoms of the current main problem at Hilti are discussed. By identifying the root causes, the need for this research is highlighted. Consequently, the research problem is formulated with corresponding research questions and the scope of the project is defined. The last section of this chapter denotes the key deliverables for this master thesis project. This chapter is based on the Research Proposal that is jointly written with Nika Schutten (Schutten & Sonneville, 2018a).

3.1. Root cause analysis

This section provides the most important causes with the corresponding symptoms which are responsible for the main problem. Currently, Hilti is dealing with increased inventory levels and a decrease in the service level to the customer. Which, basically, is caused by a wrong allocation of resources in Hilti's end-to-end supply chain. An overview of the causes and effects is given in Figure 9.

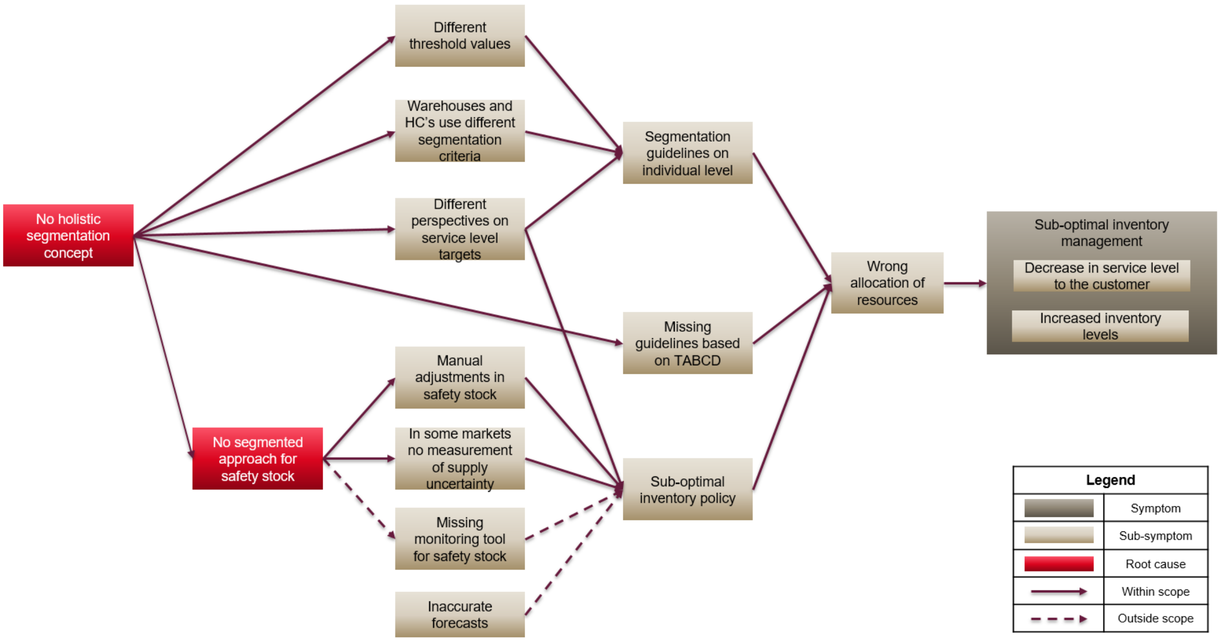

Figure 9 - Root cause analysis

First, there are segmentation guidelines on an individual level in the organisation. For instance, the segmentation concepts for the warehouses and the HC's are different. In the HC's one distinguishes the items in core or non-core, whereas this distinction does not occur at the warehouses. Furthermore, in the HC's they clearly differentiate between accessories, tools, and consumables. Where the consumables seem more critical since customers easily switch to another supplier when a consumable is not available on stock.

Another area where individual differences occur is on setting the threshold values for variables related to the order frequency or order variability. In some cases, the number of classes is different. For example, in the statistical forecasting team four classes are defined with different threshold values, whereas in the system three classes with different threshold values are defined. Moreover, there are two different methods available for determining the order frequency (i.e., the XYZ-method and the QRS-method) where the threshold values differ slightly.

Also, in the service level targets (i.e, the fill rate in SAP) there is no consistent guideline for setting the service level according to the importance in terms of sales revenue and order frequency (TABCD-XYZ). Moreover, service level targets differ per region and it differs among the warehouses (i.e., HAG WH's and CW's).

Furthermore, there are no guidelines based on the classical TABCD classification method (i.e., sales revenue times the unit price). At this moment, no actions are in place for the most important items within Hilti (i.e., the T and A items). Moreover, there is no differentiation in inventory decisions based on this classification. Hence, a holistic segmentation concept is missing. Such a holistic approach is also missing in the safety stock methods.

As depicted in Figure 9, also sub-optimal inventory policies are causing decreased service levels and higher inventory levels. First, a global monitoring tool is missing for tracking which safety stock methods are used for a certain segment. In one region (i.e., South-America, LW2) there is monitoring tool in place. However, developing such a tool for Hilti globally is not part of this thesis. From this tool, one can conclude that often the simplest safety stock method is used for the most important classes, whereby, service level factors and lead time variations are not considered. Regarding the service levels, as mentioned before, there is no structure in setting those targets. This also results in sub-optimal inventory policies.

Moreover, using the simplest safety stock method implies that manual settings or adjustments are used, even for the most important items. Also, for markets with long lead times where lead time variation is not considered this results in a sub-optimal managed safety stock.

Another cause of the higher inventory costs is the inaccurate forecasts. Especially, the forecasts for seasonality products are incorrect. Currently, 7% is classified as seasonality products by the system, however, according to a detailed analysis from the statistical forecasting team at least 40% should be classified as seasonal. However, optimizing the forecast accuracy is out of scope for this master thesis project. Although, the current method that is used for calculating the safety stock for seasonal products is quite static. The current safety stock calculation is not changing monthly when there is a clearly monthly seasonality pattern in the forecast.

3.2. Research goals and objectives

After the root causes are identified, the research goals and objectives can be formulated. Two root causes are identified, that is, 1) there is no holistic segmentation concept and 2) there is no clear integrated concept for determining the safety stock policy based on the best practices segmentation criteria.

Therefore, this project has two goals.

3. Develop a holistic segmentation concept on a high level with its advantages and principles.
4. Optimize Hilti's safety stock methods considering a segmented approach.

By considering the cause-effect relationships and the research goals, the objectives of this master thesis project can be formulated. In a chronological order, the objectives are as follows:

1. Identify current segmentation concepts in Hilti's end-to-end supply chain and their relationships to each other.
2. Evaluate current best-practice segmentation concepts in supply chain management. Moreover, evaluate current frameworks or reference models conducted in scientific literature.
3. Identify gaps in Hilti's current segmentation processes compared to best-practice segmentation concepts and scientific segmentation frameworks or reference models.

4. Provide a to-be segmentation concept for logistics in Hilti's end-to-end supply chain.
5. Identify and investigate current safety stock methods in Hilti's plants, HAG warehouses, and Central warehouses.
6. Analyse in which way the current safety stock methods can be adjusted to the to-be segmentation concept.
7. Model the safety stock methods which are adjusted to the to-be segmentation concept and evaluate performance increase in terms of costs and service level compared to the current situation.

3.3. Research questions

By knowing the research goals of this master thesis project, the according research questions can be formulated. Since there are two research goals, there are two main research questions accordingly. Each main research question consists of several sub-research questions.

Main research question 1:

How should the holistic segmentation concept be designed for Hilti's end-to-end supply chain in order to achieve lower inventory costs and a higher service level?

To answer the first main research question, the following sub research questions are formulated:

Sub research question 1: *What are the current segmentation concepts in Hilti's end-to-end supply chain?*

Sub research question 2: *Which current best-practice segmentation concepts or scientific frameworks exists for supply chain segmentation?*

Sub research question 3: *Which gaps exists between Hilti's current segmentation concepts and the scientific frameworks or best-practice segmentation concepts?*

In order to achieve the second research goal and the according research objectives, the second main research question is formulated:

Main research question 2:

How to improve Hilti's safety stock methods in the end-to-end supply chain by considering a segmented approach?

For answering the second main research question, the following sub research questions are formulated:

Sub research question 4: *Which are the current safety stock methods in Hilti's supply chain?*

Sub research question 5: *How can the safety stock methods while considering a segmented approach be modelled?*

Sub research question 6: *What are currently the input parameters for calculating the safety stock for the different safety stock method within Hilti?*

Sub research question 7: *Which decision criteria currently exist in scientific literature for using a certain safety stock method?*

Sub research question 8: *Which relationships exist for the safety stock methods with respect to the holistic segmentation concept?*

Sub research question 9: *Which performance measures are used to evaluate the (improved) safety stock methods in a simulation?*

3.4. Project scope

In this section, the scope of the master thesis is defined. Basically, the scope consists of two parts. At first, the scope of the holistic segmentation concept will be determined. At last, the scope of improving the safety stock methods is defined.

The holistic segmentation concept has a considerable scope whereby the focus will be on the logistics planning and execution. Typically, for analysing the current situation (AS-IS) the HIP (Section 2.4) will be used as a first guideline in order to discover segmentation concepts within Hilti. Besides the HIP, the other sources are used to discover segmentation concepts. Already available guidelines within for inventory positioning, lot sizing, material requirements planning, and safety stock calculations within Hilti will be used. Furthermore, segmentation concepts in the end-to-end supply chain (Figure 6) will be analysed such that interdependencies among the different locations can be identified.

For improving the safety stock methods, a quantitative model is going to be used. The scope of where to perform this quantitative model is a HAG WH (i.e., LCN) and two CW's. Whereby, one of the CW's has a long lead time from the LCN and the other CW has a short lead time from the LCN. Moreover, an improvement in the region Germany will have the biggest impact on the inventory costs. Hence, safety stock optimization within the HC's will be outside of the scope. The same holds for stock points in the plants.

4. Literature review

Segmentation, also referred to as classification, in operations research is the process of placing SKU's based on their characteristics into segments/groups with as goal to optimize decisions for every segment rather than using a one size fits all concept. Van Kampen et al. (2012) found that in literature SKU classification is mainly used in inventory management, forecasting and sporadically in production strategy. In this chapter key literature regarding segmentation is discussed. The part of the segmentation literature review is jointly written with Nika Schutten (Schutten & Sonneville, 2018b)

4.1. Segmentation conceptual framework

Van Kampen et al. (2012) developed a conceptual framework for SKU segmentation in which the goal of SKU segmentation is defined and, subsequently a method is used in order to find the number of SKU classes with their borders. As depicted in Figure 10, SKU segmentation has the goal to make better decisions with regards to inventory management, forecasting or production strategy. For determining the classes, one uses several characteristics (divided in the groups Volume, Timing, Customer and Product) in a judgmental or statistical segmentation technique.

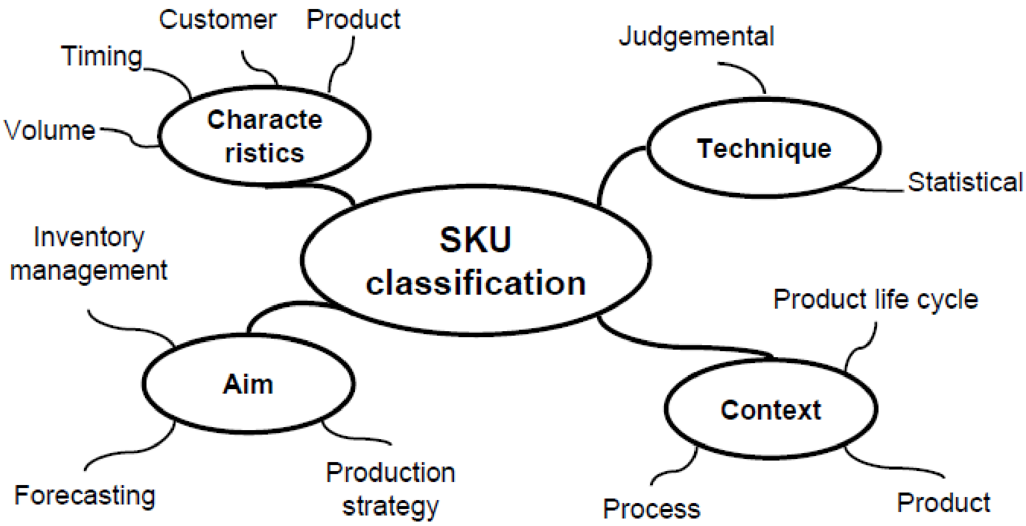

Figure 10 - Mind map of SKU segmentation (van Kampen et al., 2012)

4.1.1. Segmentation criteria

In the literature study from van Kampen et al. (2012) the characteristics are distinguished in Volume, Timing, Customer, and Product (see Table 2 for an overview). The volume characteristic relates to demand volume over a certain period in most literature, however, demand variability – measured in coefficient of variation – is also mentioned in the volume characteristic. Product's unit cost, production lead time and replenishment lead time are examples of Product characteristics whereby the unit cost of the product is most mentioned in literature. For the customer characteristic, the importance of a certain customer is addressed. This is also referred to the criticality of a product, which is more used in spare parts classification. The criticality is often determined by a qualitative framework, such as VED classification, FMECA or Analytical Hierarchy Process (AHP). However, Teunter, Babai, and Syntetos (2010) uses a Price Criticality Ratio in order to determine the Cycle Service Level (CSL) which is applicable for non-spare parts as well. The last characteristic category is Timing, which measures mostly the inter-demand interval. Hence, it gives more insight into the order frequency of a product. Moreover, it helps to investigate forecasting characteristics, such as a trend or seasonality.

Table 2 - Overview of characteristic categories and corresponding parameters

Characteristic category	Parameter
Volume	Demand volume
	Demand variability (Coefficient of variation)
	Demand pattern (how the volume evolves over time)
Product	Product's unit cost
	Production lead time
	Replenishment lead time
	Perishability
	Commonality
	Substitutability
Customer	Customer importance
	Criticality
Timing	Inter-demand interval

The listed parameters in Table 2 are subsequently used in a classification technique (Bacchetti & Saccani, 2012; van Kampen et al., 2012). This technique is either qualitative (judgemental) which is based on judgements from experts or quantitative (statistical).

4.1.2. Key segmentation techniques

As depicted in Figure 10 one can distinguish in qualitative and quantitative segmentation techniques. Furthermore, there is a differentiation between a two-criteria segmentation techniques and multi-criteria techniques.

Qualitative segmentation techniques

The purpose of the qualitative techniques is to extract knowledge that is often held by managers or other experts. These methods are mostly used to assess the importance of keeping a spare part or normal SKU on stock (Bacchetti & Saccani, 2012). The most popular qualitative techniques are e.g. VED and a (Analytic) Hierarchy Process (AHP). The VED classification distinguish in "Vital", "Essential", and "Desirable" items. Whereby, Vital items must be kept on stock, because keeping these items not on stock can have a significant impact in the operational business. Essential items should be stocked as well, although the consequences of a stock out are not as high a stock out for Vital items. For the Desirable items, one can keep these items on stock, though it is not necessary (Vrat, 2014). Hence, the VED analysis assess how critical an item is for a company. Whether an item is Vital, Essential or Desirable is determined by managerial insights. Hence it is important that the right stakeholders or knowledge holders are involved by allocating the items or product categories to the right classes. Due to its qualitative nature, the VED analysis is quite often used in hospitals or in a manufacturing environment. For these environments, it is more straightforward which products are more important than others. In a hospital, for instance, medicines that can save lives are definitely Vital (Vrat, 2014). In a complex global supply chain environment with different stakeholders and more than 20,000 SKUs it is more difficult to complete the VED assessment and is therefore less feasible.

The (Analytic) Hierarchy Process (AHP) is a segmentation technique that combines multicriteria to and uses paired comparisons in order to make a decision between different options (Saaty, 1990). Flores Olson and Dorai (1992) showed that the AHP can also be used as a multicriteria classification method for a more comprehensive ABC classification scheme. However, a major drawback of this classification method is that the weights for every criterion are determined judgementally and of high importance to allocate a SKU to a certain class. Hence, when using multiple criteria, it becomes opaquer why a certain SKU belongs to class A for instance. Another drawback in the study of Flores et al. (1992) is the lack of showing the impact on inventory costs by using the new segmentation technique. Guidelines with regards to inventory control policies are lacking as well.

A study of Bacchetti et al. (2013) skips the analytical part and has developed a multicriteria segmentation concept by a hierarchical process for specific company. A set of criteria is determined by interviews and questionnaires with employees and judgemental insights from the authors. Each criterion consists of two or three levels in order to allocate a SKU to a segment. The threshold values for each criterion except for one are determined by judgemental insights as well. For some classes three different inventory control and forecasting policies are tested and simulated to select the most beneficial control policy. To conclude, Bacchetti et al. (2013) showed that their segmented approach is more beneficial with regards to inventory costs than the current situation in that case study. Despite the judgemental and not generalizable set-up, the segmentation scheme is easy to explain compared to a multicriteria quantitative segmentation technique. Furthermore, by using a qualitative approach the segmentation concept is more comprehensive compared to a one- or two-criteria quantitative segmentation technique.

Quantitative segmentation techniques

In spare parts segmentation and SKU segmentation the most popular quantitative method is the traditional ABC/Pareto analysis (Bacchetti & Saccani, 2012; van Kampen et al., 2012) where the parameters demand volume times unit price is used. The main advantage of the ABC analysis is its generalizability. However, this segmentation technique is based on two criteria, hence, it is less sophisticated for defining inventory control and forecasting policies. Moreover, there are two opinions about the ABC segmentation technique with regards to inventory management. More specifically, about setting service level targets for each class. Some authors (D. J. Armstrong, 1985; Stock & Lambert, 2001; Vrat, 2014, pp. 40–42) argue that products in class A should have the highest service level target and demand for those items should always be met since their impact on the revenue. It is valid argument that those items contributing the most to the sales revenue. However, one should be careful with stocking these items due to high inventory cost (Sherbrooke, 1986). Hence the suggestion is to set high service level target for SKUs in class C, since it is not worth for these items to have stock outs (Knod & Schonberger, 2001).

Therefore, Teunter et al. (2010) developed a new cost criterion for the ABC segmentation technique where inventory holding costs and backorder costs are taken into account. By their cost criterion they also put more emphasis on the SKUs with a higher order frequency. In the same study, they showed that using six classes leads to better results than the three classes from the ABC segmentation. Similar to the ABC segmentation, Teunter's cost criterion is generalizable for other companies. The downside, however, is that the backorder costs are required while this for most companies is hard to determine. Moreover, Teunter's cost criterion increases the managerial complexity (Bacchetti et al., 2013), although the managerial is not as high as in the ABC extensions from Ng (2007) and Ramanathan (2006). In both studies (weighted) linear optimization is applied in a multicriteria ABC segmentation technique to determine the weights of each factor. This method is, similar to Teunter's cost criterion, easy to implement in a current ERP system (e.g., SAP) where the ABC fields are already available. However, from a managerial interpretation perspective it is not straightforward why a certain SKU is in class A. Besides, in both studies the resulted cost benefits from the new segmented approach is unknown.

As stated by Van Wingerden, Tan and van Houtum (2018) the resulting inventory costs from the ABC segmentation technique is often neglected. Teunter et al. (2010) showed by considering inventory costs, that the classical ABC technique is far from optimal and that six classes instead of three classes results in better performance. However, the threshold values for the six classes are chosen arbitrarily (van Wingerden et al., 2018). Therefore, van Wingerden et al. (2018) considered the class sizes to minimize inventory cost constraint by an aggregate fill rate target. As a result, the class size has a significant impact in the segmentation technique. Moreover, in their study they confirmed Teunter's outcome that the classical ABC technique performs far from optimal. Hence, class sizes must be considered when developing a segmentation concept based on a quantitative technique.

Besides the ABC technique, the Fast-, Slow- and Non-moving (FSN) is a popular segmentation technique as well which segments SKUs based on the order frequency in a defined period (van Kampen et al., 2012; Vrat, 2014). According to Vrat (2014, pp. 44–45) this single segmentation criterion is more helpful in selecting the appropriate inventory control model. Similar to the classical ABC technique it is easily understandable from a managerial insight perspective. It can be easily implemented in a ERP system as well. The downside of the current FSN technique is the lack of guidelines for threshold values for the classes and the class sizes. Furthermore, by our knowledge the FSN has not been combined with variability in demand or orders. Hence, this combination might be interesting for designing a holistic segmentation concept for this master thesis.

At last, van Kampen et al. (2012) discusses that the method and parameters for SKU segmentation are influenced by the aim and the context of the segmentation. Basically, three different aims are mentioned, namely forecasting, inventory management and production strategy. Although, in their study the more common segmentation aim is inventory management and forecasting. Also in the study of Bacchetti et al. (2012) these two aims are related to classification in spare parts management. Besides the aim of SKU classification, van Kampen et al. (2012) discusses the context where SKU segmentation takes place. The context can be either product specific, production process specific, or product's life cycle specific. However, Bacchetti et al. (2013) included the product's life cycle as a segmentation criterion in order to develop a holistic approach. To design a holistic segmentation concept with clear managerial insights and generalizable criteria it would be interesting to combine a qualitative and quantitative technique into a holistic segmentation concept.

4.2. Key literature safety stock

With regards to determining the safety stock one can differentiate between safety stock calculations for single echelon and multi echelon inventory systems. In this section safety stock methods in a single echelon inventory are discussed since this study examines only safety stocks in a single echelon inventory system.

The most popular way to calculate the safety stock is to multiply the standard deviation of the demand during lead time (denoted as σ_D) with a safety factor, say k, based on a standard normal distributed demand (Schmidt, Hartmann, & Nyhuis, 2012). The calculation of the safety stock in (1) can be extended by taking into account the replenishment lead time (2). Alternatively, σ_D can be replaced by considering the forecast error during the replenishment lead time σ_f.

$$SS = k * \sigma_D \tag{1}$$

By extending (1) with the replenishment lead time and using σ_f instead of σ_D Schmidt et al. (2012) claims then that calculating the safety stock is independent of a specific demand distribution. However, this is not entirely true since the safety factor is still included in the calculation and is based on the standard normal distribution.

$$SS = k * \sigma_D * \sqrt{\mu_L} \tag{2}$$

Furthermore, in literature (Axsäter, 2015; Eppen & Martin, 1988; Silver, Pyke, & Peterson, 1998) one includes the replenishment lead time variability (σ_L) and the demand during lead time (μ_D). The safety stock calculated in (3) is subsequently used for various extensions which are mentioned in Schmidt et al. (2012). An example is to extend the calculation in (3) by considering the variation of the undershoot

(U) proposed by de Kok (2002). The undershoot is referred to the problem that the inventory position has already dropped below the reorder point before an order is triggered.

$$SS = k * \sqrt{\mu_L * \sigma_D^2 + \mu_D^2 * \sigma_L^2} \tag{3}$$

Ultimately, nine safety stock calculations are denoted in Schmidt et al. (2012), hence we refer the reader to this paper for all mentioned safety stock methods. These safety stock methods are compared in a simulation with fixed values for μ_L and μ_D while assuming normal distributed demand and a fixed target service level of 95%. The results of their study show that the performance of a safety stock calculation varies enormously and, therefore, Schmidt et al. (2012) conclude that not every safety stock is suitable for every situation. They distinguish between three levels of replenishment lead time variation and demand during lead time variation, i.e., low, medium and high. The simplest safety stock method denoted in (1) is only suitable for cases where the replenishment lead time variation is low. Intuitively, this makes sense because replenishment lead time variation is not considered in this calculation and is therefore not suitable when the lead time variation is medium or high.

On the contrary, when calculating the safety stock according to (3), whether or not included with the undershoot, it results in too high inventory on hand and hence higher costs. However, for medium or high variance of replenishment lead time and high variation in demand equation (3) gives the best performance. Also, when undershoot is considered in the equation. For other instances it achieves the target service level of 95%, although the inventory holding costs are higher than the case when the safety stock is calculated by (2) in the case when the forecast error σ_f is used instead of σ_D. However, when σ_f is too large (due to bad forecasting) this also leads to too high safety stock. Hence, in cases when σ_f is too high one might opt for (3) as safety stock calculation. The complicated method of Lutz, Löedding, and Wiendahl (2003) with C-norm parameters and extreme values of demand during lead time performs also well for these cases. However, an explanation of this phenomenon is not given. Schmidt et al. (2012) do not give insights in the variances of results, which makes it harder to provide explanations. Furthermore, this method only holds for normal distributed demand, while the gamma distribution is more suitable in practice. To conclude, Schmidt et al. (2012) show that a segmented approach for safety stocks helps in reducing inventory costs. However, they do not clearly show how the demand distribution affects the safety stock calculations in certain situations. Also, they give not clear bounds for the threshold values for low, medium and high variation for demand during lead time and lead time variation. Hence, in other cases where the variation is by definition “high” this would give other implications (For instance a more unsegmented approach in safety stock methods). Furthermore, they did not vary the service level target, therefore it is unknown if the findings are similar for low service level targets (~80%) and service level targets of 97% or higher.

Besides the use of different safety stock methods, one can also use a different approach when dealing with seasonality. Herrin (2005) proposed a method on how to deal with safety stocks when demand is seasonal. He calculates the safety stock by using equation (2). However, instead of using the σ_D over the past year or even over the whole demand history data, the σ_D is determined over the same months in consecutive years. By using this method, the safety stock follows the seasonal demand more accurately. Furthermore, this approach can easily be extended to different safety stock methods as denoted in (1) or (3). It can also be used when the demand is not normal distributed. Although the seasonal approach is applicable in for other safety stock methods and demand distributions, one need human judgement in order to determine whether the demand follows a seasonal pattern. For instance, the demand might not be clearly seasonal on a monthly level. While looking on a quarterly level the demand is seasonal. In the case the safety stock is determined by using forecasted demand instead of the average demand, the seasonal pattern should be already reflected in the forecast and hence in the safety stock. However, when one is dealing with inaccurate forecasts, the seasonal approach by Herrin (2005) might give better results.

5. Current segmentation concepts

This chapter discusses the current segmentation concepts and methods. By elaborating on the current setup, a new conceptual segmentation framework can be developed based on the gaps between the literature and the current situation. The current segmentation concepts have an operational nature since they are incorporated in the monthly HIP structure. Besides operational segmentation concepts directly involved in the HIP process, the operational segmentation concepts outside the HIP process are discussed. Hence, these segmentation concepts cover decisions in forecasting, lot sizing, MRP-type selection, and safety stock method selection. Furthermore, segmentation concepts on a tactical level are discussed, such as inventory positioning and inventory policy selection. At last, segmentation concepts on a strategical level will be discussed. Besides discussing which kind of segmentation concepts are used, it is also important to address where in the supply chain these segmentation concepts take place. This part is jointly written with Nika Schutten (Schutten & Sonneville, 2018d)

5.1. Segmentation on strategical level

A common technique for segmenting products on a strategical level is the ABC analysis or Pareto analysis (van Kampen et al., 2012). In such analysis, the product's unit price is multiplied with the product's demand volume. In case of the ABC analysis, three segments are generated, whereby, segment A responsible for 80% of the sales revenue by 20% of the SKUs and, consequently, SKUs in segment C generate the least sales turnover. Furthermore, based on the segments decisions are made on what service to deliver to the customer, which inventory policies to use and where to keep stock in the supply chain. For instance, a common strategy is to differentiate in review periods for important SKUs. Whereby, more important SKUs (class A) are reviewed more frequently compared class (C). Similar to the differentiation in service levels to the customer. SKUs from class A have a higher service level compared to SKUs from class C.

Another strategical segmentation method is to decide where in the supply chain the Customer Order Decoupling Point (CODP) should be placed. Basically, the CODP decides whether a MTO, MTS, or Hybrid MTO/MTS strategy is used. Since the placement of the CODP within Hilti is already investigated by another master thesis (van Wanrooij, 2012), this will be out of scope for this master thesis project.

5.1.1. TABCD analysis

Within Hilti a differentiated approach from the ABC analysis is used, though, the principle is the same. Hence, the classes are defined based on the product's unit price times the product's unit volume. Only the classes sizes are different. The traditional class A is now divided in class T and A, and the classical class C is divided in C and D. An overview of the classes combined with the threshold values is given in Table 3. A graphical representation of the TABCD segmentation is given in Figure 11.

Table 3 - Overview classes with thresholds TABCD

Class	Relative number of SKUs	Relative number of sales turnover
T	5%	50%
A	15%	30%
B	30%	15%
C	25%	4%
D	25%	1%

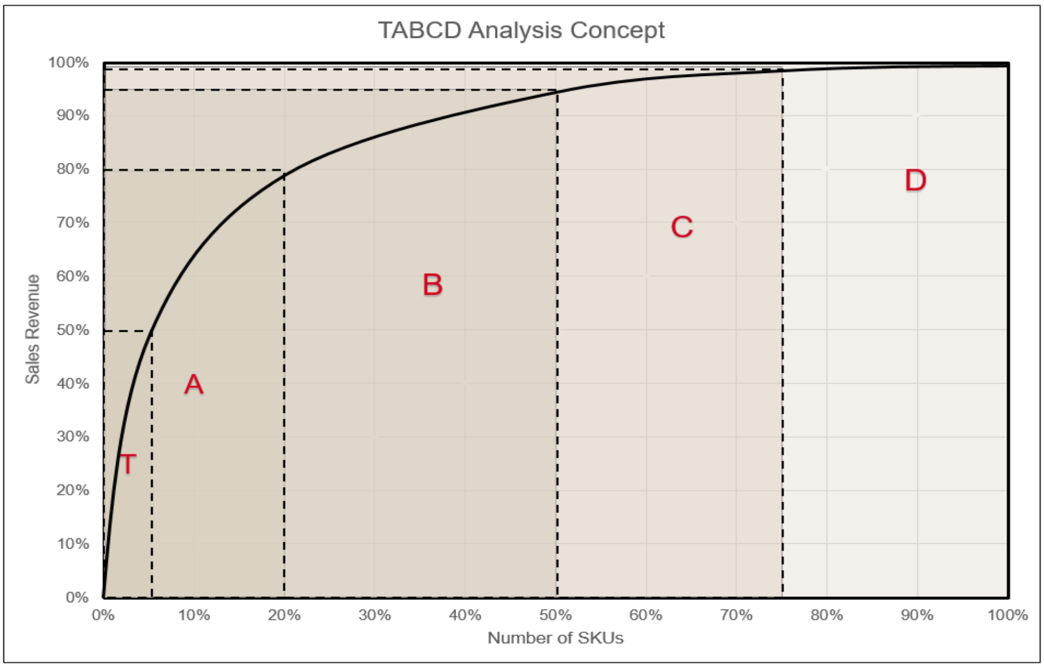

Figure 11 - The concept of TABCD analysis

Furthermore, the TABCD analysis is accompanied by order frequency[1] characteristics, i.e., the XYZ classification. Herewith, the order frequency is classified into three segments based on the order lines in the last 26 weeks. An SKU is high frequent (X) when the order lines are more than 30 in 26 weeks. Whereas a medium frequent SKU (Y) has order lines between 6 and 30. At last, a SKU is infrequent (Z) when the order lines are less than or equal to 6. This results in a three by five matrix, which is given in Table 4. Moreover, this analysis can be conducted in several locations or levels of Hilti's supply chain.

Table 4 - Segmentation matrix based on TABCD-XYZ

Order Frequency	***TABCD-classes***				
	T	**A**	**B**	**C**	**D**
X					
Y					
Z					

Such matrix as given in Table 4, should then be the reference model where for each class the most effective inventory policy and service level target is determined (Errasti, Chackelson, & Poler, 2010; Silver et al., 1998). However, within Hilti there are currently no clear defined inventory policy strategies or service level differentiations based on the TABCD-XYZ analysis. In fact, there are no guidelines at all based on the TABCD analysis. This analysis is also not incorporated in the monthly HIP process. Van Wanrooij (2012) also acknowledge this in her study. Furthermore, in some studies (Errasti et al., 2010; Scholz-Reiter, Heger, Meinecke, & Bergmann, 2012) the classical ABC-XYZ analysis is based on order variability instead of order frequency. Hence, order variability is then distinguished in stable (X), moderately fluctuated (Y), and volatile (Z) demand.

[1] Within Hilti, order frequency is measured on order line level, i.e., how frequent an order line arrives. Whereas one order line can contain more and different products. Hence, further in this document order line frequency is denoted as order frequency.

5.2. Segmentation on tactical level

As mentioned section 5.1.1, based on the TABCD analysis one makes tactical decisions with a segmented approach. Although, currently no guidelines are available within Hilti, there are tactical decisions made with respect to inventory policies and inventory positioning. In the following sections, these subjects are discussed in more detail.

5.2.1. Inventory Policies

In Hilti's supply chain inventory policy decisions depends on the location in the supply chain. The main difference is observed between plants and warehouses. Within plants one uses the EKanBan or normal KanBan system where possible. Hence, in this case inventory is continuously reviewed and an order is placed when the inventory falls below the reorder point. Hence it is similar to a (s, S) inventory control policy. Within the warehouses demand is aggregated daily and it follows the MRP logic available in SAP. In the past, Hilti used a mix between order-up-to levels (S) and fixed order quantities. Due to enough warehouse capacity a multiple of n order quantities are ordered. Which is similar to the (R, s, nQ)-inventory control policy where the replenished quantities are based on the forecasted demand.

Hence, there is not much differentiation between inventory control policies and consequently, there is no link to the TABCD-XYZ classification. While in literature (Bacchetti et al., 2013; Errasti et al., 2010; Papadopoulos, 2017; Persson & Saccani, 2009; Vrat, 2014) the decision of an inventory policy depends also on demand characteristics and the location in the supply chain. For instance, Bacchetti et al. (2013) argue that for the *Introduction Phase* one should use a (s, S) policy such that CSL targets are achieved. While for classes in the *In-use Phase* they suggest a monthly review period. For classes with high number of orders and low demand frequency a reorder level (s) is used additionally. Whereas Errasti et al. (2010) only suggest a variable order quantity for normal and medium volatile demand (X and Y classes in terms of volatility). Vrat (2014) discusses the inventory policy per class of the ABC technique. He suggests a (s, nQ)-policy for high value usage items (i.e., A-items). When one is dealing with very high usage value items (i.e., T-items in Hilti's case), a (s, S)-policy is worth to use, since a (s, S)-policy is difficult to implement due to the complex calculations, although it should result in better inventory control. For B-items a simpler inventory policy is suggested, for instance, a policy with periodic reviewing and an order-up-to level. While for C-items one should strive for rule of thumb models.

Hence, one can observe that Hilti's inventory methods are primarily based on location. There is no further differentiation in selecting inventory policies based on the TABCD-XYZ matrix (Table 4), whereas in literature guidelines are mentioned for selecting an inventory policy per class.

5.2.2. Inventory Positioning

Another part where segmentation has a role, is the inventory positioning strategy. Basically, it defines the stocking location in Hilti's supply chain and whether to use a direct shipment (e.g., downstream or upstream) based on some decision criteria. Furthermore, there is a distinction between BU level and MO/Region level.

- Demand cluster group (see Appendix II)
- Shipment lanes/routes
- Minimal delivery quantity (MDQ) from the supplier
- Country of origin requirements
- Lead time

First, the decision on where to stock items in the supply chain is primarily based on the demand cluster group. CG1 and CG2 items, i.e. normal and variable demand items, are stocked in the CWs or RDCs (hence, more downstream). Whereas, sporadic (CG3) items are stored more upstream in a regional consolidation hub or in a HAG WH. The second decision involves whether to ship directly from the plants to MO CWs/RDCs instead of shipping via the HAG WH or a consolidation hub. This decision is first based on the order quantity. If the EOQ is larger than the MDQ of the supplier, then a direct shipment is considered. Thereafter one analyses if there is a direct shipping route to the MO/Region. Otherwise, the product is stocked in a HAG WH or in a regional consolidation hub and from there on shipped to the MO CW.

Harrison and van Hoek (2008) discuss three strategies for inventory placement in a global supply chain. Product which a high frequent and predictable demand should be placed downstream in supply chain, whereas, medium frequent items which are less predictable are stored more upstream in (global) distribution centres (i.e., HAG WH in Hilti's supply chain). The low frequent and unpredictable demand items should be stored in a global distribution centre or should have a MTO strategy. Hence, one can observe that the inventory positioning strategies of Hilti and Harrison and Van Hoek (2008) are quite similar. Furthermore, Harrison and van Hoek (2008, pp. 114–115) discuss on a case study at Nike Inc. where selected shipments are directly shipped to the customer which occurs within Hilti as well. Although, the criteria for choosing for a direct shipment remains unclear.

5.3. Segmentation on an operational level

As discussed in the company description, Hilti has implemented a S&OP structure called HIP. However, the current HIP has a unmatured S&OP level, since it has been implemented recently. Therefore, it is important to map the current segmentation concepts in the HIP process in order to have segmented and more structured HIP meetings. As elaborated in section 2.4 the HIP consists of two main parts, namely Sales Planning and Operations Planning. In the Sales Planning segmentation is used in the Statistical Forecasting, during the Demand Review, and during the BU SFI meeting. Where the latter two can be referred to as judgemental forecasting. In the following sections, these segmentation concepts are explained in more detail.

5.3.1. Statistical forecasting

In the HIP structure, the first part where segmentation is used, is during the statistical forecasting. It is important to note that the statistical forecasting is done on Demand Forecasting Unit (DFU) level. That is, downstream in the supply chain and it involves sales data from every MO (Hence, a lower level of SKU). Furthermore, 36 months of history sales data is needed to perform a statistical forecast.

First, a DFU is segmented based on four attributes, that is, *Order Frequency*, *Volatility*, *Seasonality*, and *Trend* (Figure 12). The order frequency is divided in four categories, i.e., *High (H), Medium (M), Low*

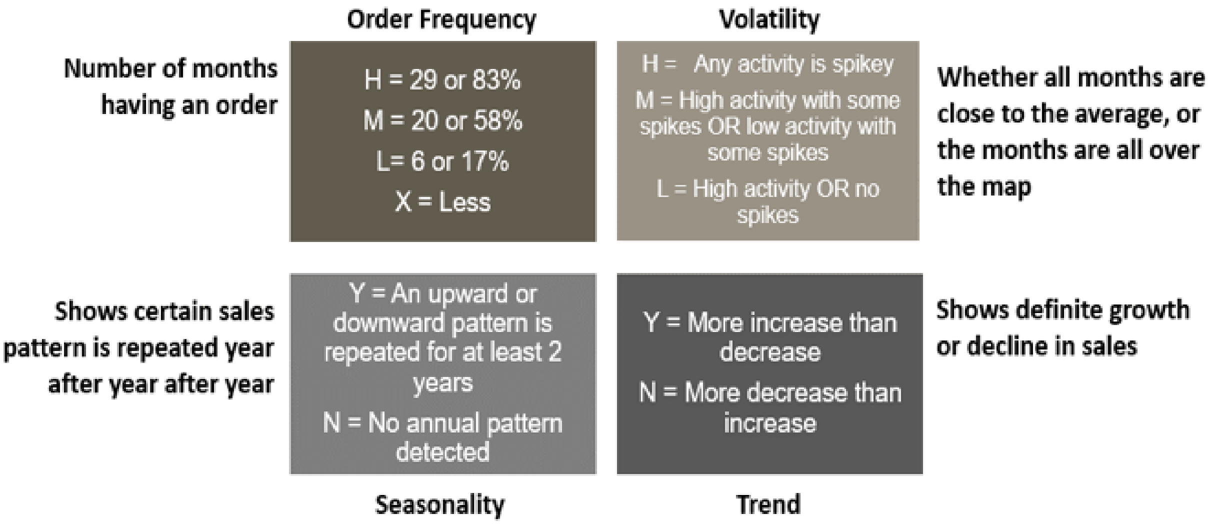

Figure 12 - Forecasting segmentation attributes

(L), and Rare (X). For instance, a DFU is classified as high if in at least the last 29 months there was an order in every month (or at least 83% of the past 36 months). The second attribute, volatility, is divided in three levels, that is, *High (H), Medium (M), and Low (L).* In this case the coefficient of variation (CV) determines the thresholds. When the CV is less or equal than 0.5, the DFU has a low volatility. A DFU had medium volatility when the CV is between 0.5 and 1.0. If the CV is higher than 1.0, the volatility is high. For the attributes seasonality and trend, the APO software from SAP decides by autocorrelation whether a DFU is seasonal or has a trend. Hence, it can only be "yes" or "no". Based on this segmentation method a forecast profile is made and one decides on the forecasting method to be used (e.g., exponential smoothing or linear regression). Basically, there are five forecasting profiles. First a DFU can have a constant profile where exponential smoothing is used to forecast. The second profile is seasonal. In this case a DFU has a more volatile demand combined with a medium or high order frequency. In this case, one uses linear regression combined with exponential smoothing or Holt-Winters. Third, a DFU can be classified as a trend profile. As mentioned before, this is done automatically by APO. The fourth profile is intermittent, which implies that the demand has high volatility and a low or rare order frequency. For such DFUs Croston's forecasting method (Croston, 1972) is used. At last, a new product is considered separately since the low sales history. For such DFUs one uses exponential smoothing with a pre-defined alpha of 0.3.

Also, in literature a segmented approach for demand forecasting is used. For instance, Bacchetti et al. (2013) proposes causal forecasting for products that substitute other products in the *Phase In* period from the product life cycle. Whereas in Hilti one uses market intelligence only for forecasting new product. When enough historical data is available time series forecasting methods are used (e.g., moving average or simple exponential smoothing) for normal or variable demand items with medium or high order frequency (Bacchetti et al., 2013; Boylan, Syntetos, & Karakostas, 2008; Ghiani, Laporte, & Musmanno, 2013). These forecasting methods are extended (e.g., Double exponential smoothing) when a trend or seasonal pattern is observed (Ghiani et al., 2013) which is observed within Hilti as well. For intermittent or sporadic demand patterns, often Croston's method or Syntetos-Boylan Approximation (SBA) are used (Bacchetti et al., 2013; Boylan et al., 2008). Hence, it is reasonable to argue that Hilti has already an extensive segmented approach with respect to statistical forecasting. Therefore, it is unnecessary to redesign the segmentation concept within the statistical forecasting process.

5.3.2. Judgemental forecasting

Since the statistical forecast does not incorporate market intelligence, the forecast needs to be updated by managerial insights. Hence, a demand review and Sales Forecast Integration (SFI) meetings are needed to adjust the statistical forecast. During these meetings marketing experts and managers, for instance, include information of a new product launch and therefore reduce the forecasted demand from predecessor of the new product. Furthermore, when a new project is initiated, this needs to be incorporated in the forecast as well. Therefore, the forecasted demand is increased for products which are involved in a project. Moreover, the forecasts for new products can be adjusted by market intelligence obtained by customer questionnaires.

However, during these meetings (i.e., demand review meetings and SFI meetings) there are no clear guidelines which products needs to be discussed and which not. More specifically, guidelines based on the strategic importance or on the volatility of a product are not available. For instance, one can argue that a product with a stable demand which is of low strategic importance can be ignored in such meetings. Whereas, strategic products (products which generate higher sales turnover) with a variable or volatile demand needs to be discussed in more detail. A similar approach is found in the McKinsey Supply Chain Segmentation Framework (Alicke & Forsting, 2017). According to their framework, stable demand items, regardless of their volume, should be driven by the statistical forecast, except when promotional campaigns are upcoming. While for volatile demand items with high volume, one should actively forecast (i.e., using managerial insights). On the contrary, volatile demand items with low volume are not forecasted. Hence, this concept could be translated to the TABCD-XYZ segmentation framework within Hilti. Since a certain guideline for judgemental forecasting is lacking.

5.3.3. MRP type selection

Outside of the schematic representation of the HIP process presented in section 2.4, there is HIP schedule. Part of this schedule involves the decision of the MRP type which is based on certain characteristics. The characteristics are follows:

- Material status in the Product's life cycle
- Location in the supply chain
- MTS/MTO
- Order Frequency
- Lead time

First, a MRP-type selection is based on the location in the supply chain. More specifically, there is a differentiation between MO's and Plants/HAG WH's. An overview of the MRP-types is given in Table 5. An extensive description can be found in Appendix I.

Table 5 - Possible MRP types per location

MRP types in MO's	MRP types in plants/HAG WH's
X0	X0
X1, X3	X1, X3
X5, X6	X9
X7	Z0, Z1
Y0, Y5	Z2
X9	Z3, Z4, Z8
	Z5

Second, the MRP type decision depends on the position in Hilti's product life cycle (Figure 13). For a new developed product, known as 'Introduction New Product' (INP) it has by definition a different MRP type compared to the 'Free' or more mature products in the product life cycle. The Phase-In phase is by definition six months. The Free phase has an undefined duration. This can vary from a couple years to 20 years. Hence, material status plays a role across the entire supply chain, since sales of phase-in products is uncertain and phase-out items is low. When a product has the status Phase-in, the MRP-type is either X0 or Z0 for the MO's and HAG WH's/Plants respectively.

If the product is in the Free stage of the product life cycle any MRP type according to Table 5 is possible and the decision depends on a demand cluster group, which is explained in Appendix II. Basically, there are three cluster groups (CG) based on *Order Quantity Variability* and *Order Frequency*. When a SKU is considered as sporadic (CG3) then a further distinction is made in the strategic importance of the SKU.

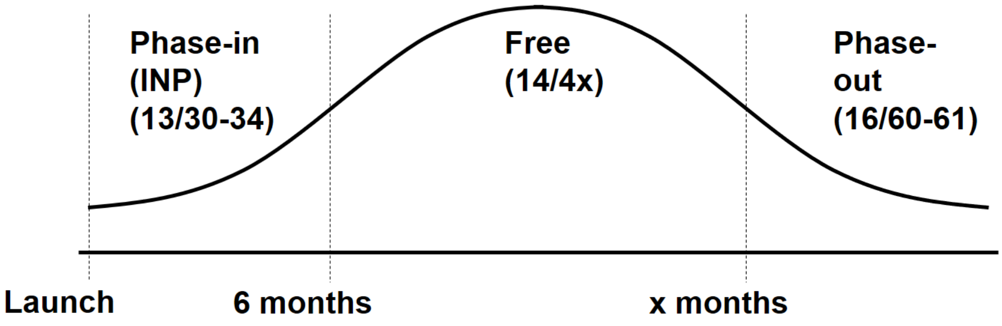

Figure 13 - Product life cycle with in Hilti

If the SKU is considered as strategic then MRP type X5 is used and safety stock (SS) is necessary. Otherwise, MRP type X6 is used with no safety stock.

If the SKU belongs to CG1 or CG2 a distinction is made in lead time. When it shorter than 14 days, MRP type Y5 or Y0 is selected in combination with safety stock and a reorder point. Of the lead time is longer, then MRP type X0 or Y0 is selected in combination with safety stock. This option is primarily applicable for MO's outside of Europe (e.g., HNA or META). MRP type X0 is also selected if the demand characteristic is seasonal. An overview of these decisions is depicted in Figure 14.

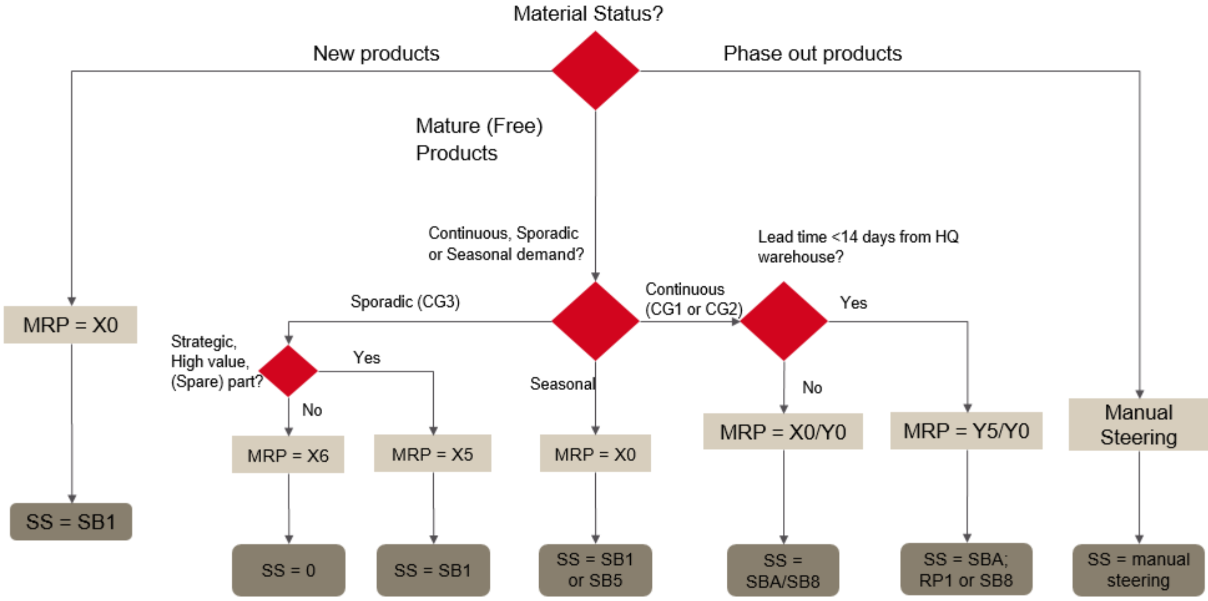

Figure 14 - Decision tree MRP type and safety stock for MOs

For the plants and HAG WHs an overview as presented in Figure 14 is not available. However, there are some clear distinctions between the MRP decision on Plant/HAG WH level and MO level. The demand cluster groups as presented in Appendix II are not used as a guideline for selecting the MRP type, due to the aggregation on Plant/HAG WH level. The material status is not leading in the MRP type decision as well. When selecting the MRP type on Plant/HAG WH level, lead time is the most important factor. When lead time is short (≤ 6 days) then either MRP type Z3, Z4, Z5, or Z8 is selected, whereby Z5 is only used in plant 4 and Z8 is only used on plant level in combination with assemblies. The difference between Z3 and Z4 is the maximum inventory level in Z3 if a plant or HAG WH is dealing with capacity constraints. Otherwise MRP-types Z0, Z1, or Z2 are used, whereby Z2 is only used for PTO items. There is no strict guideline for using either Z0 or Z1.

5.3.4. Safety stock methods

After the MRP type is defined, the safety stock method is selected as depicted in Figure 14. An overview of the safety stock methods with the calculation method and the corresponding MRP type is given in Table 6. According to Table 6, one can observe that again the safety stock method can be different for the location in the supply chain. For instance, the safety stock method SB1 corresponds to the same MRP-type in the plant and the HAG WH (Z0). However, the corresponding MRP type (X0, Y0) in the MO Warehouse is different. Moreover, for the HAG Warehouses a certain MRP-type (Z0) has three different safety stock methods (i.e., SB1, SB9, and SBA).

Table 6 - Safety stock methods with corresponding MRP type

Safety stock method/ROP method	Corresponding MRP type		
	Plant	HAG WH	MO WH
RP1	Z3, Z4	Z3, Z4	Y5
RP2	-	-	Y5
RP3	-	-	Y5
SB1	Z0	Z0	X0, Y0
SB5	-	-	X0, Y0
SB8	Z2	-	X0, Y0
SB9	Z0, Z8	Z0	X0, Y0
SBA	Z0	Z0	X0, Y0
SBB	-	-	X0, Y0, X5
SRS			

As denoted in Figure 14, the decision of which safety stock method to use depends, besides the product's life cycle, also on the lead time and the demand cluster group. By definition, the safety stock SB1 is used for new product such that one can use manual steering for the safety days and be more flexible in the safety stock settings. For the sporadic (CG3) SKUs a differentiation is made between strategic or non-strategic SKUs. When the SKU has strategic importance, a MTS strategy is used with the SB1 method. Otherwise, one uses a MTO strategy without safety stock.

If the SKU has a seasonal demand characteristic either the SB1 or SB5 method is used. In this case there are no guidelines or standards for choosing one these methods. This holds also for the products which are classified as continuous (CG1 and CG2). In both cases safety stock method SBA or SB8 should be used, however, it is not clear which one to select based on certain criteria. This also holds for whether to use a ROP method (i.e., RP1 or RP2). According to Figure 14 when the SKU has MRP type Y0/Y5 (when lead time to the markets is short) a material manager is advised to use a ROP.

For phase-out products manual steering is advised with respect to the safety stock method decision. This implies, that material managers should aim for using the SB1 method. Moreover, manual steering is also proposed for spare parts in the phase out status in literature (Bacchetti et al., 2013). However, Bacchetti *et al.* (2013) make a distinction for phase out items with respect to the response lead time to the customers. Only when the replenishment lead time is shorter than the response lead time to the customer an order-up-to level is used based on the average (Poisson distributed) demand. Furthermore, Papadopoulos (2017) investigated in his study that the inventory level of phase out spare parts within Hilti declines exponentially. For this situation, he proposes a (s, S)-policy with a reorder point (s) that is based on the lead time multiplied by the annual demand.

Furthermore, one can observe that there is no connection between the safety stock method selection and the TABCD-XYZ matrix (as discussed in section 5.1.1). Although, differentiation is based on demand cluster groups and strategic/high-value parts. Whereas, the term 'strategic/high-value parts' remains fuzzy in the classification scheme depicted in Figure 14. Compared to literature a similar approach with respect to the decision-making process for safety stock methods is observed. For instance, in the segmentation framework developed by Bacchetti et al. (2013) safety stock methods are used only for classes with high number of orders and for both low and high demand frequency. Although, for classes in the *Introduction Phase* and for classes with a low number of orders, no safety stock is used. For the introduction phase, they argue that due to the lack of demand history a safety stock calculation is not applicable. Consequently, a high order-up-to level (based on 6 months average demand) combined with a two weeks review period is used to assure the 95% CSL.

Gelders and van Looy (1978) proposed that for all normal-moving and fast-moving items safety stock needs to be used. In both studies, the safety stock includes demand variability and CSL. However, both studies do not consider lead time variability, whereas every safety stock method, proposed for CG1 and CG2 in Figure 14, consider lead time variability.

In addition, for seasonal products two safety stock methods are suggested according to Figure 14. Whereas, method SB1 does not consider variability, forecast error, and CSL compared to method SB5. The decision between these two methods remains unclear. Furthermore, when it is known one is dealing with seasonal products (based on history sales data), one needs to consider adjusting the safety stock according to the seasonal period as suggested by Herrin (2005).

To conclude, the decision of which safety stock method to use is not related to the strategic segmentation method TABCD, although strategic importance plays a role in the decision. In addition, the decision tree is a guideline, however, this guideline is not always followed by the end-users. Furthermore, in literature (Bacchetti et al., 2013; Papadopoulos, 2017) more sophisticated approaches with respect to the *Phase-In* and *Phase-out* phase are used. Also in literature (Herrin, 2005) one finds a method for calculating safety stock when dealing with seasonal products. This kind of method does not exist within Hilti. Hence, a more segmented approach is necessary.

5.3.5. Lot sizing and ROP

Lot size decisions occur in every location in Hilti's supply chain, hence, at the plants, the HAG WH's, and CWs. These decisions are made twice a year. First data is extracted, secondly this data is converted into demand and material cluster parameters and thirdly the Lot-size is determined.

For determining the order quantity, the demand cluster groups (Appendix II) are used. In principle, one uses the Economic Order Quantity (EOQ) when dealing with CG1 and CG2. Consequently, the order quantity is limited to nine times the average weekly demand. The minimum coverage is expressed in days while considering the lead time. When dealing with sporadic demand items, the aim is to order one product when needed. In Figure 15 a decision tree is given for determining the EOQ.

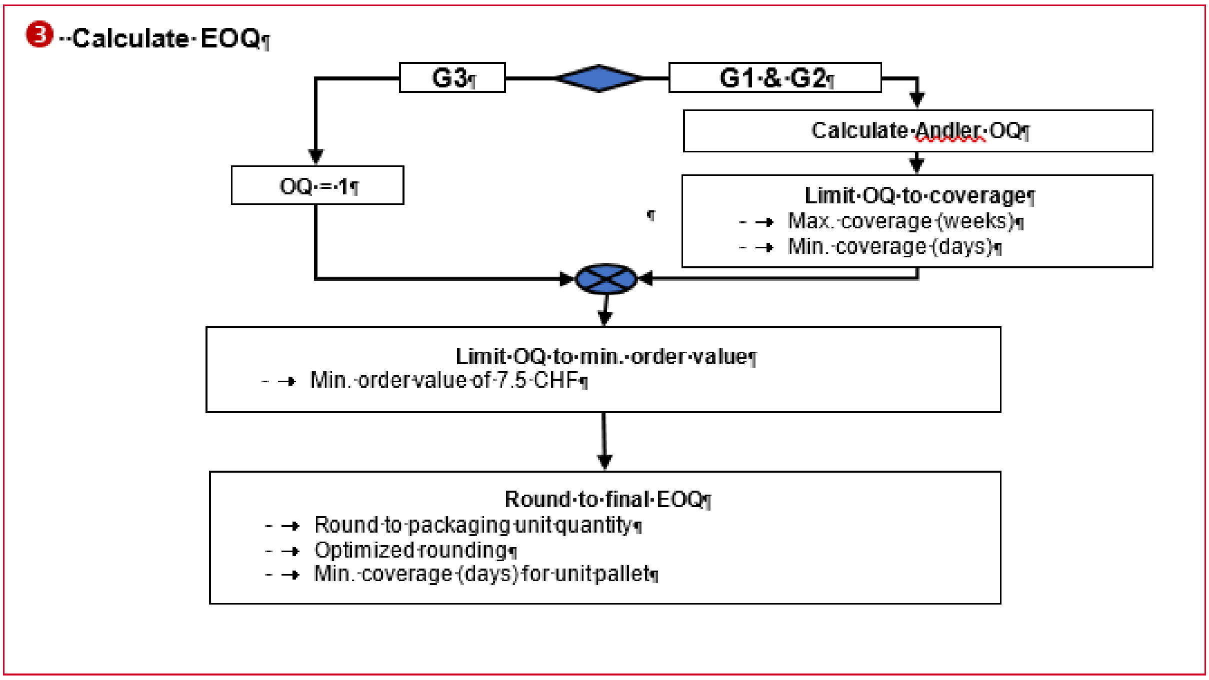

Figure 15 - Decision tree EOQ

Subsequently, the order quantity is limited to the minimum order value. Hence, when the order quantity has a value below 7.50 CHF the order quantity is rounded up according to a price range where it is in (which for segmentation purposes is not considered as important). This is also called the Minimum Order Quantity (MOQ).

As mentioned in section 5.2.1 inventory policies with an order quantity and with an order-up-to-level are used. The operational decision on how the order quantity should be, is clear defined, that is apply EOQ when possible otherwise MOQ.

Comparing the lot size decisions with the segmentation framework from Bacchetti *et al.* (2013), and the suggestions proposed by Vrat (2014) and Gelders and Van Looy (1978), one can observe a similar decision. Both studies argue that for items with a high demand frequency one should the EOQ as order quantity. The main driver for using this method, is that it is easy to implement in practice. However, dynamic lot sizes model or heuristics, such as the Wagner-Within algorithm or Silver-Meal heuristic, are not considered.

Furthermore, there are currently no guidelines within Hilti for calculating the order-up-to level when a fixed order quantity is not applied. In addition, there are no rules for determining the order-up-to level according to a product segment. Bacchetti et al. (2013) apply a segmented approach for determining the order-up-to level for some segments. The order-up-to level is then determined either by the average demand over previous periods or by a forecasted demand. A similar approach is also observed in Axsäter (2015). Axsäter (2015, pp. 116–118) uses as a practical example a monthly updated forecast in order to determine the new order quantity Q based on EOQ and normally distributed demand. The ROP (R) is determined by using the service level and assuming normal distributed demand. Additionally, the (s, S)-policy is approximated as a (R, Q) policy with $s = R$ and $S = s + Q$. This approach is a reasonable approximation according to Axsäter.

6. Conceptual design of segmentation concept

In the previous chapters it was shown that clear segmentation guidelines are missing within Hilti while a segmented approach can reduce inventory costs and optimize service levels. In this chapter a conceptual segmentation framework is designed for Hilti. This chapter discusses first the variables and parameters on which the segmentation concept is based on. Subsequently, these variables and parameters are used by a classification technique, as discussed in van Kampen et al. (2012), such that the segments and their boundaries are defined, and SKUs are allocated to these boundaries. Thereafter, for each segment guidelines are presented with regards to tactical decisions (e.g., inventory control policies and service level definition) and operational decisions (e.g., SFI meetings and forecasting). This chapter gives also the answer on sub research question 3 and on main research question 1. This part is jointly written with Nika Schutten (Schutten & Sonneville, 2018c)

6.1. Conceptual Design

The conceptual design is the main pillar for constructing the scientific design in 6.2. It includes the input parameters, decision variables and the output for designing the segmentation concept. First the main assumptions are mentioned for designing the segmentation concept.

- The inventory is controlled by a (R, s, nQ)-policy with a review period of $R = 1$.
- Demand cannot be partially fulfilled, and unsatisfied demand is backordered.

The (R, s, nQ)-policy with a daily review period is a valid assumption since the orders in the SAP system are aggregated on a daily level. The demand and order line data are available on a daily level as well. Furthermore, the (R, s, nQ)-policy can easily be converted to a base stock policy by changing the order quantity Q to 1 for PTO items (i.e., MRP-types X5 and X6). Further assumptions are:

- There is ample capacity in the warehouse
- The safety factor for the safety stock calculation is based on normal distributed demand since the aim of the segmentation concept is to provide guidance on a high level.
- When lead time variation is known, it is assumed to be normally distributed.
- Demand and order lines are known from the system

These assumptions are the fundamentals for designing the segmentation concept. From this point segmentation criteria can be transformed into different quantitative segmentation techniques (van Kampen et al., 2012) whereas each segmentation technique is evaluated by inventory costs and the aggregated service to the customer. At last, a sensitivity analysis is performed on the class sizes on the best performing segmentation concept, since Van Wingerden et al. (2018) shows that the class size has an impact on the inventory costs at different service level targets.

6.2. Scientific design

The conceptual design as discussed in the previous section forms the basis of the scientific design. In the first section, the different segmentation techniques (based on the criteria presented in section 4.1) are briefly discussed which are compared to each other in the model. The corresponding class sizes used in the model are presented as well. Secondly, the way on how to measure the performance to the customer is discussed. At last, the data selection and scope of the analysis is discussed.

6.2.1. Segmentation techniques

According to section (4.1.2) there are many segmentation techniques varying from simple (i.e., one or two segmentation criteria) to complex (multi-criteria) models. Since, practical use and implantability is important for Hilti, we focus on the following segmentation techniques.

- TABCD analysis
- TABCD analysis in combination with Order Frequency
- Teunter’s cost criterion
- Order frequency in combination with order variability
- Order Frequency and Order Variability separately

6.2.1.1. TABCD-analysis

The TABCD analysis (Demand * Unit Price) is considered since this segmentation technique is used in the TABCD-XYZ analysis within Hilti. This technique is selected in order to determine if the current segmentation TABCD-XYZ analysis can be simplified to just the TABCD analysis. The threshold values for the classes are defined as described in section 5.1.1.

6.2.1.2. TABCD-analysis with order frequency

For this segmentation technique, the same class sizes are used for the TABCD classification as described in section 5.1.1. The classes for the order frequency are denoted as XYZ (similar to the current situation within Hilti). However, during a workshop within Hilti it turns out that the current fixed class sizes are not feasible for every region. The current absolute threshold values are not suitable for some markets due to a lower order frequency in general. Therefore, a relative approach is used to classify the order frequency. The threshold values are determined based on the gradient of the line depicted in Appendix IV and summarized in Table 7.

Table 7 - Threshold values for Order Frequency

Classes Order Frequency	**Threshold values**
X	80% of total orders
Y	19% of total orders
Z	1% of total orders

Furthermore, Vrat (2014) argues that the ABC or Pareto analysis is less suitable for inventory decisions, whereas the order frequency (in Vrat (2014) denoted as Fast-, Slow-, and non-moving) is more suitable for making inventory decisions per segment. Also, Gelders and van Looy (1978) shows a segmented approach for inventory management for Fast- and Slow-movers. Based on the number of classes from TABCD and XYZ there are 15 classes in total. Since 15 classes are too difficult to manage by setting service level targets for each class (van Wingerden et al., 2018, p. 4), we decided to cluster some segments to five cluster groups. By clustering the segments, it makes the segmentation less complex and more manageable. Simultaneously, some authors (Graham, 1987; Silver et al., 1998) mentioned that using more than six classes the complexity increases.

Part of defining classes is setting target service levels per class. Within literature there are two views on this topic. For instance, Armstrong (1985) and Stock and Lambert (2001) argue that SKUs in class A should have the highest target service level, whereas Knod and Schonberger (2001) suggests the opposite and argues that it is not worth to have stock outs for SKUs in class C. Moreover, Sherbrooke (1986) showed that high valued items should have a low service level target in order to reduce inventory holding costs. The opposite is suggested for low valued SKUs. This idea is confirmed by Teunter et al. (2010) and Van Wingerden et al. (2018) by using the cost criterion for ABC segmentation developed by Teunter et al. which implicitly has the same idea as suggested by Sherbrooke and Knod and Schonberger. Hence, we used the approach with high service levels for low

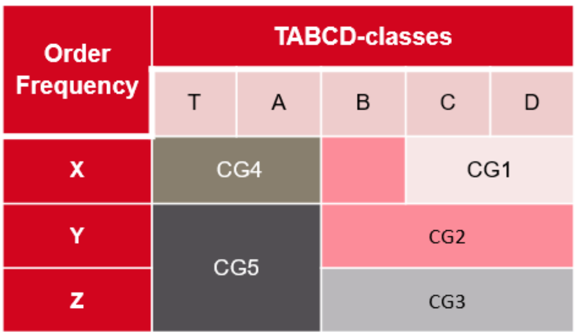

Figure 16 - TABCD-XYZ higher target service level for CG1 and lower target service level for CG5

valued items with high order frequency and vice versa for high valued items with low order frequency. Figure 16 summarizes the segmentation design for the TABCD-XYZ approach that is used in the case study.

6.2.1.3. Teunter's criterion

Teunter's criterion is considered since Teunter et al. (2010) showed that inventory costs can be reduced significantly. Although, in Hilti's situation the Teunter's criterion needs to be adjusted.

Table 8 - Threshold values for Teunter's criterion

Classes Teunter's criterion	Threshold values
A	20% of SKUs
B	30% of SKUs
C	50% of SKUs

Teunter's cost criterion is based on the criterion $\frac{b_i D_i}{h_i Q_i}$. Since Hilti has not defined a backorder cost and no different criticality measures are known for the products we assume that backorder costs are linear to price, $b_i = b * price_i$, due to the lost revenue when a backorder results in lost sales. Holding cost per product are also linear to the price, $h_i = h * price_i$. Hence, Teunter's criterion can be rewritten for Hilti as $\frac{D_i}{Q_i}$. According to Teunter et al. (2010) applying six classes leads to better results compared to three classes. However, three classes are used in order to see first how beneficial the simplified version of Teunter's cost criterion is. The classes and corresponding threshold values are given in Table 8.

6.2.1.4. Order Frequency in combination with Order Variability

As mentioned before, segmenting on order frequency has the advantage that one can use specific inventory policies for slow- or fast-moving items (Gelders & van Looy, 1978; Vrat, 2014). Secondly, in Hilti's case segmenting on order frequency corresponds with Hilti's performance measures which are based on order line level.

Subsequently, Van Wanrooij (2012) suggests segmenting on order variability since Hilti is dealing with high variable demand. For instance, she showed that at least 30% of the T are classified as highly variable according to the variability thresholds from the cluster groups in Appendix IV. For C and D items even at least 90% of the SKUs are classified as highly variable. Furthermore, order variability is also used for determining replenishment strategies and or forecasting techniques (Errasti et al., 2010; Reiner & Trcka, 2004), however, a segmented approach for setting target service levels per class is not discussed in both papers. We expect that segmenting on variability is useful, because products that have a higher variability need to be stocked more to reach the same fill rate. Hence, the expectation is that segmenting on order variability will reduce the total inventory cost. This can be explained by the cost structure (4) and the volume fill rate (5).

$$C(Q,R) = h\left(\frac{Q}{2} + R - \lambda\tau\right) \tag{4}$$

Where:

- h = the holding cost per period
- Q = the order quantity
- R = the reorder point
- λ = Demand rate in the period
- τ = lead time

The inventory costs increase by $h * p_i$ for every increase of R. The volume fill rate, when assuming customer order per one piece is given by:

$$\beta = 1 - \frac{\sigma L(\frac{R-\mu}{\sigma})}{Q} \quad (5)$$

Where in addition to Equation (5):

- σ = standard deviation in demand
- μ = average demand
- L = lead time

From this formula, the volume fill rate is lower for products with higher variability. Increasing stock levels of products with less variability increases the volume fill rate more than increasing stock levels for products with more variability. Therefore, the order variability is combined with the order frequency. The threshold values for order frequency are similar to the threshold values in the TABCD-XYZ analysis. Whereas the threshold values for order variability (divided in three classes as well) are determined based on the gradient of the order variability in the sample data Appendix IV. The threshold values are summarized in Table 9.

Table 9 - Threshold values for Order Frequency and Variability

Classes Order Frequency	Threshold values	Order variability	Threshold values
Q	80% of total orders	U	CoV<1
R	19% of total orders	V	1≤CoV<2
S	1% of total orders	W	CoV≥2

Hence, this results into a 3 by 3 matrix with nine classes. However, nine classes are difficult to manage since it is more complicated to set target service levels per class (van Wingerden et al., 2018, p. 4). Therefore, similar to the TABCD-XYZ segmentation we clustered some classes into five cluster groups (CG) as depicted in Figure 17. The principle with regards to setting service level targets for each class for this segmentation technique is that fast-moving SKUs with a low order variability (e.g., CG1) have a higher target service level than slow-moving SKUs with a high order variability (e.g., CG5).

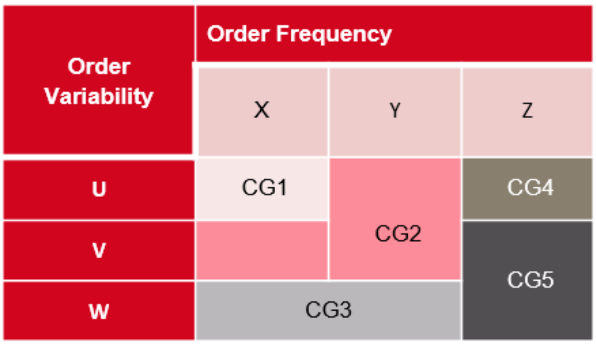

Figure 17 - Graphical representation of order frequency and order variability

6.2.1.5. Order Frequency and Order Variability

Since the order frequency and the order variability are combined in one segmentation technique, it is also interesting to see how these techniques perform independently from each other. Segmenting SKUs based on order frequency is already a well-known segmentation technique on itself. In contrast to order frequency, segmenting solely on order variability is by the author's knowledge not investigated so far. Hence, as an exploratory analysis order frequency and order variability are separately investigated in the case study as well. The threshold values are similar as summarized in Table 9 presented in section 6.2.1.4.

6.2.2. Performance Evaluation

The performance of this model will be evaluated by the inventory costs while achieving an aggregated service level. In studies from section 4.1.2 the segmentation concepts are evaluated by the fill rate (i.e., the fraction of demand that can be satisfied from stock). However, in practice companies strive to satisfy a customer by fulfilling the complete customer order. This holds for Hilti as well. One of the performance measures looks to the fraction of the numbers of replenishment order lines that can be delivered from stock. However, this performance is measured based on the confirmed order date and not on the actual incoming order date. Hence, the well-known fill rate approach would not reflect the real performance. Moreover, in the current situation all products are equally contributing to the performance measure. There is no difference in fulfilling an order that contains more order lines or an order that only contains of one order line.

Therefore, the service level is measured by using the order fill rate adopted from Larsen and Thorstenston (2014). The aggregate order fill rate (OFR) is given in Equation (6) and a small and simple example and comparison between the CSL and the fill rate is given in Appendix V.

$$OFR = \sum_{i=1}^{I} \frac{OF_i}{\sum_{i=1}^{I} OF_i} OFR_i \tag{6}$$

Where:

- OF_i = the order frequency of product i
- OFR = the order fill rate for product i

Hence, products with a higher order frequency contribute more to the OFR and should therefore be prioritized. Larsen and Thorstenston (2014) also showed that the order fill rate is always less or equal to the volume fill rate.

6.2.3. Objective function

The scientific model can be mathematically formulated where the goal is to minimize the total inventory costs $C(\alpha)$ by selecting a service level α for each class $k \in K = \{1, \dots, |K|\}$. In which K is the set of classes and class $k = 1$ is the class with the highest priority regarding the service level setting. Each SKU i is allocated to one of the segments, where k_i denotes the segment in which SKU $i \in I = \{1, \dots, |I|\}$ belongs. The objective function is constrained to an aggregate target OFR^0. Hence,

$$minimize\ C(\alpha) \tag{7}$$

s.t.

$$OFR(\alpha) \geq OFR^0 \tag{8}$$

Where $\alpha_i = \alpha_k \forall\ i,\ k_i \in k$ and $\alpha_k = [0,1)\ \forall\ k \in K$

The total cost $C(\alpha)$ can be denoted as the sum of all inventory cost for each SKU i based on the service level for SKU i.

$$C(\alpha) = \sum_{i \in I} C_i(\alpha_i) \tag{9}$$

The inventory cost per item is denoted as the on-hand inventory for each SKU i in time period $T = \{0, \dots, |T|\}$ and is dependent on the price of the SKU i times the interest rate of the holding cost h.

$$C_i(\alpha_i) = p_i * h * \sum_{t=0}^{T} IOH_i^t \;\; \forall\, i \in I \tag{10}$$

For calculating the $OFR(\alpha)$ we denote N as the total number of order lines during the period under consideration and $n = \{1, \ldots, N\}$ where order line $n = 1$ is the first order line and $n + 1$ is the next order line that arrives. Furthermore, let N_i^t be the set of incoming order lines in period t for SKU i. Then the aggregate order line fill rate of all items can be calculated by aggregating the order line fill rate per item over the frequency (where satisfied orders of SKU i at time t are denoted as: $s_i^t \subseteq N_i^t$).

$$OFR(\alpha) = \sum_{i \in I} \sum_{t=1}^{T} \left(\frac{|s_i^t|}{|N_i^t|} \right) \tag{11}$$

In order to solve the model, a recursive formula is applied in which the inventory on hand for each SKU in the initialization period 0 IOH_i^0 is equal to the inventory on hand according to the system for each item i. The Inventory Position (IP_i^0) at the initialization period for SKU i is equal to IOH_t^0.

$$IOH_i^0 = startIOH_i \;\; \forall\, i \in I \tag{12}$$

$$IP_i^0 = IOH_i^0 \;\forall\, i \in I \tag{13}$$

Before satisfying order on the next day, the backorders from the previous day are satisfied first when possible. Let $IOH_i^{t-\Delta}$ defines as the starting inventory of the day when supply has arrived, and backorders are satisfied.

$$IOH_i^{t-\Delta} = IOH_i^{t-1} + SR_i^t - \min(IOH_i^{t-1} + SR_i^t - BO_i^{t-1}) \;\forall\, i \in I, \forall\, t \in T \tag{14}$$

Every period, orders come in one by one according to a *First Come, First Served* principle, in the order of N. Orders that can be satisfied from stock belong to the subset $s_i^t \subseteq N_i^t$, no partial fulfillment is allowed, and therefore the set of order lines which are directly satisfied from stock are:

$$s_i^t = \left\{ x_i^t : \left\{ \max\left|x_i^t\right| : \left[\sum\nolimits_{s \in x_i^t} OL_s \right] \leq IOH_i^{t-\Delta}, x_i^t \subseteq N_i^t \right\} \right\} \;\; \forall\, i \in I, \quad \forall\, t \in T \tag{15}$$

Then the unsatisfied order lines for time t, u_i^t are:

$$u_i^t = N_i^t \setminus s_i^t \;\; \forall\, i \in I \,\forall\, t \in T \tag{16}$$

BO_i^t, denotes the total open ordered quantities that still should be satisfied from stock at t.

$$BO_i^t = BO_i^{t-1} + \sum_{n \in u_i^t} OL_n \quad \forall\, i \in I, \forall\, t \in T \tag{17}$$

At the end of the day the satisfied order lines are no longer on inventory and the IOH and IP on day t for SKU i is:

$$IOH_i^t = IOH_i^{t-\Delta} - \sum\nolimits_{s \in S_i^t} OL_s \quad \forall\, i \in I, \forall\, t \in T \tag{18}$$

$$IP_i^t = IP_i^{t-1} - \sum_{n \in N_i^t} OL_n + SR_i^{t-1} \quad \forall i \in I, \forall t \in T, and\ t > 0 \tag{19}$$

Furthermore, the scheduled receipts at time t for SKU i (SR_i^t) are zero when the inventory position at time t for SKU i is greater or equal than the reorder point of SKU i, ROP_i.

$$SR_i^t = \begin{cases} 0 & if\ IP_i^t \geq ROP_i \\ \left\lceil \frac{ROP_i - IP_i^t}{OQ_i} \right\rceil OQ_i & else \end{cases} \qquad \forall\, i \in I, \forall\, t \in T \tag{20}$$

The ROP_i is based on the safety stock and the mean demand during lead time. The safety stock for SKU i is only calculated when class k has a service level α_k greater than 50%. Hence the ROP_i is:

$$ROP_i = z_{\alpha_i} \sqrt{\sigma_{L_i}^2 \mu_{D_i}^2 + \sigma_{D_i}^2 \mu_{L_i}} + \mu_{D_i} L_i \qquad with\ \ \alpha_i = \alpha_k, k_i \in k \quad \forall\, i \in I \tag{21}$$

6.2.4. Data selection & scope

For the case study one year of demand history data (i.e., year 2017) is used from a CW in Germany, since this warehouse covers the most important regions for Hilti (Observe that the sales in Europe are the highest within Hilti according to Figure 4). The analysis is conducted for 500 randomly picked SKUs from the CW Germany. From this sample size five SKUs were omitted, because of no demand information during this year. Hence, 495 items SKUs remain. The selection was made from SKUs that are in the life cycle free and since another approach is recommended for spare parts these were also excluded from the selection. In reality, the segments based on historical data can differ from the actual segment, since the purpose of the case study is to demonstrate the impact on service levels and costs. An overview of the selected SKUs can be found in Appendix III.

The data is retrieved from the ERP system SAP. No information was found that represented the real customer sales orders, hence instead the delivery lines, the orders that where actually shipped out to the customer, where used. Customer sales orders and delivery orders can differ when there was not enough stock on hand, but since Hilti has a high customer performance target we expect this difference to be minimal.

6.3. Case study results

This section discusses the results obtained from the scientific design. First the results from the case study based on the 495 items are presented. Secondly, we validate the results by using another randomly selected data set of 100 items. Ultimately, the results of the sensitivity analysis are discussed from the best performing segmentation technique.

In order to have a fair comparison, the current situation for the 495 items is considered in the case study (presented as the single dot in Figure 18). In the current situation, the system is analysed by using the known demand stream in 2017, the order quantity, safety stock, and service level settings according to the system. Resulting from the case study the current situation achieved an OFR of 89% with 63 kCHF inventory costs. As depicted in Figure 18, the current situation performs far from optimal whereby even an unsegmented (where all SKUs have equal service level settings) approach performs better. The TABCD-XYZ approach with relative order frequency thresholds and a higher service level for the C and D classes has the best performance with the lowest inventory cost from an aggregated service level of 85% and onwards. Compared to the current situation it achieves a cost reduction of 28%. Hence, as discussed in Teunter et al. (2010) and in Vrat (2014) the addition of the Order Frequency should be useful in selecting the right inventory control policy. However, the case study shows that the Order Frequency is useful for target service level setting per segment as well and reducing inventory costs.

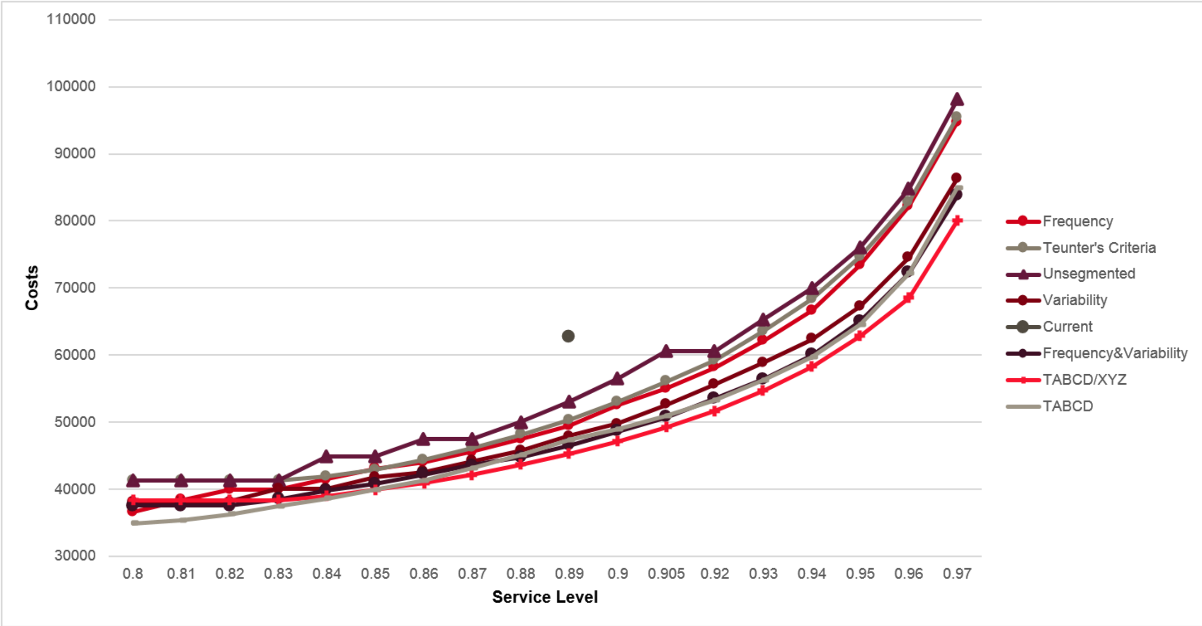

Figure 18 - Results from case study

Observe that the TABCD segmentation technique (i.e., solely based on demand value) has a similar performance compared to the Order Frequency/Order Variability technique. This is because in the TABCD segmentation the C and D items have a higher service level than T and A items. Consequently, resulting in lower inventory costs.

A remarkable result is that Teunter's cost criterion is performing worse than other segmentation techniques. A possible explanation is the simplification as described in 6.2.1.3. Due this simplification the cost aspect is omitted from the equation. However, this is not validated.

Furthermore, the case study gives no results for target service levels above 97%. When achieving an aggregate performance of 97% the algorithm selects already a 99.5% service level for some classes (see Appendix VI for an overview of the service level settings per segment). A possible explanation is standard normal distribution assumption of the safety factor. Another explanation is that the order quantity is not optimal. However, the objective was to investigate which segmentation concept results in the lowest costs constrained by target service level. Hence, if we relaxed the assumptions this would have had no impact on which segmentation technique performs better compared to the other techniques. An overview of the exact service level setting per class and corresponding inventory costs can be found in Appendix VI.

Similarly, we are aware that the dataset is quite small. Therefore, the results are validated by randomly selecting another dataset from the same warehouse with material status "Free". For this dataset the same approach as for the 495 items is used for determining the current situation. In the validation run, the current situation achieves a target of 91% (Figure 19). For this dataset, the unsegmented approach as well as the Teunter's cost criterion performs worse than the current situation. The worse performance of the unsegmented approach is straightforward because slow-moving-items have same service levels as fast-moving items, resulting in high inventory costs and the risk of obsolescence. The best performing segmentation technique is still the TABCD-XYZ approach as depicted in Figure 19. Furthermore, there is no significant difference in the performance of other models. One can still observe that the Order Frequency/Order Variability and the TABCD approach are still performing well with a minor difference of 4.6% and 6.2% respectively at a target service level of 97% compared to the TABCD-XYZ approach.

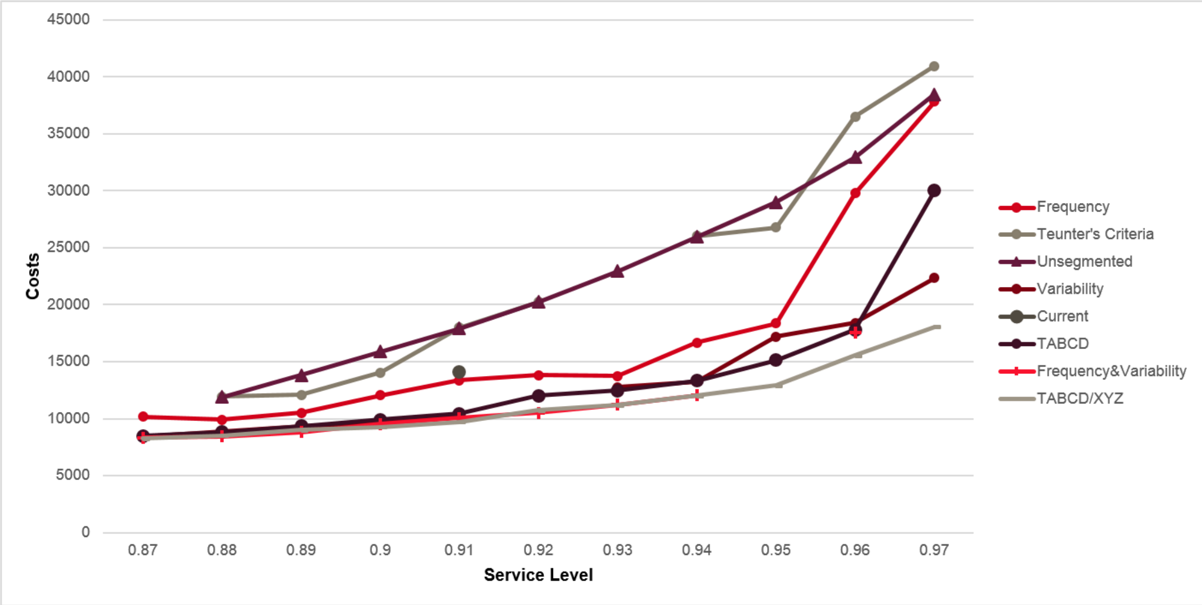

Figure 19 - Results from case study with 98 SKUs

We can conclude that in a quantitative segmentation technique order frequency is an important criterion to segment on. It performs well with the TABCD segmentation. Hence, this is a confirmation of the system approach (Sherbrooke, 1986) where SKUs with a high price should have a lower service level target compared to SKUs with a low price. Moreover, this also confirms the idea of Teunter's cost criterion (Teunter et al., 2010; van Wingerden et al., 2018), although the segmentation technique based on Teunter's cost criterion performs worse in the case study.

6.3.1. Sensitivity analysis class sizes

Since the class sizes do have a significant impact on the performance of a segmentation technique (van Wingerden et al., 2018), a sensitivity analysis is performed on the class sizes of the TABCD-XYZ approach. Especially for the classes (in this case CG5) where the decision is made to keep the items not on stock due to the slow-moving demand and high valued items. The class size needs to be such that an aggregate service level will be met with the lowest costs.

For the TABCD-XYZ segmentation technique the class size is dependent on the numbers of SKUs in the T and A class (Demand value), and dependent on the number of products in the X class (Order frequency). The size of the T and A class is of importance due to high valued items. If this class is too small, it means that the most expensive items are in the other classes with higher service level targets, and consequently, higher inventory costs. If this class is too large, fast-moving items with a relatively lower value will have a lower service level, which results in not achieving the aggregated target service level. According to the results (Figure 20) one can observe that the inventory costs are high when the T/A class is too small. For an aggregate service level target of 97% the T/A class should consist of maximum 9% of the total amount of SKUs.

Similarly, the same reasoning holds for the size of class X (i.e., fast-moving SKUs). If class X is too large, it means that it is more likely that slow- or non-moving items are then classified as fast-moving as well. Consequently, this results in high service levels for slow-moving or non-moving items, which implies high inventory costs. On the contrary, when the size of class X is too small, it results in items that are classified as slow-moving or non-moving with lower corresponding service levels. Hence, it is most likely that the aggregate target service level is not achieved. With regards to the class size of the X items one can observe similar results for an aggregate service level of 95% and 97% (Figure 21). In these cases, the class size should be around 63%. When the aggregate target service level is lower, the class size of X items can be smaller since fast-moving items contribute more to the aggregate target service level (6) and, consequently, the target service level is reached earlier.

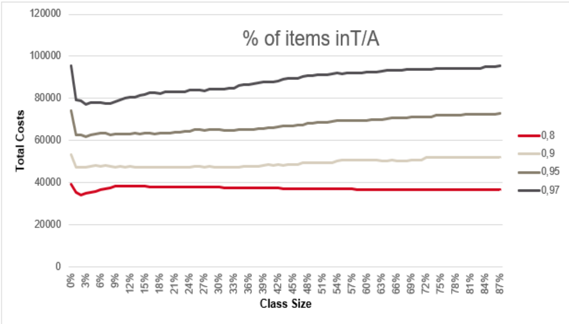

Figure 20 - Sensitivity analysis class size T/A items

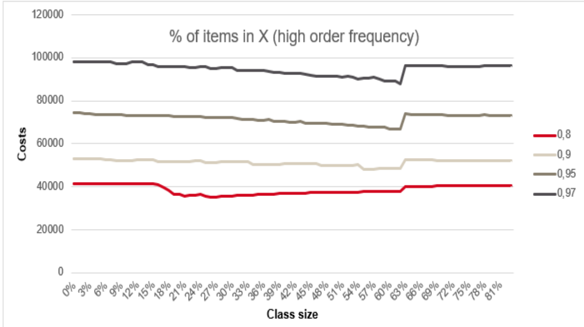

Figure 21 - Sensitivity analysis class size X items

6.4. Segmentation design

In the previous section we showed which quantitative segmentation technique achieves the best performance by setting service levels per class in order to achieve an aggregate target service level. However, the holistic approach with regards to e.g. products in the phase-in and phase-out life cycle are neglected. Therefore, the hierarchical process approach (Bacchetti et al., 2013; Papadopoulos, 2017) is used. By using the hierarchical process nine classes are obtained. How these classes are obtained, and which guidelines should be used for each class is discussed in this section.

The segmentation concept is based on the following criteria:

- Material Status
- Innovativeness
- Cluster group derived from TABCD-XYZ
- Lead time

The segmentation concept based on these criteria is depicted in Figure 22. Furthermore, the reasoning behind each criterion is described below.

Material Status

The first segmentation criterium is the *Material Status* which is already explained in section 5.3. According to literature (Persson & Saccani, 2009; Rink & Swan, 1979) one differentiates between four categories in the product life cycle (i.e., *Introduction phase, Growth phase, Mature Phase, Decline Phase*), whereas Hilti uses three categories. As observed in Bacchetti et al. (2013), three categories for the product life cycle are fine as well. Hence, we propose to use three classes as currently used within Hilti. The main reason is that from an inventory management perspective there is no difference between the *Mature Phase* and the *Growth Phase*. Only from a forecasting perspective one should be careful with selecting the correct forecasting policy. Since in the *Growth Phase* a company might experience an exponential increase in demand (Rink & Swan, 1979). Hence, the (double) exponential smoothing forecasting strategy might be the most suitable for this life cycle phase since it put more emphasis on the latest history, which makes it more useful for forecasting the increasing trend (J. S. Armstrong & Green, 2012).

Further segmentation is considered for the *Introduction phase* of the product life cycle, that is, *Innovativeness*. It distinguishes between products with a predecessor and without a predecessor. For the *Mature Phase* a differentiation is made in the cluster groups derived from the TABCD-XYZ analysis (see section 6.2.1.2). Nevertheless, for determining the cluster groups at least six months of sales history data is needed. There is no further distinction for *Phase-out* items since this requires more judgemental coordination in general (see section 6.5).

Innovativeness

With regards to *Innovativeness*, a distinction is made between items with a predecessor and without a predecessor. The reason behind this distinction is that a new product with a predecessor can use data from its predecessor in the past. This data can be useful to successfully introduce the new product based on causal relationships from its predecessor, which is also observed in Bacchetti et al. (2013). Whereas, for items without a predecessor a more judgemental approach from the marketing department is needed for introducing the product into the market.

Cluster Groups

The results of the case study from section 6.3 shows that the TABCD-XYZ (a 5 by 3 matrix) divided in five cluster groups (CGs) results in the best performance regarding inventory costs. As earlier mentioned the CGs were defined for avoiding long calculation times in the case study and for manageability. CG1 consists of the fast-moving and relatively cheap items. Hence, keeping this SKUs on stock would not results in high inventory costs. Similarly, for CG2, these items are relatively cheap as well, and it contains fast-moving items and slower-moving items (i.e., class Y). CG3 contains slow-moving items only, though relatively cheap. The case study showed that this CG should have a higher service level than CG4 which contains of relatively expensive though fast-moving items only. Hence, items from CG3 should always be stocked in a warehouse. Furthermore, items in CG3 are more difficult to forecast because of the slow-moving demand. One should pay attention to CG4, since these items are expensive (i.e., the T and A class) though fast-moving. Hence, over stocking these items will negatively impact the inventory costs. More care should be taken for CG5 since this CG contains expensive and slow-moving items only. Hence these items are difficult to forecast and keeping safety stock for these items would result in too high inventory costs and on the long term the risk of obsolescence arises.

Lead time

In the case study the policy for CG5 is to keep no safety stock in all cases. However, according to internal safety stock documentation and the study from Papadopoulos (2017) Hilti should keep safety stock for items with a lead time of more than 10 working days (Papadopoulos, 2017). In chapter 7 it will be investigated if this is indeed more beneficial and, if yes, which safety stock should be applied. In the next section we propose guidelines per segment with regards to MRP-type selection, safety stock, order quantity and forecasting strategy.

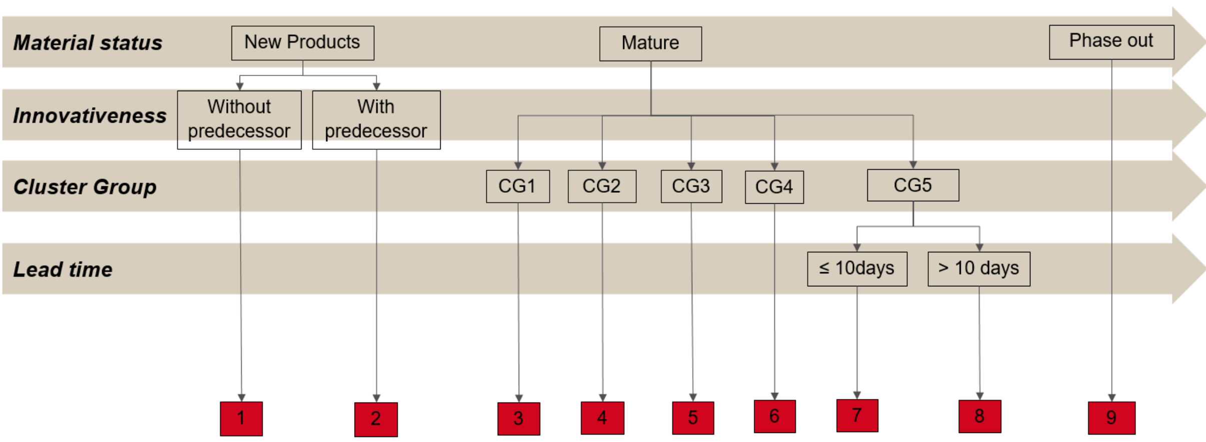

Figure 22 - Proposed Conceptual segmentation framework for Hilti

6.5. Guidelines for each segment

This section elaborates on the guidelines for each segment. For each segment guidelines are given with regards to which forecasting and MRP-type to use. In the case study a (R, s, nQ)-inventory control policy was used due to modelling purposes. However, within Hilti the MRP logic in SAP is used instead of the classical inventory control policies from Silver et al. (1998), which is also a misconception in the study of Papadopoulos (2017). Therefore, we suggest per segment a MRP-type. Furthermore, almost for every segment the EOQ is used as order quantity since Axsäter (2015) argues that an order-up-to level policy is approximately equal to an inventory policy with fixed order quantity and a fixed review period when demand is Poisson or continuous distributed. Since in practice the demand distribution is either normal distributed or gamma distributed it is a reasonable assumption. Furthermore, using a fixed order quantity (EOQ or MOQ) in a MRP environment tends to reduce nervousness at upstream locations in the supply chain (Hopp & Spearman, 2011).

Segment 1 - New products without predecessor

- Forecasting policy: Judgemental forecast.

  Due to the lack of data judgemental forecasting is required. The judgmental forecasting should be mainly performed by, for instance material managers in alignment with the marketing department.

- MRP-type: X0 with $SS = SB1$ method and $Q = EOQ$.

  New products, excluding specials, should be stocked close to the customer to encourage sales. The focus for new products should be to get the sales up. Less important are the inventory costs. With regards to the parameters of the SS method (i.e., the safety days, see Appendix VII), the lead time is suggested as the number of safety days. A service level as safety factor is not applicable in this case.

Segment 2 – New Products with predecessor

- Forecasting policy: Statistical forecasting with judgemental downward adjustments

  These products will cannibalize the sales of its predecessors. In the start of the *Introduction of the New Product* (INP) process the supply chain pipeline is filled with the INP products and the phase-out products are cleaned from stock. The statistical forecasting should be based on data from its predecessor before the INP process starts, since predecessor sales start declining when the INP process starts. Furthermore, statistical forecasting should include a factor to reflect sales increase due to renewal. In general, product renewal increases product sales (Cucculelli, Le Breton-Miller, & Miller, 2016). Hilti should investigate the impact of product renewal on its sales. Judgemental downward adjustments should be performed when inventory levels of the predecessor are still high.

- MRP-type: X0 with $SS = SB1$ and $Q = EOQ$.

  Due to the lack of data of lead time variability, the use of safety stock method SB1 is proposed whereby the safety days must be equal to the lead time. Furthermore, the safety stock should be kept close to the customer (hence, downstream in the supply chain) in order to achieve a high service level. The order quantity Q should be based on the EOQ while considering the average demand from the causal forecast from its predecessor.

Segment 3 – Mature products, CG1

- Forecasting policy: According to statistical forecasting segmentation

Products in this segment show a stable high frequent demand, which makes statistical forecasting suitable. The forecasting policy is selected according to the segmentation concept for forecasting presented in section 5.3.1. However, caution must be taken with items which are in the *Growing phase* (see section 6.4). Therefore, double exponential smoothing should be used in order to consider the upward sales trend from the most recent sales period(s).

- MRP-type: X0, Y7, Z4 with $SS = SB9$ and target service level of 99.5% and $Q = EOQ$

  For CG1 MRP-type X0, Y7 or Z4 should be used. CG1 consist of fast-moving items, hence a consumption driven MRP-type (i.e., Y7) is more suitable since it also forces to use a ROP for determining when to place an order. The difference between X0 or Y7 is on which level the forecast takes place. Typically for smaller markets the forecast is made on an aggregated level (i.e., HQ level), whereas for larger markets the forecast is made on MO-level. The MRP-type Z4 is only used for plants and HQ warehouses.

  During this phase there is enough data available to consider safety stock method SB9. Whereby the safety factor k should be based on a 99.5% service level according to the results in section 6.3.

Segment 4 – Mature products, CG2

- Forecasting policy: According to statistical forecasting segmentation

  This CG contains fast-moving and slower-moving items; hence forecasting is possible. Although, the statistical forecasting team selects the correct method and parameterization of the variables.

- MRP-type: X0, Y7, Z4 with $SS = SB9$ and target service level of 99.5% with $Q = EOQ$.

  Similar to CG2, one should use the MRP-type X0, Y7, or Z4, depending on the location in the supply chain. Since the items in this CG are (relatively) fast-moving and (relatively) cheap, a consumption driven MRP type should be used. Regarding the safety stock, a safety factor based on a 99.5% service level is used since this was the outcome of the case study when the aggregated target service level is 97%.

Segment 5 – Mature Products, CG3

- Forecasting policy: Corporate forecast only.

  Since this CG contains only of slow-, or non-moving items a statistical forecast is not necessary. Hence, a corporate forecast is sufficient, this also complies with the MRP-type.

- MRP-type: X5 or X6 with $SS = SB9$ and target service level of 98.5% with $Q = EOQ$.

  Due to the sporadic demand the MRP-type X5 or X6 is the most suitable since these items are generally PTO-items. The case study showed that (see section 6.3) the safety factor for the SS-method should be 98.5% in order to achieve an aggregated target service level of 97%. However, since the items in this CG are slow-moving, another safety stock method might be suitable as well, which is investigated in chapter 7.

Segment 6 – Mature products, CG4

- Forecasting policy: According to statistical forecasting segmentation

SKUs in CG4 are generally expensive and fast-moving, therefore forecasting is applicable and important as well. Especially for this CG one should strive for an accurate forecast, because in case of over forecasting the inventory holding costs increase significantly.

- MRP-type: X0 or Z0 with $SS = SB9$ and target service level of 65% with $Q = EOQ$

  The MRP-type should be forecast driven with high accuracy, since consumption driven might result in high inventory cost due to the high value SKUs. Therefore, MRP-type X0 for the MOs and MRP-type Z0 for the plants and HQ warehouses are appropriate. The case study (see section6.3) showed that for this CG a service level is appropriate for achieving an aggregated target service level of 97%. The reason for such a low safety factor in the safety stock calculation is for preventing high inventory costs.

Segment 7 – Mature products with short lead time (≤ 10 days), CG5

- Forecasting policy: Corporate forecast only.

  Since this CG contains only of slow-, or non-moving items a statistical forecast is not necessary. Hence, a corporate forecast is sufficient, this also complies with the MRP-type.

- MRP-type: X5 or X6 with no SS and $Q = MOQ$

  Because of the sporadic demand, the MRP-types X5 or X6 are used. The case study showed that, in order to reduce inventory costs, no safety stock is needed. Hence, safety stock should be considered for one location upstream in the supply chain. With regards, to the order quantity Q, the minimal order quantity should be used in order to reduce obsolescence risks.

Segment 8 – Mature products with long lead time (> 10 days), CG5

- Forecasting policy: Corporate forecast only.

  Since this CG contains only of slow-, or non-moving items a statistical forecast is not necessary. Hence, a corporate forecast is sufficient, this also complies with the MRP-type.

- MRP-type: X5 or X6 with $SS = SBB$ and $Q = MOQ$

  Similar to segment 7, the MRP-type X5 or X6 should be used for this segment. In order to comply with the current guidelines for safety stock and inventory positioning, a small amount of safety stock should be considered for long lead time markets. Hence, the SS method SBB is appropriate for this case. In chapter 7 the impact of the safety stock method will be evaluated.

Segment 9 – Phase-out items

- Forecasting policy: rule-based forecasting

  With rule-based forecasting managerial information can be included that is necessary to predict the decrease in demand during phase-out.

- MRP-type: X5 or X6 with $SS = SB1$ and $Q = MOQ$

A phase-out product is sold to get rid of inventory of the product in the pipeline. Because of the rule-based forecasting a MRP-type should be selected were planning is allowed, therefore X5 or X6 should be used. Normally, phase-out products have a decreasing demand pattern. Especially when the product has a successor Hilti has to a certain extend influence on the decrease in sales. Within the INP process the introduction to the market is done stepwise in multiple waves. The products are first introduced to the stable markets, every three months the product is introduced to other markets. Total inventory in the location should be limited to the expected demand until the new product will be sold. To overcome obsolescence the order quantity should be minimized. Furthermore, the safety stock requires manual steering. Therefore, one should use the SB1 method whereas the safety days are determined based on the rule-based forecasting. Since the duration of the phase-out period for a non-spare part is not as long for spare-parts (Papadopoulos, 2017), no service level target is required.

6.6. Concluding remarks

From the analysis provided in this chapter we can conclude that a segmented of any kind performs better than an unsegmented approach. From the analysed segmentation techniques, it turned out that is highly recommended to include the order frequency of the SKUs for determining the classes (Figure 18). Segmenting based on order frequency is also in line with the studies from Sherbrooke (1986), Teunter et al. (2010), and Van Wingerden et al. (2018). Although, the presented approach is different compared to the mentioned studies, the concept is valid for other companies as well since in this study specified order quantities are used instead of a base stock policy (Sherbrooke, 1986; van Wingerden et al., 2018). If a company with an ABC-classification approach cannot, by any reason, include the order frequency in their segmentation framework, it is recommended to set high target service levels for C-items and low target service levels for A-items in order to reduce inventory costs. This approach captures the idea of Sherbrooke (1986) to keep cheap and fast-moving items on stock and be more careful with stocking expensive slow-moving items.

Furthermore, when one is dealing with nine or 15 classes, it is from a managerial point of view beneficial to cluster those segments into five cluster groups such that one can have a better focus on cheap fast-moving items and expensive slow-moving items. Van Kampen et al. (2012) and Van Wingerden et al. (2018) also argues that more than six classes becomes too complex and more than six classes does not result in a significantly better performance in terms of inventory cost. Besides the number of classes, attention must be paid to the class size. When combining an ABC segmentation technique with order frequency, whereby SKUs in class A have lower service level targets, the class A respective to B should not be too big. Otherwise items which are relatively cheap and fast-moving are not kept on stock and, hence, the target service level is not satisfied. For Hilti's case the class size of the T/A class should contain approximately 9% of the total SKUs. Similarly, attention must be paid to the class size of the order frequency classes (i.e., in Hilti's case XYZ). When striving for a high aggregated service level target (more than 95%) the class size should not be too big otherwise risks arises that slow-moving items end-up in the fast-moving class. In this case study, it turned out that for high service levels, class X should contain approximately 63% of the total SKUs. For low service level targets (i.e., 80%) the class size of fast-moving SKUs is smaller. For Hilti's case it is reduced to approximately 27%.

7. Safety stock optimization

Since in common one argues that one size does not fit all with regards to inventory control it is interesting to see if a segmented approach for safety stock methods is helpful for achieving lower inventory costs and the same or a better service level to the customer. Schmidt et al. (2012) showed that a segmented approach is useful based on the lead time variability and demand during lead time variability. This chapter, however, describes if a segmented approach based on the segmentation framework in section 6.4 is suitable for achieving a better performance in terms of inventory costs and service to the customer. For this analysis the current safety stock methods within Hilti are used in three different warehouses. First, insight is given in how the current safety stock methods are used for each warehouse. Thereafter, a comparison is made regarding the performance between the current situation of the safety stock methods, the current decision framework (see section 5.3.4) and the new segmentation concept developed in chapter 6. Additionally, the demand distribution for some SKUs is fitted to see whether the current normal distributed demand assumption is valid. The impact of using another demand distribution is also covered in this chapter.

7.1. Currently used safety stock methods

To have an insight in the currently used safety stock methods, 654 SKUs are selected which are available in all three warehouses (one HAG WH and two CWs) such that safety stocks in a two-echelon distribution system can be analysed as well. Of the CWs, one (denoted as CW 8150) has a relatively short lead time (i.e., approximately 6 days) and the other (denoted as CW 0650) has a relatively long lead time (i.e., approximately 47 days). The selected items are all of type 'free' from the Product Life Cycle to make sure that a demand period of three years can be analysed. Spare parts are excluded from the data set due to a different supply chain structure.

The used safety stock methods in each warehouse grouped per segment are depicted in Figure 23 - Figure 25. Hence, there is no structure of selecting a certain safety stock method per segment. Moreover, the selection of a safety stock method, differs per warehouse. Remarkably, the simplest safety stock method SB1, is the most frequently used safety stock method for the HAG WH 0550 and CW 0650. Even for the most important items (T-items) this method is used more than 70% and 95% for the HAG WH and CW 0650, respectively. Since, the SB1 method requires no service level measure, there is a high risk for insufficient stock or excess safety stock when an arbitrary high value for the days of coverage is selected. Hence, the safety stock settings are not optimal.

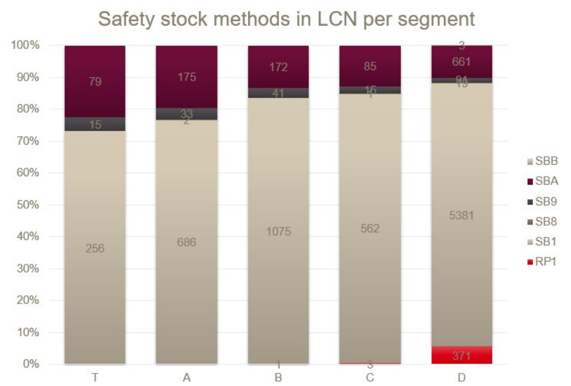

Figure 23 - Safety stock methods in HAG WH 0550

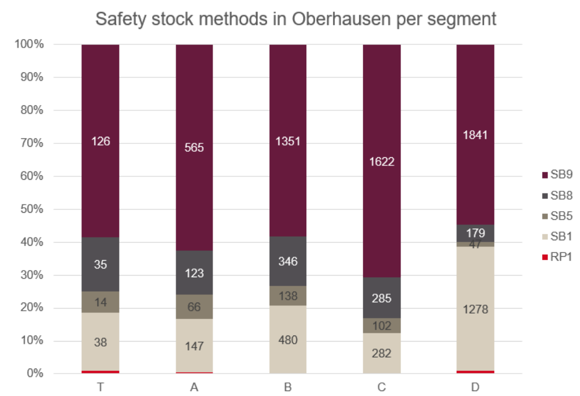

Figure 24 - Safety stock methods in CW 8150

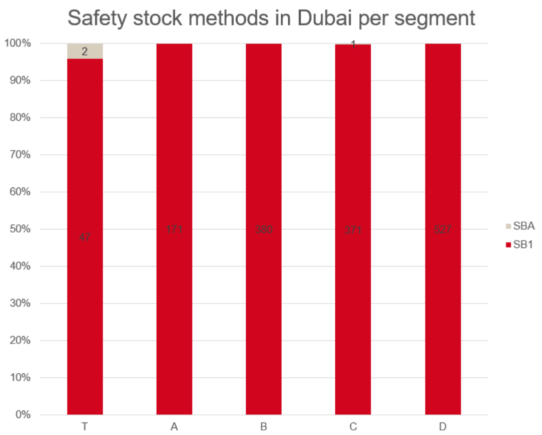

Figure 25 - Safety stock methods in CW 0650

Furthermore, according to the description of the safety stock methods (Appendix VII) and the safety stock decision framework (Figure 14), the safety stock of items with continuous demand (i.e., X and Y items) and a long lead time (> 14 days) should be calculated by SBA or SB8. Since the average lead time in CW 8150 is 47 days (st dev = 13,46) and 59% of all the items are categorized as continuous demand, it means that the safety stock of more than 50% of all the items should have been calculated by SBA or SB8 method. Hence, the safety stock guidelines in section 5.3.4 are clearly not followed. To clarify this situation, the current safety stock methods for each warehouse are compared with the situation when the safety stock methods were selected according to the guidelines (Table 10).

Table 10 - Comparison between current safety stock methods and safety stock methods according to guidelines

	Current safety stock methods						Safety stock methods according to the current guidelines						
Location	**RP1**	**SB1**	**SB5**	**SB8**	**SB9**	**SBA**	**No SS Method**	**SB1 or SB5**	**SB8 or SBA**	**SB9 or SBA**	**SBB**	**SB1 or SBA**	**SB9 or RP1**
8150	4	38	21	31	560		10	85	40	509	10		
0650		652				2	223	19	409	3			
0550	91	448			36	79	4					644	6
Total	**95**	**1138**	**21**	**31**	**596**	**81**	**237**	**104**	**449**	**512**	**10**	**644**	**6**

Observe that the most changes take place at CW 0650, since there the SB1 method is currently the most used, while according to the guidelines either no safety stock or the SB8 or SBA method should be used due to low order frequency or long lead time respectively. For the HAG WH, approximately 80% of the safety stock methods follow the guidelines (Figure 26), because the guidelines are indecisive about using either the SB1 or the SB9 method. Hence, this explains the popularity of the SB1 method in the HAG WH. For CW 8150, the safety stock method SB1 or SB5 should be used more frequently due to seasonal nature of the demand of those products (see section 7.2).

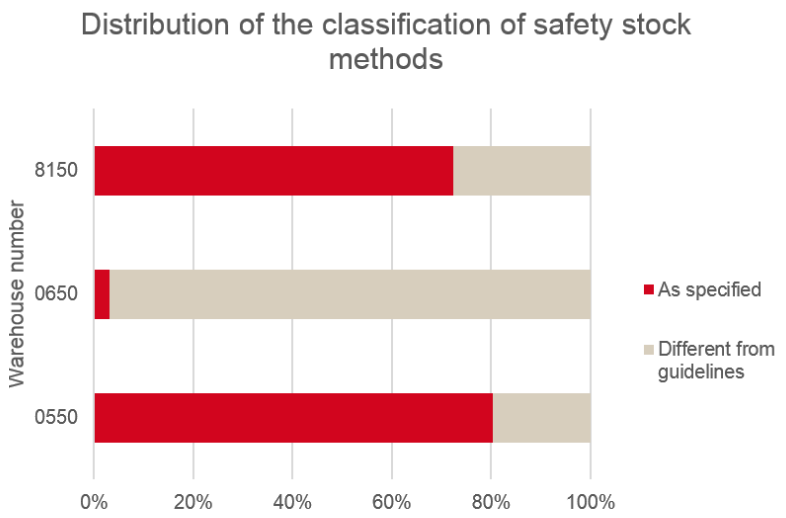

Figure 26 - Distribution of correctly used safety stock methods

7.2. Seasonality

Besides not following the guidelines, Hilti is also struggling with the safety stock calculation for seasonal products. In the region that is served by CW 8150, 6% of the SKUs is categorised as seasonal. However, this share contributes to 24% of the total value in this region. According to the guidelines, either SB1 or SB5 should be used for calculating the safety stock. In both methods, the average forecasted demand in the next 90 days is the most important parameter Appendix VII). However, these guidelines for seasonal products are not followed, since for 93% of the seasonal items the SB9 method is used (Figure 27). One of the reasons to not choose for the SB1 or SB5 method is that the forecast demand does not reflect the seasonal pattern of the product (see Appendix IX).

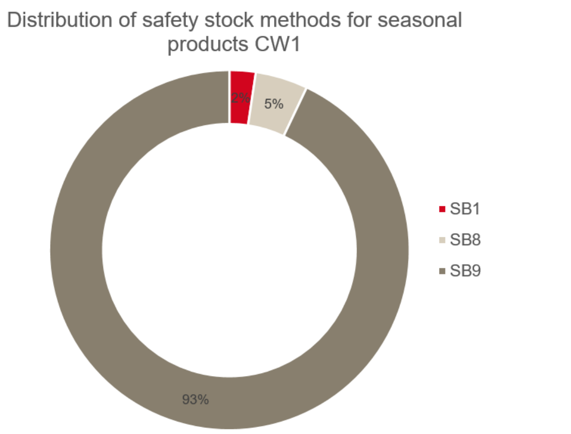

Figure 27 - Distribution of safety stock methods for seasonal products

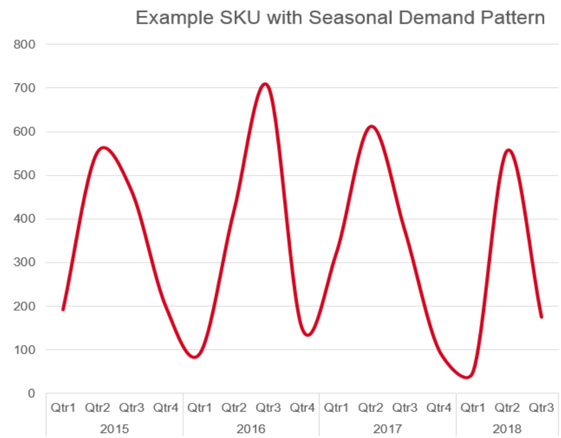

Figure 28 - Forecasted demand vs. actual demand for an item

In an example of a SKU from CW 8150 which is seasonal (Figure 28), the demand and the safety stock over the past year is given (Figure 29). In contrast with the guidelines, the SBA method with a service level of 99% is used to calculate the safety stock. Observe that the safety stock does not follow the seasonal pattern and there is in some period an excess of safety stock. Furthermore, several stockouts occur when in the period with high demand.

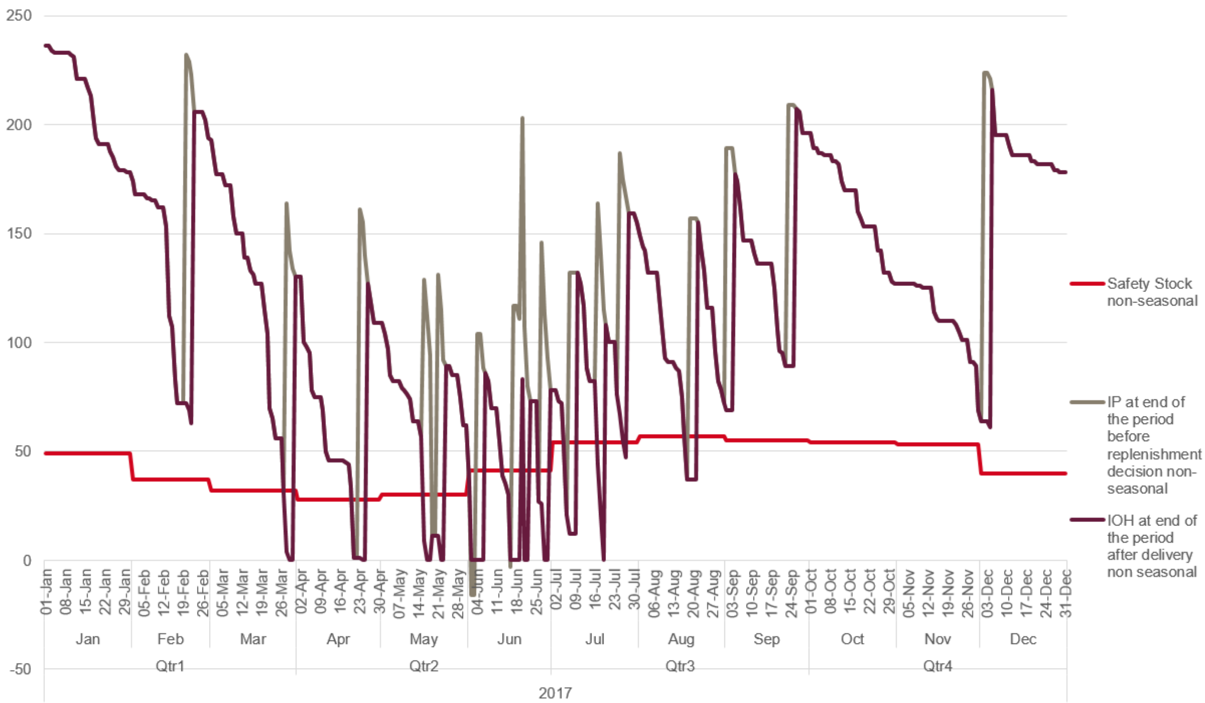

Figure 29 - IP and IOH non-seasonal safety stock

7.3. Conceptualization

This section discusses the conceptual model which is the main pillar for the analysis for the scientific model. The conceptualization starts with the main assumptions regarding both safety stock problems discussed in section 7.1 and section 7.2, namely:

- The Segmentation concept presented in section 6.4 is assumed to be a valid segmentation concept for all warehouses in Hilti's supply chain
- The inventory in all warehouses is controlled by an (R, s, nQ)-policy with review period is 1.

As discussed in section 6.4 the (R, s, nQ)-inventory control policy is a reasonable assumption since incoming orders in SAP are aggregated on a daily level.

- If lead time variation is known, it is assumed to be normal distributed.
- The service levels per segment from the segmentation concept for achieving a target service level of 97% are used as input for the safety stock methods
- Demand is known and retrieved from the ERP system
- Demand is independent of the inventory level in the warehouse and i.i.d.
- There is ample capacity in the warehouse
- Items are non-perishable
- The order quantity is known and derived from the system
- Undershoot is not taken into account in the safety stock calculations

By considering these assumptions we can construct the conceptual model by defining the input parameters, the decision variables and the output of the analysis. The main objective of the safety stock analysis is to cope with demand and supply uncertainty while promising a certain percentage of product availability and simultaneously minimizing the inventory costs while considering a segmented approach. In order to analyse the segmented approach with regards to the safety stock, some input parameters are needed (Figure 30) which are needed for calculating the safety stock according to the defined method (Appendix VII) and the demand distribution of the SKUs. Eventually these two decision variables show the results in terms of inventory costs and service level performance.

Figure 30 - Input, decision variables and output of conceptual model

7.4. Scientific model

The conceptual model presented in section 7.3 is the foundation to construct the scientific model. First, the objective function is presented constrained by a service level target. Subsequently, the model on how to determine the inventory cost is discussed. Thirdly, the method on how to calculate the safety stocks or reorder point is explained.

7.4.1. Objective function

When optimizing the safety stock – considering a segmented approach – the total inventory costs are minimized constrained by an aggregated target service level, which can be formulated as:

$$minimize\ C_{tot} = \sum_{j \in J} \sum_{i \in I} C_{i,j} \tag{22}$$

$$subject\ to\ \beta_{tot} \geq \beta_{target}$$

Where the aggregated fill rate $\beta_{tot} = \sum_{j \in J} \sum_{i \in I} \frac{D_{i,j}}{D_j} * \beta_{i,j}$

The inventory costs are divided in holding costs h per SKU i for each warehouse j and handling costs per order K for each SKU i in every warehouse j. and can be formulated as follows:

$$C_{i,j} = h_{i,j} * E[IOH_{i,j}] + K_{i,j} * E[OL_{i,j}] \tag{23}$$

Where $E[IOH_{i,j}]$ and $E[OL_{i,j}]$ are the expected inventory on hand and expected orders for every SKU i in warehouse j respectively. The total service level β_{tot} consists of the service levels per CG presented in section 6.5.

7.4.2. Model set-up

For the analysis the terminology of van Donselaar and Broekmeulen (2014) is used. Whereby a distinction is made between the review cycle and the potential delivery cycle. Hence, the on-hand inventory and the backorders are analysed in two moments, i.e., after a potential delivery $(\tau + L)$ and just before the next potential delivery $(\tau + R + L)$. The terminology is as follows:

$L_{i,j}$	= lead time for SKU i to warehouse j
R	= review period
$D(t, t+1)_{i,j}$	= Demand in interval $(t+1, t]$ for SKU i at warehouse j
$IOH_{i,j}(t)$	= On-hand inventory at time t for SKU i in warehouse j
$BO_{i,j}(t)$	= Backorders at time t for SKU i at warehouse j
$SR_{i,j}(t)$	= Scheduled receipts at time t for SKU i at warehouse j

$IP_{i,j}(t)$ = Inventory position at time t of SKU i in warehouse j

The parameters are calculated as follows:

$$IOH_{i,j}(\tau + t) = \left(IP_{i+j}(\tau) - D_{i,j}(\tau, \tau + t)\right)^{+} \tag{24}$$

$$BO_{i,j}(\tau + t) = \left(D_{i,j}(\tau, \tau + t) - IP(\tau)\right)^{+} \tag{25}$$

$$IP_{i,j}(\tau) = IOH_{i,j}(\tau) + SR_{i,j}(\tau) - BO_{i,j}(\tau) \tag{26}$$

Note that these equations are valid for $t = L_{i,j}$ and $t = L_{i,j} + R$. Therefore, the backorders in the system during the time interval $\left(\tau + L_{i,j}, \tau + L_{i,j} + R\right)$ are derived as follows (van Donselaar & Broekmeulen, 2014):

$$BO_{i,j} = BO_{i,j}\left(\tau + R + L_{i,j}\right) - BO_{i,j}(\tau + L_{i,j}) \tag{27}$$

Hence the expected inventory on hand and expected backorders for every SKU i at warehouse j can easily be derived:

$$E[IOH_{i,j}(\tau + t) = E\left[\left(IP_{i,j}(\tau) - D_{i,j}(\tau, \tau + t)\right)^{+}\right] \tag{28}$$

$$E\left[BO_{i,j}(\tau + t)\right] = E\left[IOH_{i,j}(\tau + t)\right] + E\left[D_{i,j}(\tau +, \tau + t)\right] - E\left[IP_{i,j}(\tau)\right] \tag{29}$$

Furthermore, there is an order line when the inventory position at the review moment is below the reorder point. Therefore, the expected number of order lines can be denoted as (van Donselaar & Broekmeulen, 2014):

$$E\left[OL_{i,j}\right] = P\left(IP_{i,j}(\tau) - D_{i,j}(\tau, \tau + R) < s\right) \tag{30}$$

Eventually the performance of the analysis can be evaluated by the fill rate (β) and the order line fill rate (OFR, see section 6.2.2). The fill rate is denoted as:

$$\beta_{i,j} = 1 - \frac{E\left[BO_{i,j}\left(\tau + R + L_{i,j}\right)\right] - E\left[BO_{i,j}\left(\tau + L_{i,j}\right)\right]}{E\left[D_{i,j}(\tau + L, \tau + R + L)\right]} \tag{31}$$

As a starting point ($t = 0$) from the analysis, the $IOH_{i,j}$ is equal to the current inventory on hand in the system. It is assumed that at the starting point there are no backorders and that the inventory position is equal to the inventory on hand.

7.4.3. Determining safety stock/reorder point

The key decision variable in the analysis is the determination of the safety stock or reorder point. As mentioned before, the objective is to strive for a segmented approach with regards to the existing safety stocks (Appendix VII). Remarkably from these presented safety stock methods there is only one safety stock method (i.e., the SB9 method) that is familiar in literature (Eppen & Martin, 1988). Furthermore, by the author's knowledge there is no literature available that differentiates in different safety stock methods according to an, e.g., ABC segmentation technique in a single echelon inventory system. Though, it is interesting to investigate if there is a difference in performance when using the safety stock methods within Hilti for different segments. The service factor k in the safety stock methods can be calculated by the standard normal inverse distribution. Teunter et al. (2010) show that the Cycle Service Level is similar to the fill rate definition by using the assumption that order quantities are relatively big and in practice the expected backorders are small due to high service level targets.

Furthermore, special attention is needed for determining the safety stock for seasonal products (see section 7.2. Herrin (2005) showed that for calculating safety stock with seasonality no new developed safety stock method is needed. Merely, an adjustment in the calculation of the average demand and standard deviation of demand and, therefore, calculating the safety stock monthly instead of a whole year. In a mathematical notation we denote the safety stock for month $m \in M$ in the current year y as $SS_{m,y}$, where M = (1, 2, …, 12). Due to the limitation of data availability, we used only demand data up to two years back from the current year y. Hence, the SS is denoted according to the safety stock formula from Eppen and Martin (1988) in case lead time variability is known:

$$SS_{m,y} = k * \sqrt{LT * \sigma_{D,m,y}^2 + \sigma_L^2 * \mu_{D,m,y}^2} \qquad (32)$$

Where the average demand for month m in the current year $\mu_{D,m,y}$ is calculated as follows:

$$\mu_{D,m,y} = \frac{1}{n}\sum_{i=1}^{n} \mu_{D,m,y-i} \qquad (33)$$

Where n is denoted as the number of years for going back in time (in this study equal to 2). A similar approach is used for calculating the standard deviation for each month in year y.

7.4.4. Demand distribution

Besides the safety stock method, the demand distribution is of importance for calculating safety stocks or reorder points. Currently, the standard normal distribution is used for calculating the safety factors. According to some authors (Axsäter, 2015; Burgin, 1975; van Donselaar & Broekmeulen, 2014) the normal distribution assumption does not always hold. In most cases the normal distribution assumption simplifies heuristics or calculations. For instance, when demand is lognormal, or gamma distributed, the calculation of the safety stock differs slightly. The lognormal or gamma inverse function with a given service level, and estimated parameters based on the mean and standard deviation of the demand results directly in the reorder point (Mirzaee, 2017, p. 11). Hence, the safety stock is determined by subtracting the average demand during lead time. Therefore, the demand distribution is fitted by using the fitdistrplus package (Delignette-Muller & Dutang, 2015) in the R programming language (R Core Team, 2018). Before fitting the demand distribution, the outliers need to be removed from the dataset. Outliers are considered as values who are out of the 1.5 Inter Quartile Range (Montgomery & Runger, 2014). The outliers are depicted as the dots in a boxplot (Figure 31).

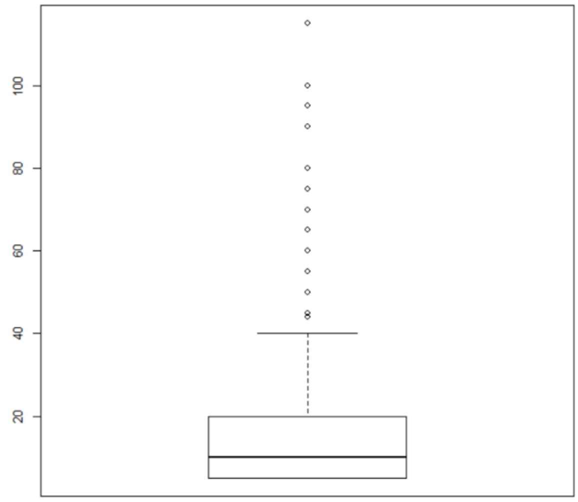

Figure 31 - Boxplot Example SKU

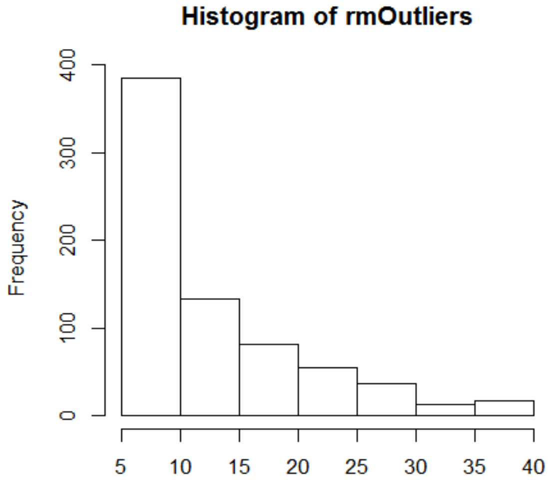

Figure 32 - Demand frequency of example SKU (outliers removed)

Figure 32 shows the frequency of the demand when the outliers are removed. For warehouse 0550 and 0650 it turns out that the demand seems to be gamma distributed for the whole dataset. Whereas, the demand distribution for warehouse 8150 shows that approximately 40% is normal distributed. The parameters α and β for the gamma distribution are estimated based on the mean and variance of the demand for each SKU i in the dataset:

$$\widehat{\alpha_{i,j}} = \frac{E^2[D_{i,j}]}{Var[D_{i,j}]} \qquad and \qquad \widehat{\beta_{i,j}} = \frac{E[D_{i,j}]}{Var[D_{i,j}]}$$

Hence, after the safety stock methods are determined for each class, the impact of the demand distribution on the safety stock calculations for each warehouse are analyzed and compared.

7.5. Results from analysis

As discussed in the previous section, several problems are discussed regarding the current safety stock methods. For these problems solutions are provided and explained in this section.

7.5.1. Segmented approach safety stock

Section 7.1 describes that in the current situation the segmentation guidelines for safety stock are not followed. Therefore, this section compares the current situation with the current segmenting guidelines, and the guidelines from the new segmentation concept described in section 5.3.4. As mentioned in section 7.4 the three cases are compared based on the $E[IOH]$, $E[BO]$, β_{tot}, Holding costs, and ordering costs. Furthermore, the safety stock value is included as well in order to see what the impact is on the safety stock itself.

For the current situation the inventory data for each SKU in each warehouse is retrieved from the system. The results are given in Table 11 as is used as baseline for further analysis. In the case that Hilti would follow their own guidelines this would result in a significant decrease in average IOH for warehouses 0550 and 0650. Simultaneously, a decrease in service level is observed. For warehouse 0550 this is partly caused by the significant reduction (more than 50%) in average IOH and, consequently the reduction in the average safety stock. As depicted in Appendix VIII, one can observe that only three safety stock methods are used (i.e., SB1, SBA and RP1). The SB1 is still the most used safety stock method in this case (~70%). However, the safety stock is now calculated according to parameters in the system and there are no manual calculations as in the current situation. The second cause of the decrease in service level, is the way how Hilti measures its performance (see section 6.2.2). Hence, when a delivery of a product is delayed, a new delivery date is communicated to the customer. When the customer agrees with this new date, the actual performance is not affected when a SKU is out of stock. In the analysis this is not the case. When a SKU is not available on stock, or when an order line cannot be fulfilled immediately from stock, it will negatively influence the service level. This issue also holds for the decrease in fill rate for warehouse 0650. Moreover, observe that for warehouse 0650 the safety stock is increased significantly compared to the current situation. According to the system, there is often no safety stock registered, while it is necessary in order to achieve a fill rate of 88.4%. Another reason that the performance for warehouse 0650 has decreased, is that for more than 30% of the SKUs no safety stock method is needed according to Hilti's guidelines (Appendix VIII), since these SKUs have MRP-type X6. The enormous decrease in holding costs (68%) is a result of the elimination of the over structurally over forecasting in warehouse 0650. For warehouse 8150 promising results are observed. The service level has decreased slightly, while the holding costs and, consequently, the safety stock value are decreasing.

Table 11 - Comparison between segmented approach safety stocks and relative performance compared to current situation

	SS current segmentation			SS new segmentation			Only SB9 method		
Warehouse	**0550**	**0650**	**8150**	**0550**	**0650**	**8150**	**0550**	**0650**	**8150**
Average IOH	-53%	-68%	2%	-57%	-69%	-26%	-62%	-69%	-26%
Average fill rate	-8%	-31%	-2%	-7%	-4%	-1%	-11%	-7%	-2%
Holding costs	-32%	-68%	-25%	-53%	-78%	-46%	-58%	-78%	-45%
SS value	-4%	1209%	-75%	-50%	594%	-89%	-59%	444%	-89%
Handling costs	90%	-6%	-25%	89%	-5%	-25%	89%	-6%	-25%

With regards to the new segmented approach, we see that for all warehouses the total costs decrease compared to the current situation and to the situation where the safety stocks are defined by Hilti's guidelines. Compared Hilti's safety stock segmentation, the service levels are quite similar for warehouses 0550 and 8150, while achieving a total cost reduction of 22% and 18% respectively. However, compared to the situation where only one safety stock method is used based on the holistic segmentation concept, one can observe that the cost decrease are slightly higher compared to a segmented approach. However, the segmented approach achieves on overall a better fill rate. In Table 12 the safety stock methods per warehouse per CG are summarized which are the result from the analysis. In Appendix I the results are given for the safety stock method according to the new segmentation concept for both gamma as normal distributed demand. Using the gamma distribution for determining safety stocks results in a better performance for warehouse 0550 (+0.7%) and 0650 (+1.4%) in terms of service level accompanied with higher costs inventory costs. However, the performance increase is not as high as expected. For warehouse 8150, the service level increase is not significant (94.4% vs. 94.5%) and therefore one can conclude that normal distribution assumption is valid.

Table 12 - Safety stock method per warehouse and per CG according to analysis

	Warehouse		
Cluster group	0550	0650	8150
CG1	SB9	SBA	SB9
CG2	SB9	SBA	SB9
CG3	SB9	SBA	SB9
CG4	SB9	SBA	SB9
CG5 (Short LT)	SB1	SBB	No SS Method
CG5 (Long LT)	SB1	SBB	SBB

Furthermore, we see for warehouse 0650 (with long lead time) a better performance by using the SBA safety stock method, compared to the SB9 method for CG1 until CG4. According to the segmentation concept in section 6.5 it turned out that is more beneficial to keep no items on stock for CG5 at all, which is based on one warehouse. However, warehouse 0550 is the upstream warehouse in Hilti's supply chain. Since from a practical point of view in some plants one cannot keep stock or just a small amount due to legislations, it is reasonable that the finished goods from the plants for CG5 are stored in the most upstream warehouse. Because there are no service level targets available for CG5, the safety stock method is limited to SB1 and SBB. Using the SB1 method results in the best performance for warehouse 0550.

7.5.2. Seasonality

A current problem is that Hilti is treating seasonal products differently in safety stock calculations, however, in a wrong way. Section 7.2 showed that the used safety stock methods for seasonal products are not according to the presented guidelines. Moreover, it does not consider calculating the average demand and standard deviation according to the seasonal pattern.

Therefore, the current method for a single item (SKU 2065447) is compared to a safety stock calculation based on Herrin (2005). Daily demand data from 2015 until 2017 is used for the safety stock calculation. The seasonal method considers a (R, s, nQ)-policy with $Q = 40$ and $R = 1$. The reorder point s is calculated for each month in 2017, based on demand history from 2015 and 2016. The order quantity Q is 40 according to the current information in the system. Lead time is considered as deterministic, since for this item no data is available of the variation of the lead time.

Figure 29 and Figure 33 show the Inventory on Hand (IOH), the Inventory Position (IP) and the Safety stock per month for both situations. Observe that the safety stock follows the seasonal pattern (Figure 33) and consequently it is reduced by 7.6%. Furthermore, the average IOH decreases from 106 units to 68 (-36.1%) while the number of orders increases from 46 to 110 (+139%).

Since backorder costs are not available, these are approximated by using a newsvendor model equation (Axsäter, 2015, pp. 96–97). By using the holding costs per unit, current service level target, and assuming normal distributed demand the backorder costs can be determined.

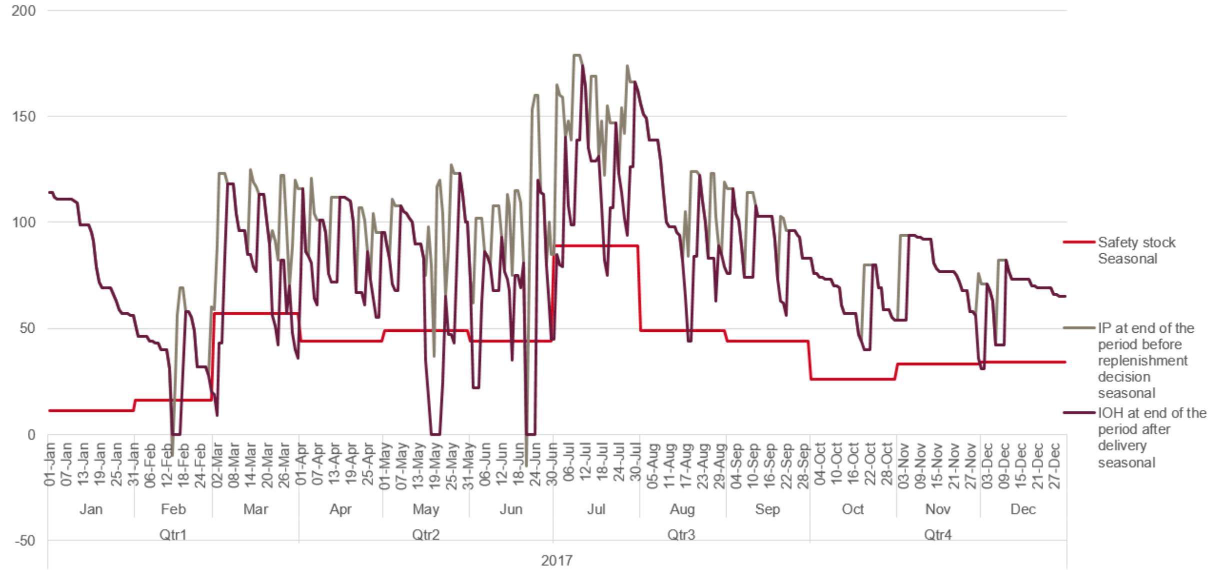

Figure 33 - IP and IOH seasonal safety stock

The analysis shows that when the order quantity $Q = 40$ the seasonal approach performs slightly better than the non-seasonal approach (total costs decreases by 2.04%). The minor cost total cost decrease is caused by the significant increase in handling costs, which implies that the current order quantity is far from optimal. Therefore, the order quantity is determined by using the standard EOQ model. However, the standard EOQ model does not consider backorder costs (b). A modification on the EOQ model is used as described in Axsäter (2015, pp. 51–53) in order to determine the order quantity when backorders are allowed.

$$Q^* = \sqrt{\frac{2KD(h+b)}{hb}} \tag{34}$$

By applying the EOQ and EOQ with backorders allowed it turned out that the EOQ without backorders was performing better than the EOQ with backorders. This was caused by the current demand stream. In order to which method performs the best, the demand is assumed to be stochastic. Subsequently, a simulation is used for determining the performance on the long run. The demand distribution is fitted by using the descdist function from fitdistr package (Delignette-Muller & Dutang, 2015). The results show that the demand is gamma distributed (Figure 34 and Figure 35). Because within Hilti the safety factor is always based on the normal distribution, it is compared when the safety factor is based on the gamma distribution.

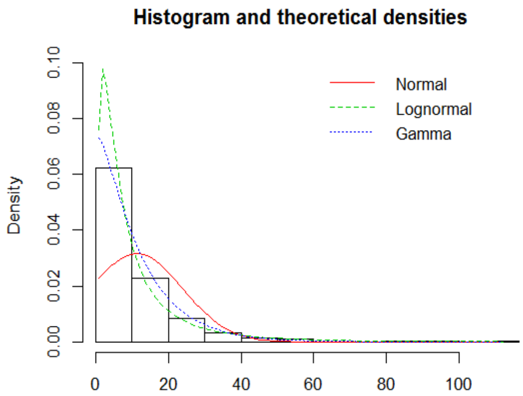

Figure 34 - Fitted distributions on demand

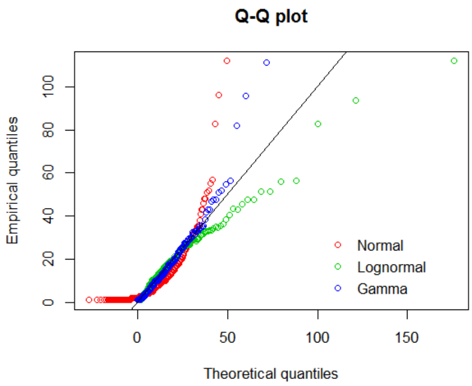

Figure 35 - Q-Q plot for Normal, Gamma and Lognormal distribution

According to the results in Table 13, the EOQ when backorders are allowed performs better than the normal EOQ. Clearly, the current order quantity of 40 is far from optimal, when considering that the EOQ calculations results in order quantities of 130. By using the EOQ calculations the service level increases further from 94% to approximately 97.5%. Whereby, the total costs compared to the current situation decreases by more than 35%. The decrease in total costs is caused by the decrease in backorder costs. Observe that the handling costs are still higher compared to the current situation due to the MRP logic in SAP. Furthermore, there is no significant performance difference when assuming gamma distributed demand or normal distributed demand (Table 13). On average the safety stock is higher when using the gamma distribution because it has to cover the longer tail (Figure 34).

Table 13 - Results when adopting seasonal approach for safety stock

	Non-seasonal approach	**Seasonal Approach $(Q = 40)$**	**Seasonal Approach $(Q = EOQ)$**	**Seasonal Approach $(Q = EOQ_B)$**	**Seasonal Approach $(Q = EOQ_B)$ with gamma distribution**
Average IOH	106	68	114	115	122
Average BO	1.96	0.80	0.19	0.17	0.22
Fill rate	84%	94%	97.5%	97.9%	97.9%
Average safety stock	44	41	41	41	45
Holding costs increase/decrease		-36%	2%	3%	9%
Handling costs increase/decrease		194%	12%	9%	11%
Backorder costs increase/decrease		-59%	-87%	-89%	-89%
Total costs increase/decrease		-2%	-37%	-39%	-36%

Since the handling costs per order (K) are the same for every product in the same warehouse, this would not reflect the real handling costs for this specific SKU. Therefore, a sensitivity analysis is performed on the handling costs. For each value of the handling costs, the EOQ is calculated and used with the current demand stream in order to determine the effect on the total cost increase or decrease compared to the current situation (Figure 36). Since the current demand stream is used for the

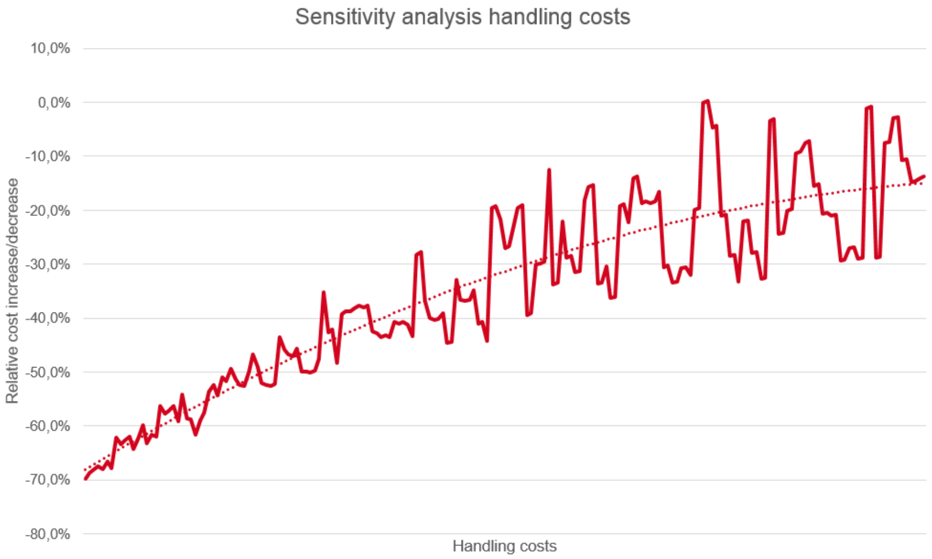

Figure 36 - Sensitivity analysis handling costs

sensitivity analysis, and not a stochastic demand which is simulated for n times, there are some peaks and troughs observed. When simulating the demand, the curve would be approximately similar to the dotted curve. Nevertheless, one can conclude that the handling costs have a significant impact on the total costs.

Furthermore, unlike the handling cost, the holding cost are strictly depending on the price of the product. Hence, the more expensive a product is, the higher the holding cost, while the handling cost remains the same for every product. Nevertheless, Hilti should adopt the seasonal approach, since it results in a better service to the customer (especially during the periods with high demand) and, consequently, lower costs. Moreover, round 20% of the SKUs in this warehouse are categorised as seasonal. However, care must be taken with regards to the seasonal items, since some items are categorised as seasonal while they are not (an example is given in Appendix XI). Besides this analysis, it is interesting to see how a seasonal approach can be used in a multi-echelon setting, which is not analysed in this study and is not seen in literature by the author's knowledge.

7.6. Solution design

Concluding from the results presented in section 7.5 the decision on which safety stock method is used per segment can be redesigned. Section 7.5 proved that the new segmentation concept from section 6.4 performs better compared to Hilti's safety stock guidelines and to the current situation. Furthermore, the segmented safety stock analysis showed that a segmented approach regarding the safety stock method selection is more beneficial in terms of inventory costs and performance. There is also a differentiation observed between warehouses with long (> 10 working days) and short (≤ 10 working days) replenishment lead times. Another observation is that when the demand from a SKU has a seasonal pattern the calculation of the average demand during lead time and the variation of the demand during lead time should follow the seasonal pattern as well. Hence, the following decision matrix (Figure 37) can be designed for choosing the right safety stock method within Hilti. Furthermore, when a SKU has seasonal demand there is no need for a new safety stock method as proposed in section 5.3.3.

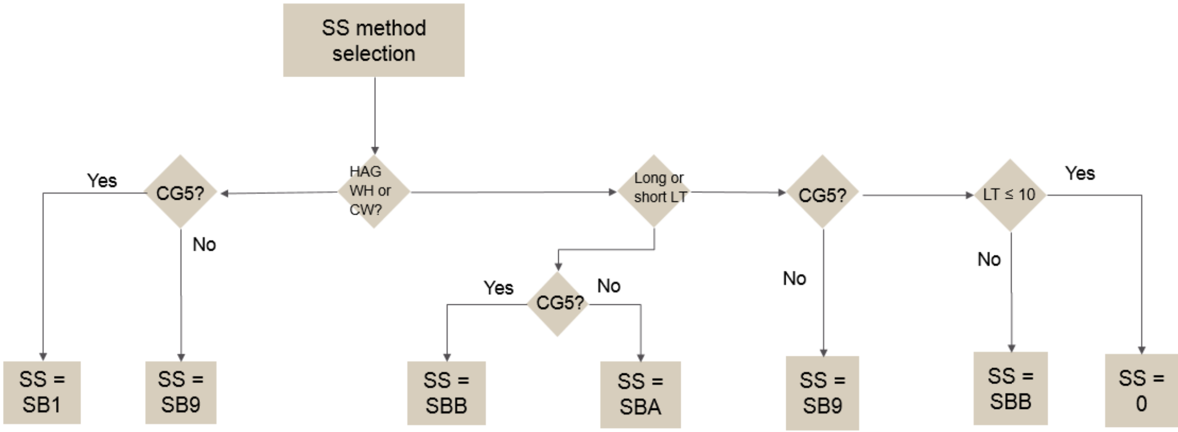

Figure 37 - Redesigned decision tree safety stock methods

8. Implementation

Regarding the segmentation technique presented in section 6.3 it is relative easy to implement for companies which have already an ABC classification system in combination with order frequency, because it requires from a system perspective less effort to change the ERP system. Also, for defining the CGs in a situation where products are segmented by a 3-by-3 matrix, the presented technique is easy to implement since it requires no changes in the way on how to define the CGs. However, when implementing an ABC classification technique, one should be careful with the class sizes. Hence, a sensitivity analysis on the class sizes is needed in order to find the (near) optimal solution. Furthermore, in our analysis relative class boundaries are used for the order frequency. Hence, this approach is less situation specific compared to absolute class boundaries. Although, a sensitivity analysis on the class sizes is again needed in order to determine a (near) optimal solution.

Also, the holistic concept presented in 6.5 is applicable for other companies since it is quite common from a marketing perspective that companies define certain stages for the product life cycle. Consequently, the guidelines presented for new products with regards to forecasting a suitable in other situations as well. The guidelines for each CG, however, are less generic and are more specified to the situation of this case study. For instance, the selection of the MRP-type for each CG are too specific for the current situation. Other companies might have another strategy for MRP-types or are not using a MRP-structure at all. Moreover, in Hilti's case it is straightforward to apply a daily review period regarding inventory due to the ERP system. For instance, Bacchetti et al. (2013) proposed different review periods per class due to the lack of an advanced ERP system. Hence, attention should be paid to the review periods when implementing such concept in other companies. At last, a different strategy is needed for the phase-out method when one is dealing with spare parts. Normal SKUs have a relatively short phase-out time (i.e., six months up to one year), whereas Papadopoulos (2017) showed that for spare parts in phase-out are still supplied for approximately 15-20 years. Hence, the current specified guidelines for Hilti might not be suitable for other companies.

In Hilti's situation it is also easy to implement since there are already 15 classes available. Hence, no significant changes are needed in the ERP system and the service level targets be can be changed accordingly. Although, the change of absolute threshold values for the order frequency to relative threshold values take quite some time (approximately six months) since it is a SAP R/3 change. Furthermore, for implementing the holistic concept, a communication plan (PowerPoint) and training to the stakeholders is sufficient, since currently existing terms and strategies are used in the segmentation concept as well (e.g., the MRP-type structure and the Product life cycle).

9. Conclusions

By the analysis that is performed in this study the research questions mentioned in chapter 3 can be answered. Hence, this chapter discusses the main findings and provides the answers of the research questions. In this master thesis there are two main research questions:

Main research question 1:

How should the holistic segmentation concept be designed for Hilti's end-to-end supply chain in order to achieve lower inventory costs and a higher service level?

Main research question 2:

How to improve Hilti's safety stock methods in the end-to-end supply chain by considering a segmented approach?

Main research question can be answered by using sub research questions 1-3. These questions are answered in chapter 4 and 5. Chapter 5 provides the current situation regarding existing segmentation concepts. Simultaneously, the gap between literature and the current situation is discussed. Based on this case study, we can conclude that the available guidelines for MRP-type selection, safety stock methods, service level targets, and lot sizing are not related to the main segmentation concept, i.e., the TABCD-XYZ analysis. While literature suggests having a differentiated strategy for inventory control based on, for example an ABC segmentation technique. Hence, in general a company should strive for guidelines based on the segmentation concept on the highest level. For instance, setting service level targets per segment based on an aggregated performance is important for reducing inventory costs. Chapter 6 showed that it is in any case important to set higher service levels for inexpensive fast-moving items compared to expensive slow-moving items. Compared to the current situation in the case study, a cost reduction of more than 20% can be achieved for an aggregated service level target by applying this approach. Hence, when (re-)designing a segmentation concept, it is recommended to include order frequency on a relative scale in the segmentation concept. Subsequently, when a quantitative segmentation technique consists of for instance 9 or 15 classes, it is recommended to use cluster groups in order to reduce the number of classes to 5 (as proposed in this case study) and, therefore, increase the manageability of the segmentation technique. Besides the strategy of setting service levels per segment, it is recommended to give more attention to the class sizes. For instance, when one is using a classical ABC segmentation technique, the size of class A should be reconsidered. When the class size is too large, it will affect the aggregated performance, since inexpensive fast-moving items are then classified as expensive. When one is segmenting based on the order frequency, the class size of the fast-moving products is of importance. For high service levels (≥95%) the class size should not be too large, because then expensive slow-moving product are classified as fast-moving. This results in high service levels targets, and consequently, higher inventory costs. In case of Hilti's situation, the class size of the T/A segment should not exceed 10% of the total SKUs. While for the fast-moving SKUs (i.e., segment X), the class size should be approximately 63%. Furthermore, when designing a holistic segmentation concept, other factors need to be included as well. Therefore, a quantitative method should be combined in qualitative method (i.e., a Hierarchical Process). In such case one can also set guidelines based on the product life cycle status of a SKU (Bacchetti et al., 2013), and if necessary, include other factors as well. Based on this case study, the product life cycle status of an SKU is included as well. Furthermore, lead time (either short or long) plays a role in deciding to use safety stock or not for expensive slow-moving items (CG5) as confirmed in chapter 7.

Main research question 2 is answered in chapter 7. Hence, the safety stock methods can be improved by applying a segmented approach based on the holistic segmentation concept presented in chapter 6. When a company is using different safety stock methods it is, based on this case study, recommended to differentiate between central warehouses and local warehouses, long and short replenishment lead times, and seasonality. In cases when one is dealing central warehouses and local warehouses and limited storage capacity in the factories, it is important to have always safety stock based on forecasted demand in the central warehouse. Particularly for Hilti this means to use the SB1 safety stock method for SKUs in CG5 in warehouse 0550. Furthermore, when one is resupplying a local warehouse with a long replenishment lead time (within Hilti > 10 days) it is important to keep an amount of safety stock for the inexpensive and expensive slow-moving items as well. Furthermore, for a long replenishment lead time it is recommended to use a safety stock method that incorporates lead time variability and demand variability. In case of Hilti this means to use in general the SBA safety stock method, except for the CG5. For this CG it is recommended to use the SBB method, such that the inventory costs will not be too high. If the replenishment lead time to a local warehouse is short, one is advised to apply no safety stock method for expensive slow-moving items with a short lead time (i.e., CG5 with short lead time within Hilti). Regarding the effect of the demand distribution on the safety stock calculation compared to the assumption of normal distributed demand are relatively small in this case study. The biggest impact is observed when the replenishment lead time is long (+1.4% increase in fill rate).

Regarding the seasonal approach (Herrin, 2005), the effect of a different demand distribution in the safety stock calculation (i.e., gamma vs. normal distribution) is negligible as well. While according to a distribution fitting procedure, the demand was more likely gamma distributed. This effect was observed where the order quantity was equal to ±130. Furthermore, the numerical analysis showed that a seasonal approach in calculating the safety has a positive effect on the service level to the customer and on the inventory costs. However, it is sensitive to the fixed handling costs and to price of the product. For instance, when the price of the product is high, the holding cost will increase. When the handling cost is fixed for all SKUs, it will have less impact on the total costs and vice versa. Within Hilti, the handling costs have more impact on the performance, due to low handling cost. Simultaneously, it showed that the order quantity needs to be optimized accordingly and that the backordering cost have the highest impact due to high service level target setting. Hence, this seasonal approach is beneficial for Hilti and has a high potential since the cost reduction is approximately more than 35%. This method also results in a safety stock that follows the seasonal pattern.

9.1. Limitations and further research

This study has also some limitations, which can be further investigated:

- The new designed segmentation approach is designed based on a case study of almost 600 SKUs in one warehouse. The number of items is randomly picked and due to small size, it might not be representative. Hence, further research is needed if the segmentation concept is valid for other markets as well. However, when conducting the analysis in another location with more items we are still convinced that similar results are obtained. That is, the order frequency plays an important role in designing a segmentation concept. This idea is also showed in Sherbrooke (1986), Teunter et al. (2010), Van Wingerden et al. (2018). Moreover, chapter 7 showed that optimizing the safety stock method based on the segmentation concept results in significant cost savings of approximately 20% for warehouses 0550 and 8150.
- A drawback of the segmentation concept is that the cluster groups are designed based on judgemental insights which is inherent to sub-optimality. For instance, one can argue that CG2 should be designed differently, because it is a combination of fast-moving items and slower-moving items. When the fast-moving items are classified in a separate segment with higher

service level compared to the slower-moving items, it might result in a better performance in terms of holding costs and service level to the customer. Hence, further research should be performed to the optimal solution of these cluster groups, or one should consider investigating 15 classes. However, the main drawback the lack of manageability.

- In the case study, the normal distribution is assumed when lead variance is known. However, there was no information available for fitting the lead time distribution. Hence, when the lead time follows a different distribution, the analysis is less accurate. Although, when it turns out that the lead time is, for instance, gamma or lognormal distributed in general, the results regarding the segmentation would not differ. There will be primarily a difference in the inventory costs compared to the situation where lead time is normal distributed. Differences occur when there is a clear variety of lead time distributions. Hence, further analysis is needed for determining the lead time distribution.
- The Teunter's cost criterion is simplified due to the relationship of backordering costs and holding costs. Which resulted in a worse performance of Teunter's cost criterion, whereas some studies (Teunter et al., 2010; van Wingerden et al., 2018) showed that it has promising results. In case the backorder costs are not directly dependent on the price of a SKU, it is also not directly dependent on the holding costs. Therefore, it cannot be cancelled out of the equation. Consequently, Teunter's cost criterion will perform better in that way, since then stocking slow-moving items is more penalised compared to stocking fast-moving items.
- In the safety stock analysis, the order quantity is not taken into account. Hence, the results from the analysis are not optimal and safety stock can be further reduced. Considering the order quantity in the safety stock calculation will especially affect the holding costs in positive way for items with high order quantities. Although, one should consider loss functions in order to determine the safety factor k, which makes the models more complicated as well. Whereas, the main objective in this study was to investigate whether a clear segmented approach between the current safety stock methods is more effective.
- The backorder costs for analysing the seasonal safety stock are approximated due to lack of the backorder costs. In this study it turned out that the backorder costs have severe impact on the total costs, due to the high service level target. In general, when the backorder costs in practice are lower, and one optimizes the order quantity based on the EOQ, the order quantity will decrease and therefore the holding cost will decrease.
- The safety stock analysis is only conducted for three single-echelon systems. However, for such a complex supply chain as in Hilti, a multi-echelon approach would be a more interesting research direction. When applying a multi-echelon system, the reorder points for the warehouses will be more optimised due to the system approach, and consequently it will result in lower inventory costs. Simultaneously, the seasonal approach for safety stock analysis can be extended for a multi-echelon system as well.

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Appendices

Appendix I. MRP Types

MRP type	Description	Used for
ND	No active planning and forecasts used. Safety stock is possible, but not mandatory	- Obsolete items - Items into phase out - Items without any replenishment function - Indirect items
X0	Planning through APO. Mostly used in MO's, SS calculation takes place into APO	- Standard calculated items in the several MO's
X1	Planning through APO - SS calc. in R/3 - Purchase to Order (production takes place when there is a demand).	- Purchase to Order items - **Not** planned special or make to order items
X3	Planning through APO without any transmission to R/3 - Special Items	- Planned special items and MTO items
X5, X6, X7, Y0, Y5	Only used in MO's – Forecast via corporate Forecast – adjustments taken over through the HQ Material management.	- Sporadic items - Phase out - No forecast driven items on MO side.
X7	Consumption driven requirements planning with reorder point in R/3 and fill up to defined maximum stock level (Min/Max). Forecast is used only for demand review and capacity planning. The maximum stock level is based on the capacity in the plant or it is a rounding value from the EOQ calculation.	- Products with short lead time. - High volume products
X9	MRP-type used in MO's and plants where a subcontractor is needed. Items are sent to the subcontractor for assembling or packing. Thereafter, the items are sent back to the plant or warehouse.	- Items that needs to be assembled or packed at a subcontractor.
Z0	Standard definition for HQ and Plant items where the SS calculation or settings takes place in APO and overwrites the Safety Stock method in R/3.	- In-house produced items - Purchased items
Z1	Similar to MRP-type Z0, however, the safety stock is calculated or determined in R/3 and cannot be overwritten by APO.	- In-house produced items - Purchased items
Z2	Only used in HQ WH and plants. Z2 items are only produced with an existing customer order. A customer order is done in R/3 and generates automatically a production order. Forecasting is only used for demand review and capacity planning. There is no safety stock.	- MTO/PTO items.
Z3	Only used in HQ WH and plants. Consumption driven requirements planning with reorder point in R/3 and fill	- In-house items and purchased items

	up to defined maximum stock level (Min/Max). Forecast is used only for demand review and capacity planning. The maximum stock level is based on the capacity in the plant or it is a rounding value from the EOQ calculation.	o Products with continuous demand during replenishment time o Product with short lead-time (<6 days) o **Not** used for phase-out items
Z4	Similar to MRP-type Z3, however, there is no maximum stock level.	- In-house items and external purchased items o Items with short lead times (<6 days) o For some phase-out items
Z5	Only used in Plant 4. Kanban items. Consumption driven requirements planning via annual order level. The article is planned in APO. The in R/3 created order is not transmitted to APO. Articles are via Kanban either manual (Kanban cards) or E-Kanban.	- Purchased items in plant 4 o C-part (e.g., screws, labels or card boxes) o Products with short lead time (<6 days) o Products from regional suppliers with the possibility to order and deliver in a regular base. o **Not** for phase-out items
Z8	Similar to MRP-type Z4, however, a reorder point or safety stock is not needed. Hence, the safety stock or reorder point can be set to 0.	- In-house items and purchased items o Assemblies (e.g., engines, impact testers etc) o Allowed for manufacturing plants and for replenishment items.

Appendix II. Demand Cluster Groups

Several segmentation methods (see section 5.2) within Hilti uses demand and cluster groups. Therefore, it is important to elaborate more on these cluster groups. These cluster groups are originated from two variables, i.e., Order Frequency and Order Quantity Variability.

The order quantity variability is measured in the coefficient of variation (CoV). It is a ratio of the standard deviation of the orders to the mean of the orders. Furthermore, the variability is divided into three groups (i.e., U, V and W) as depicted in Figure 38. On the other hand, the order frequency is based on the number of movement documents (i.e., the number of order lines) in the last 26 weeks. Similar to the order variability, the order frequency is divided into three groups (i.e., Q, R, and S) of which the threshold values between the different groups is given in Figure 38.

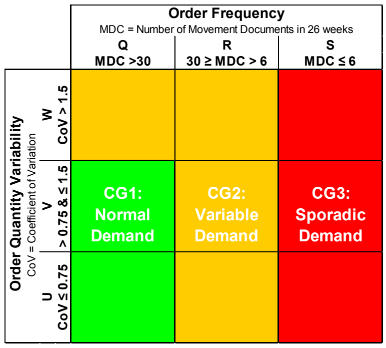

Figure 38 - Demand cluster groups

Note that this results in a 3x3 matrix and that the demand is clustered in Normal (CG1), Variable (CG2), and Sporadic (CG3) demand. These cluster groups are used in decision models for the MRP-type selection in the MO's, for whether to use the EOQ and which safety stock method to use. Note as well that the differentiation is primarily driven by the order frequency. In fact, as described in the section 5.2 one can conclude that in practice there is no difference between CG1 and CG2.

Appendix III. Data set information for segmentation modelling approach

In order to get more insight in the randomly selected data, the distribution of TABCD-items and XYZ-items is given in the figures below. It seems that a relatively small amount is T- and A-items. Furthermore, 50% of the items are fast-movers (X-items). In addition, more than 80% are MTS items (MRP-type X0), whereas the remaining items are PTO items (MRP-type X5 or X6). The dataset contains 495 SKUs.

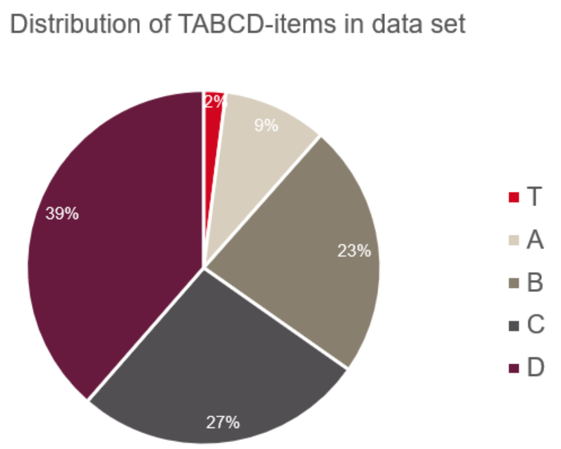

Figure 39 - Distribution of TABCD items in data set

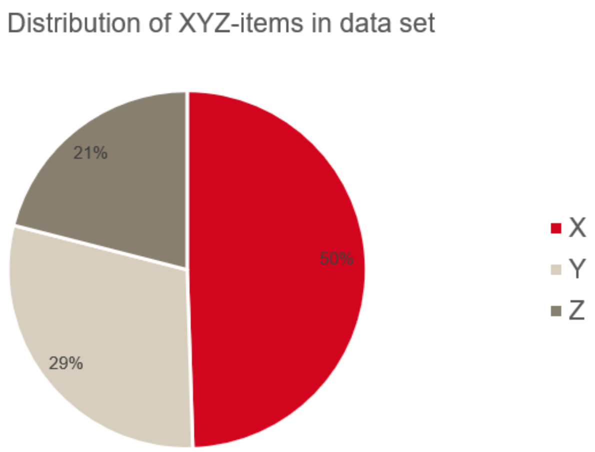

Figure 40 - Distribution of XYZ items in data set

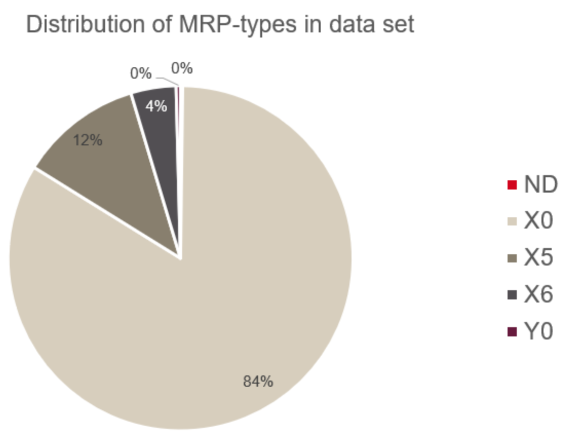

Figure 41 - distribution of MRP types in data set

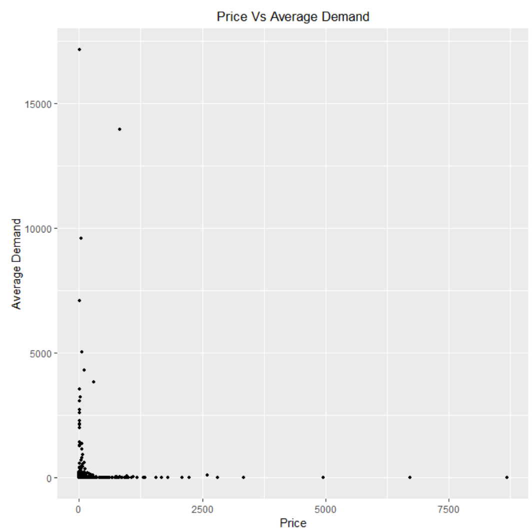

Figure 42 - Average demand compared to the price of SKUs

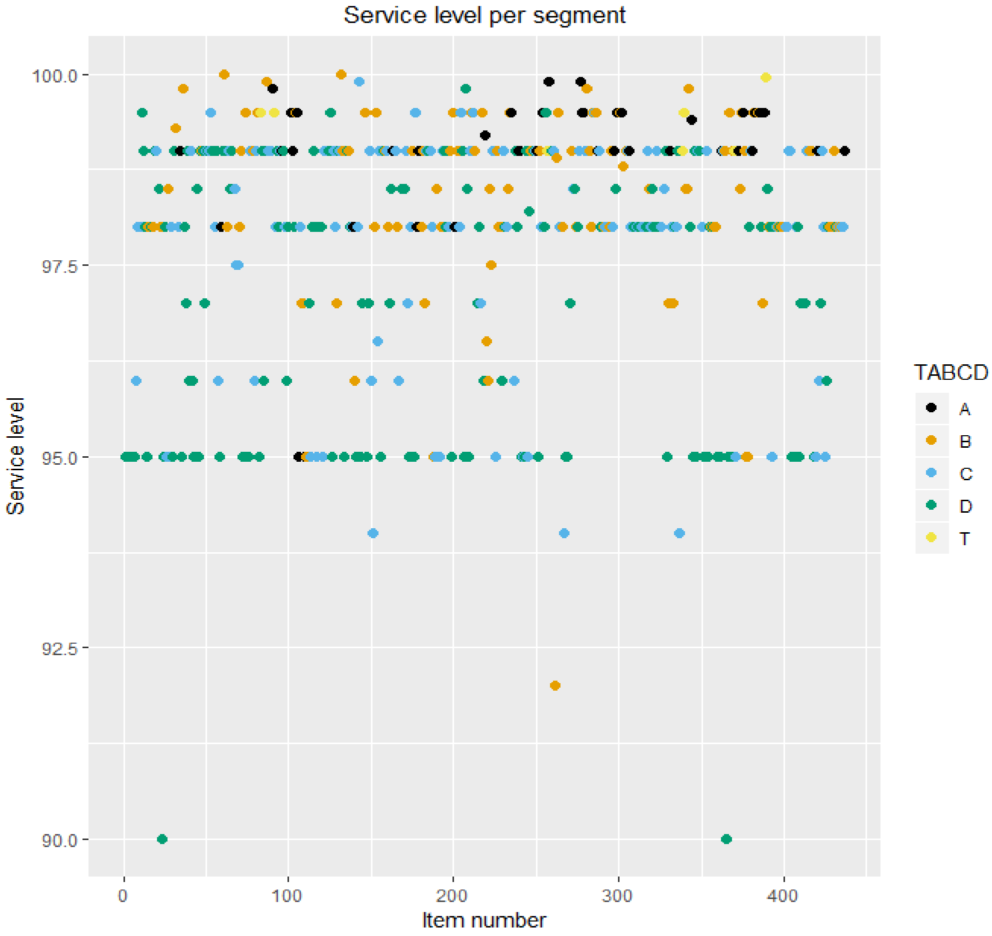

Figure 43 - Service levels according to the system in data set

Appendix IV. Figures for determining threshold values

Figure 44 gives the cumulative distribution function of the TABCD segmentation technique. Although less extreme then for Hilti's overall portfolio, it is observed that a small amount of product contributes to a large amount in revenue. Hilti currently divides its items into five clusters. In these 495 products the cut-off between T and A items seems unnecessary. From the relatively constant slope of the first 20 products it can be concluded that these products have approximately the same contribution to the total revenue and segmenting should not be necessary. During the simulation, these five segments where preserved.

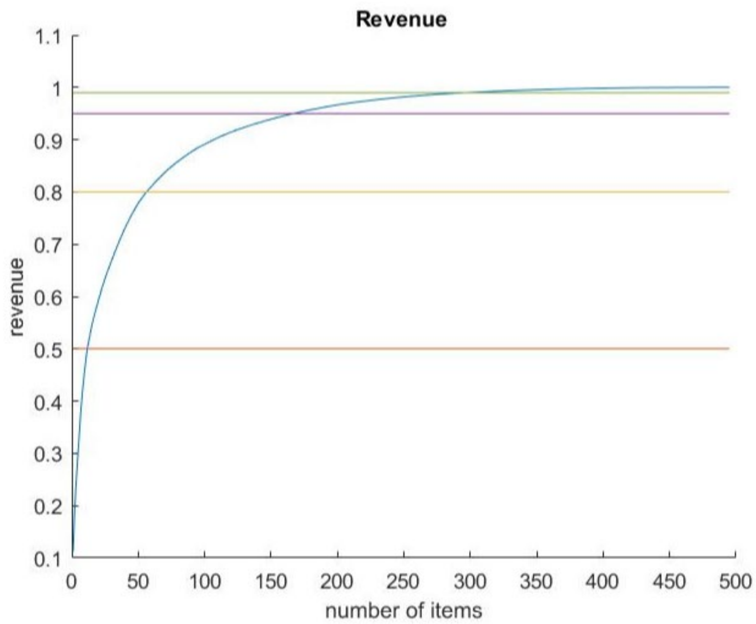

Figure 44 - TABCD in simulation data

In comparison to the previous criteria order frequency is more spread out over the 495 items. The slope of the graph is slowly decreasing without any outstanding bending points. It was chosen to classify slow movers as the slow-moving items that contributed together only for 1% of the total orders placed. This is in line with the current cluster group cut-off setting since these were products with less than 24 orders per year. However, the current cluster groups are currently defining fast movers as products with more than 60 order lines per year, in our case study this was only a very small part of the products. If we would preserve this cut-off value 65% of the products would have been classified as fast movers. Hence, we have chosen for a different cut-off, on 80% of total orders. Although the current case study only looked at 495 items, the overall high number of order lines asks for further investigation into the correct cut-off values.

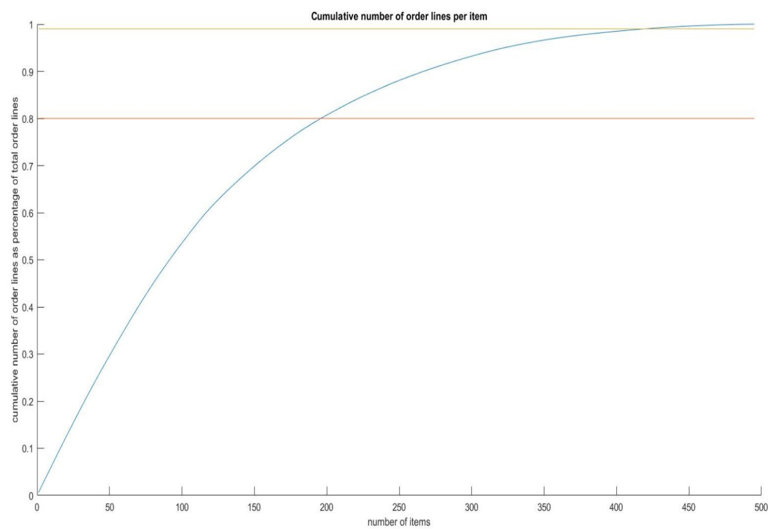

Figure 45 - Order frequency for simulation data

Order variability

From the 495 selected items RDC Oberhausen 13 items have a purchase to order policy and only 2 of the items are not kept on stock. The proposed threshold values by van Wanrooij (2012) for order variability are 0.75 and 1.33 would mean that almost 60% of the products are highly variable, see Figure 46. The threshold values of 1 and 2 where chosen instead. Further research should be conducted to determine the right cut-off values for Hilti.

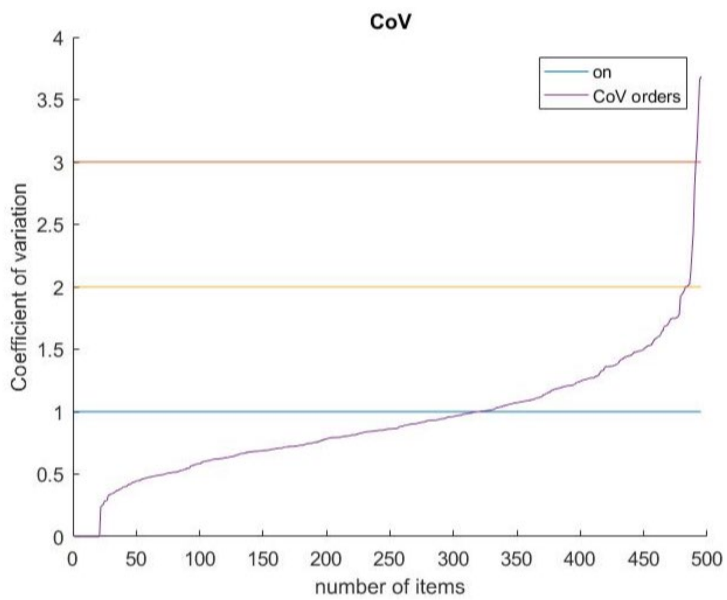

Figure 46 - Order variability for simulation data

Appendix V. Comparison fill rate, cycle service level and OFR

The order line fill rate (OFR) seems to be a more realistic case for measuring the performance in Hilti's situation. To see what the OFR exactly is and how it behaves compared to the cycle service level (CSL) and fill rate, a small example is given in Table 14. For simplicity in this example, it assumed that the average order size is equal to the demand divided by the number of lines.

Table 14 - Example of OFR compared to CSL and Fill rate

Inventory	Demand	# of Order lines	CSL	Fill rate	OFR
100	20	2	100%	100%	100%
80	40	4	100%	100%	100%
40	60	4	0%	66.6%	50%

Appendix VI. Service level settings per segmentation technique

Target service level	TABCD – XYZ		TABCD		Frequency – Variability		Frequency		Variability		Teunter's cost criterion	
	Class/CG	Service Level setting	Class/CG	Service Level setting	Class/CG	Service Level setting	Class/CG	Service Level setting	Class/CG	Service Level setting	Class/CG	Service Level setting
85%	CG1	80%	T	n.a.	CG1	60%	Q	55%	U	60%	A	60%
	CG2	55%	A	60%	CG2	50%	R	50%	V	50%	B	55%
	CG3	50%	B	60%	CG3	50%	S	50%	W	n.a.	C	50%
	CG4	n.a.	C	75%	CG4	50%						
	CG5	n.a.	D	94%	CG5	n.a.						
90%	CG1	93%	T	50%	CG1	80%	Q	75%	Q	80%	A	80%
	CG2	80%	A	65%	CG2	65%	R	60%	R	75%	B	70%
	CG3	60%	B	70%	CG3	50%	S	50%	S	n.a.	C	65%
	CG4	50%	C	85%	CG4	50%						
	CG5	n.a.	D	97%	CG5	n.a.						
95%	CG1	99%	T	55%	CG1	96%	Q	95.5%	Q	95%	A	96.5%
	CG2	96.5%	A	91%	CG2	93%	R	80%	R	92%	B	95.5%
	CG3	87%	B	96%	CG3	75%	S	80%	S	60%	C	89%
	CG4	55%	C	99%	CG4	70%						
	CG5	n.a.	D	99%	CG5	n.a.						
97%	CG1	99.5%	T	80%	CG1	99%	Q	99%	Q	99.5%	A	99.5%
	CG2	99.5%	A	99.5%	CG2	99%	R	98%	R	99.5%	B	99.5%
	CG3	98.5%	B	99.5%	CG3	99%	S	87%	S	65%	C	98%
	CG4	65%	C	99.5%	CG4	99%						
	CG5	n.a.	D	99.5%	CG5	50%						

Appendix VII. Safety stock methods within Hilti

Table 15 - Safety stock method used within Hilti

Safety stock method	Description
SB1	The simplest method which considers the average forecasted demand (μ_f) times the Safety Days or Days of Coverage (DoC). Hence, $$SS = \mu_f * Safety\ DS$$
SB5	Also, a forecasted based method similar to SB1, including statistical elements (i.e., a service factor k) and the deviation of the monthly forecast consumption over the past 12 months (MAD). $$SS = \mu_f * Safety\ DS + k * MAD * \sqrt{\frac{LT}{p}}$$
SB8	Primarily statistical based safety stock method for products with a long lead time. $$SS = k * \sqrt{MST * \sigma_D^2 + \sigma_L^2 * \mu_D^2} + \sigma_f * LT$$ Where $MST = \min\{\max(CT, 3), LT\}$ with cycle time, $CT = \frac{EOQ}{\mu_D}$ In this safety stock method average demand, standard deviation of demand and lead time are measured over the past 182 days.
SB9	Statistical based safety stock method for short lead time. $$SS = k * \sqrt{LT * \sigma_D^2 + \sigma_L^2 * \mu_D^2}$$ In this safety stock method average demand, standard deviation of demand and lead time are measured over the past 182 days.
SBA	Statistical and forecast based safety stock method $$SS = k * \frac{\sigma_D}{\mu_D} * \sqrt{LT + GR} * \mu_f$$
SBB	Consumption dependent safety stock method based on the number of items sold from the current location in period x divided by the number of order lines in period x. $$SS = \frac{Orig. Hist.(x\ months)}{Frequency(x\ months)}$$

Appendix VIII. Safety stock methods using Hilti SS segmentation

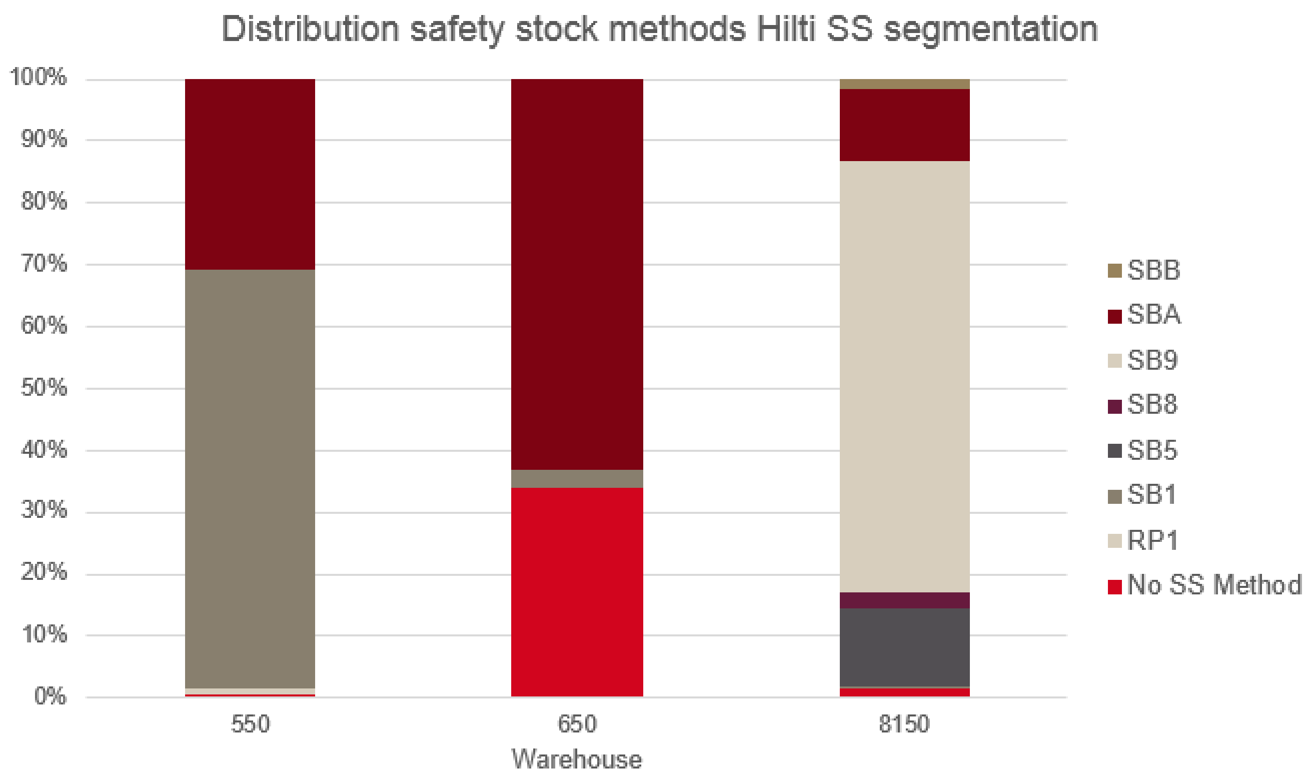

Figure 47 - Distribution of SS method when using Hilti's SS segmentation

Appendix IX. Seasonal product with weekly forecast

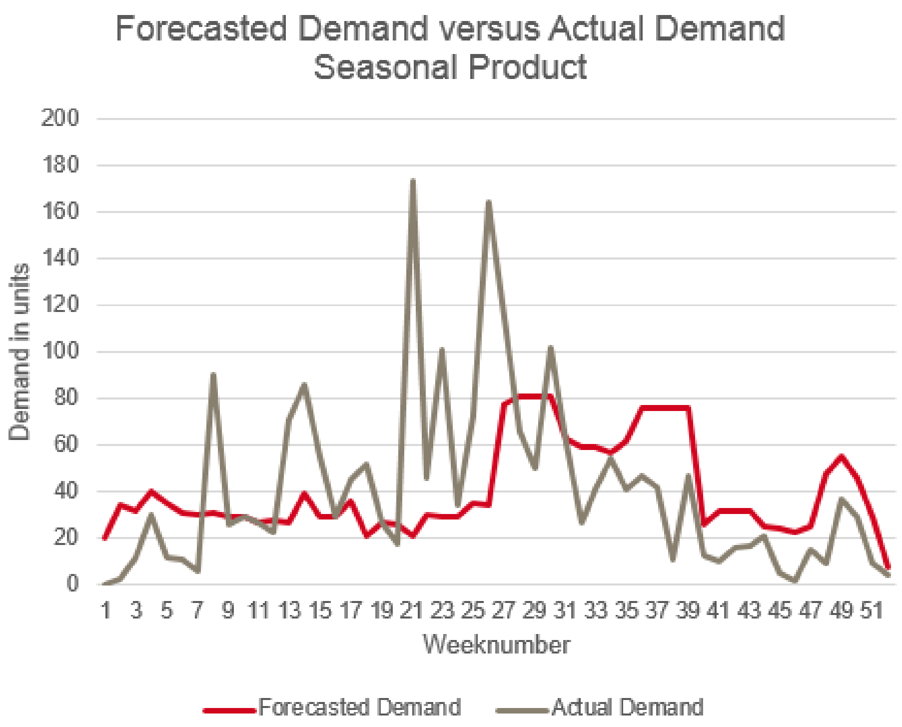

Figure 48 - Comparison real demand and forecasted demand on weekly level

Appendix X. Comparison Gamma distribution and Normal distribution

Table 16 - Comparison between normal distributed demand and gamma distributed demand

	SS new segmentation			SS new segmentation Gamma distributed		
Warehouse	**0550**	**0650**	**8150**	**0550**	**0650**	**8150**
Average IOH	12,847	2,302	1,817	14,928	2,956	2,014
Average fill rate	91.9%	84.7%	94.4%	92,5%	85,9%	94.5%
Holding costs	CHF 370,854	7,048,702	CHF 146,102	CHF 417,730	Local currency 8,714,857	CHF 156,533
SS value	CHF 168,475	5,258,455	CHF 36,073	CHF 211,124	Local currency 5,217,821	CHF 44,862
Handling costs	CHF 215,089	CHF 62,837	CHF 101,442	CHF 215,047	CHF 62,654	CHF 101,386

Appendix XI. Example of wrong categorised seasonal product

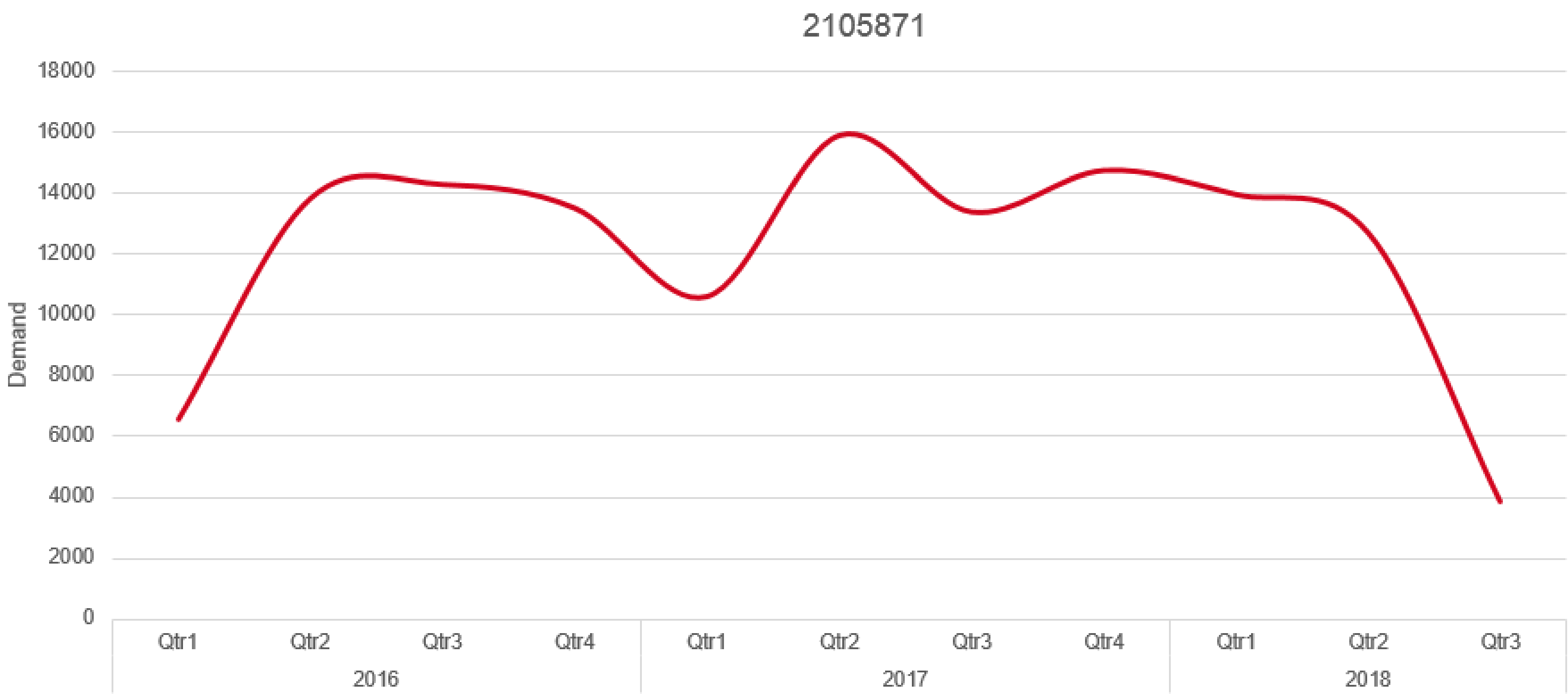

Figure 49 - Demand of item 2105871 which is categorised as seasonal