Stock Control in an Aftermarket Environment

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BACHELOR THESIS

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PREFACE

The past 4.5 months I have worked on this report at Company X in Hengelo. I would like to thank mr. X for giving me the opportunity to conduct my thesis at Company X and making me feel at home, my lovely and funny colleagues of the department SCM. I also thank my parents and friends for their support and motivation, my supervisor Matthieu van der Heijden for giving me the necessary support and even working overtime when I got stuck, and my second supervisor from university Ahmad Al Hanbali for his valuable feedback.

Enjoy reading!

Linda Nijland

Enschede,

September 5th , 2016

EXECUTIVE SUMMARY

Currently Company X thinks that they are keeping too many excess stock levels and obsolete inventory in stock. This research aimed to provide a method to assess whether keeping an item in stock is justified at all, and if so, how many should be in stock. The research was carried out for the product line 'Aftermarket', which is an umbrella group for all products that are not manufactured anymore, but still being serviced and therefore need spare parts in stock.

The presence of excess stock level and obsolete inventory is measured with Company X's Excess and Obsolete (E&O) guideline, providing calculation methods for the financial reservation on the firm's profit that is made for excess and obsolete stock. The aftermarket product line contains a total value of € xxx on E&O, which Company X wishes to reduce.

We found that the aftermarket product line is split into three different phases:

- First aftermarket stage: providing refurbishments and extensions, spare parts and generic maintenance
- Second stage: providing spare parts and generic maintenance
- Third stage: only obliged to provide generic maintenance

And that E&O occurs most in the first aftermarket stage. We continued to conduct a root cause analysis and found four root causes, responsible 20.18% of aftermarket obsolescence, which we decided to further investigate on how they can be improved: overestimated demand in last time buys, responsible for about €xxx, deliberately high amounts stocked to guarantee availability (€xxx) or reduce start-up costs (€xxx) and too high minimum order sizes (€xxx).

The research continued to examine how a method could be provided to assess whether the stocking of an item is justified, and found three key factors that justify (E&O) service spare parts to be kept in inventory if either of them is fulfilled: non-reproducibility, criticality and items of which the replenishment lead time is longer than the allowed maximum response time by the customer (LLTs).

We then analysed Company X's demand data to determine what inventory models or forecasting methods are suitable, and discovered that the vast majority 98% of demand was not suitable for a regular inventory model, as leads time occur without demand due to intermittent demand. Therefore we searched literature to find a forecasting method suitable for intermittent demand, and found Croston's method.

For the four root causes we also did a literature study and found Moore's method for forecasting demand in last time buys, and derived a method from the Economic Order Quantity (EOQ) method to compare what service level is established if Company X would reduce the order size for items put in stock in high quantities deliberately to guarantee availability, and how costs can be compared by ordering a larger amount for a lower unit price, to ordering a smaller amount for a higher unit price.

We then continued to validate the proposed methods, starting with the developed decision model. We started with presenting the decision model's outcomes about stocking an item or not to Company X's service supply chain analyst (SCA), and found that the model accurately determines the right items to

stock. The model also identified that the high E&O value in the first stage of aftermarket is partly due to the stocking of items that Company X should not keep in stock.

Moore's method for forecasting the necessary size for last time buys could not be validated due to a lack of data. More historical demand is needed to successfully determine the size of a last time buy. Also Croston's method was also not validated properly, as we were only able to test it for two items due to the limited time for this research. The method should be tested on more items to fully test its usefulness.

At last we tested the method for comparing order sizes and prices on an item with a high minimum order size and an item that was stocked deliberately to reduce start-up costs. For the minimum order size we found that Company X could still establish a 96.3% service level by ordering 23 units instead of the minimum order size of 100. The unit price is then allowed to rise from €40.50 to €183.91, so renegotiating the unit price for 23 units to below €183.91 will provide the company a profit. For the item put in stock deliberately at an amount of 40 we found that ordering 7 units still establishes a 94.88% service level, but would have saved the company €11,286.46 over three years time, minus three times the start-up costs, which we were unable to retrieve.

We recommend Company X to put both the decision model and the method for comparing order sizes into operation, as the first has proven to be valid and the latter gives at least a good indication on the consequences of ordering a certain amount for a certain order price. To fully operate the decision model, data needs to be gathered on each item on its non-reproducibility, criticality and lead time related to customer expectations of replenishment.

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LIST OF ABBREVIATIONS AND TERMS

E&O	Excess and Obsolete
SCA	Supply Chain Analyst
FFF	From fit function
LLT	Long Lead Time item
LTB	Last time buy

Frequently used terms

Baan	Company X's ERP system Baan
System failure	Failure of a system at the customers' site, for which Company X's emergency service has to be present within 4 hours
Critical	Items that can cause a system failure or significant safety issues for which the system has to be shut down until the item is replaced
LLT	Item which lead time is longer than the maximum time allowed to replenish by the customer
Non-reproducibility	When it is not possible to reproduce an item, for instance when the supplier decides to quit offering the item (purchasing items) or Company X itself is not able produce the item anymore

1 INTRODUCTION

- Confidential

This introductory chapter describes the context and motivation for this research. Section 1.1 will describe the history of Company X and its position in the switchgear market. Section 1.2. describes the problem definition and section 1.3 defines the research objective.

1.1 RESEARCH CONTEXT

1.1.1 Company X

- Confidential

1.1.2 Company X's Products

- Confidential

1.2 PROBLEM DESCRIPTION

Company X's products are durable goods: they have a life time of over 40 years. Therefore service activities take up a significant amount of the company's activities. To guarantee on-time service, Company X holds service spare parts in stock. Company X's product portfolio contains 24 active product lines that are offered after-sales services and another 47 lines in aftermarket: products that have left the active stage but still are being serviced.

Cohen et al. (2006) argue that inventory kept to enable these after-sales service activities, need different forecasting and control methods than inventory of products in manufacturing. They estimate the inventory turns of an after-sales services supply chain to be one to four a year, whereas manufacturing inventory turns about six to 50 a year. Slow inventory turnovers are likely to become in conflict with the Excess and Obsolete (E&O) guideline: items that meet the E&O specifications defined in this guideline are considered to be overstock, harming the company's profit.

1.2.1. Company X's E&O Policy

Company X's Excess and Obsolete or E&O guideline is a financial policy stating that all operating units, in this case the Hengelo unit, must financially provide for shrinkage, obsolescence and excess inventory in the inventory allowance accounts. This provision eventually decreases the unit's profit, and therefore a decrease in E&O inventory is desirable. In this section it is reviewed what kinds of stock Company X defines to be contributing to the level of E&O inventory on hand, and what financial impacts are concerned.

Company X distinguishes three different types of E&O inventory: technical obsolete, obsolete and excess items in stock. Parts that are neither are called courant, which means that they have sufficient usage and non-excessive stock levels. Below, detailed definitions are given of how the E&O value of each of these types is calculated. A complete description can be found in Company X's financial policy, which is included in Appendix 1.

Technical obsolete
Technical obsolete items are replaced by a new, modernized or improved quality release, making the old ones superfluous. Usually this happens when a new technology is found by R&D and integrated in the systems. Technical obsolete items are recognized by a mark that they are 'closed' or 'ended'. If items are ended, it is not allowed to use the stock on hand anymore. Usually this happens if an item does not passes the minimum quality or safety requirements. Closed items are allowed to use until leftover stock is gone, but purchasing new ones is not allowed. This can happen when a more modern or improved technology is found. Ended items contribute 100% of their cost price times the amount of on hand stock to the E&O value, while only 50% of the cost price of items on hand is added for closed items.

Obsolete
Besides technical obsolete items, there are also items that are just obsolete. These items are at least three years old, and did not had any usage in the past year. Obsolete items also contribute 100% of their cost price multiplied by the amount of items on hand, to the E&O value.

Excess
When items are not considered obsolete or technical obsolete, items are checked for another type of E&O: Excess. Items are considered excess when the physical inventory on hand is higher than the theoretical three year usage. This theoretical three year usage is calculated by taking the usage in the recent 24 months and multiplying this number by 1.5. The difference of the amount of stock on hand and the theoretical usage is then considered to be Excess inventory. If this difference in number of items is multiplied by 50% of the cost price per item we find the contribution of the item to the E&O value. This only holds for items that are older than 3 years.

When E&O items are in stock for a long period of time, and demand does not seem to attract, Supply Chain Analysts (SCAs) sometimes decide to throw away (a part of) the item inventory. This activity is named 'scrapping'. Scrapping E&O items reduces the amount of E&O on hand and therefore reduces the costs of E&O. At Company X, the Supply Chain Analysts are responsible for the scrapping of E&O parts.

1.2.2 Financial impacts of E&O Inventory
At the end of 2015, an additional value of € xxx was added to E&O, on top of the E&O items already on hand from previous years. This corresponds to a 0.7% of the sales volume in the same year.

E&O Forecast
For three upcoming months, Company X conducts a forecast on what part of its items is likely to become E&O. The E&O forecast is computed as the sum of the financial provisions given to the expected items on hand that meet the requirements of the E&O guideline. Updating this forecast includes forecasting what items will become E&O in the upcoming months, and what E&O items will change to courant due to usage in the upcoming months. The current on hand E&O stock is valued at € xxx.

E&O on hand in April 2016
To examine in what kind of E&O troubles are centered, we have analyzed the data of the E&O forecast in April 2016, which results are shown in table 1. We first assessed the 'normal' value of stock in each category and the number of items in each category, meaning that for excess items the normal value

includes the part of the stock level that does not exceeds the theoretical three year usage, as the whole stock level is marked excess as soon as the theoretical usage is exceeded with 1 item that actually is excess. Also all present stock that is marked as technical obsolete was multiplied by the full cost price, regardless closed or ended. The normal value is therefore just the amount in stock multiplied by the full cost price for each item categorized by one of the four E&O classifications.

Then we derived the sum of all E&O values. As expected, the E&O value for obsolete items is the same as the normal stock value, as the whole amount of present stock for each obsolete item is multiplied by the full cost price. The excess value turned out to be much lower than the normal stock value, but this is also logical as only the amount that exceeds the three year usage boundary is multiplied by 50% of the cost price and added to the E&O value.

The E&O value for technical obsolete was split up in a E&O value for both closed and ended items. We then found that Company X could have reduced the level of E&O by € x by just scrapping ended items in stock. For confidentiality reasons, only the number of items considered as courant or E&O are shown.

	Number of items
Courant	13048
Excess	1929
Obsolete	4093
Techn. Obsolete	43
Closed	26
Ended	17
Total	19,113

Table 1 Stock on hand in April 2016

At this point in time, the majority of inventory is classified as courant. As can be seen in table 1, the majority of the E&O value is centered in items that are considered obsolete, followed by excess and technical obsolete relatively. But relating these values to the number of items that they come from, we see that technical obsolete items have the highest E&O value per item type. But as technical obsolete does not have a large share in the total E&O value, we will proceed to focus our research on excess and obsolete items.

1.2.2 Problem Statement

Company X aims to keep the E&O value as low as possible, but lacks clear insight in how it can best manage inventory to prevent items of becoming E&O. Therefore the following problem statement is defined:

Problem statement
'*Currently Company X considers the value of E&O stock on hand to be too high. There is a need for insight in to what extent Company X can prevent items of becoming E&O, and if prevention is possible, how Company X should do it.*'

1.3 Research Objective and Approach

E&O appears in all of Company X's product lines. As these product lines are numerous and different in factors as life cycle stage, application and complexity, Company X indicated that it wanted to start with the aftermarket product line, taking all three types of E&O into account. This product line consists of multiple products of which production has terminated, but services and spare parts are still being offered. Therefore we will name items related to aftermarket service activities ‘aftermarket service spare parts’, or briefly just ‘service spare parts’, as we will not take any active product lines into account anymore.

Earlier was mentioned that aftersales services supply chains require a different inventory control strategy. Due to the low inventory turnovers in aftermarket in comparison with manufacturing supply chains, it contains more slow movers and therefore is more sensitive for obsolescence. Another reason is that the department Supply Chain Management (SCM) wonders if all the inventory of slow moving service spare parts is justified: ‘Do we really need it to be available? In these quantities?’ Also declining demand patterns are very common in aftermarket, which hardens the choice of an appropriate order size. Company X currently does not have any rules or methods to regulate inventory in these cases. Declining demand patterns moreover increase excess stock levels and obsolescence. For these reasons, Company X chose to focus this research on the aftermarket product line.

The following main research question has been developed in order to reduce E&O in aftermarket:

Main research question
‘What determines if an item is necessary to stock and what methods of demand forecasting and order-sizing, can be applied to reduce E&O items in aftermarket?’

To answer this main research question, the following research questions were developed:

1. How can the current situation and practices be described and what factors are involved in the high aftermarket E&O value?

    Before we dig into what is currently causing the high aftermarket E&O value, the second chapter will examine first how aftermarket services are structured, how corresponding information flows go through the different divisions of the company and who are involved in decision-making about aftermarket materials management.

    Once this information is gathered, we continue by searching for factors that are involved in the high aftermarket E&O value. Current E&O inventory data will be analyzed for root causes, experts will be interviewed on their experience with aftermarket E&O, and the relative importance of Excess, Obsolete and Technical Obsolete will be assessed.

    In summary, the first research question can be further divided into the following subquestions:

    - How are services in aftermarket structured?
    - What information flows are considered with aftermarket services?
    - Who are involved in decision-making about aftermarket materials management?
    - What root causes play a role in items becoming E&O in aftermarket?
    - What factors do experts consider to be involved in aftermarket items becoming E&O?
    - How are Excess, Obsolete and Technical Obsolete divided over aftermarket E&O inventory?

These issues will be addressed in chapter 2.

2. How can Company X determine which parts should be- and which parts don't have to be stocked in aftermarket?

   Based on the exposed root causes and problems concerned with decision-making in aftermarket materials management, a decision model will be developed in the third chapter for determining what items should be stocked in aftermarket, and which should not. To do this, parameters have been proposed to SCAs that filter out the items that are necessary to stock. For items that do get the conclusion of being necessary to stock, the decision model will be expanded to decide what kind of inventory model fits with the type of demand. These issues will be addressed in chapter 3.

3. What are frequently occurring demand patterns in aftermarket and which of them are involved in the high E&O level?

   Before we start analyzing literature on what methods on forecasting and order sizing are available to reduce excessive stock levels and obsolescence in aftermarket, Company X's aftermarket data will be analyzed and classified. From these classifications we will consequently look for methods that fit with the occurring demand patterns in aftermarket. These issues will be addressed in chapter 4.

4. What demand methods are available for service spare parts management in literature?

   Now that we are able to determine which parts should be stocked and which shouldn't, we continue to investigate what inventory models and methods of forecasting can be applied to Company X's aftermarket inventory. This will be done by a literature study. Furthermore, inventory control methods will be selected that fit with the by the decision making model specified demand types. The literature study can be found in chapter four. These issues will be addressed in chapter 5.

5. Are the proposed models and methods valid for Company X's situation?

   In order to assess the validity of the decision making model and forecasting methods data needs to be gathered on demands of aftermarket items. A test will be run on a selection of Company X's aftermarket items with available data, to check whether our developed decision model justifies the stocking of items currently in inventory. Demand forecasting methods will be validated by checking their predictions with real occurrences of demand, and by comparing them with the forecasts that Company X currently is conducting. We will examine order sizes of previously ordered now E&O items, and compare them to what order size would be recommended by our models. These issues will be addressed in chapter 6.

6. How should the redesigned process be implemented?

   The last chapter will be about what Company X should do to implement the findings of this research. Recommendations will be given for acquiring necessary information and data. Also suggestions will be done for integrating methods in current procedures. These issues will be addressed in chapter 7.

1.3.1. Research limitations

The research encounters some limitations, namely:

- The decision making model selecting the items to stock should, in all time, give priority to Service if Service and E&O interests conflict.
- The E&O level should be reduced by improved logistical performance, not by increased scrapping.

Before starting the research, some assumptions were agreed upon by the researcher (Linda Nijland) and Manager Materials (Mr. X):

- Item lead times and cost prices can considered to be fixed.
- Information in ERP system BAAN, including minimum order sizes and lead times, can be considered to be up-to-date
- Stock levels, counted at the yearly Wall to Wall, can considered to be correct.
- Rules for determining a part as either excess, obsolete, or technical obsolete cannot be changed.
- Sometimes customers store spare parts on their location at own initiative. Thus, sometimes they are able to independently conduct repair activities. In this research we don't take this into account.

More assumptions will be done later on, this will be indicated when the situation occurs.

2 How can the current situation and practices be described and what factors are involved in the high aftermarket E&O value?

In this chapter an answer will be formulated to the first research question 'How can the current situation and practices be described and what factors are involved in the high aftermarket E&O value?' In order to do so, first Company X's policies for services in aftermarket will be addressed. Secondly, a more detailed view of E&O in aftermarket in respect to other product lines will be given. At last, root causes for E&O items were determined by data analysis and interviews.

2.1 The aftermarket process

Aftermarket products are the responsibility of the department Services and Aftermarket. The department offers services and solutions to Company X customers. At Services and Aftermarket, processes differ from those in manufacturing. Although for aftermarket products production has terminated, still some production takes place in the service workshop, but only new switches, retrofits, extensions and transition panels are built[1]. Whereas a complete switchgear installation can contain over ten panels, extensions do usually not contain more than one. This subsection will take a closer look on how aftermarket service activities are organized, what stakeholders are involved and how material information flows through the company.

2.1.1 Warranties and service contracts

When Company X sells an installation to a customer, it comes with a warranty. When the one year warranty has expired, customers will be offered a service contract. In the service contracts Company X makes agreements with the customers about response times, prices and spare part availability. The contract mentions that when Company X detects defect parts at maintenance activities, it is up to them to assess the necessity of replacing the item. They also define spare parts as: 'conventional repair- and spare parts for Company X products that are still manufactured on regular basis'. The most important finding from examining the service contract is that Company X is obliged to be present in 4 hours in case of a system failure. Remark that this definition does not hold for aftermarket products, for which the contract refers to the product support policy (Appendix 3 and 4). The most important finding in the analysis of the product support policy is Company X's 3 different stages in aftermarket, which will be addressed in more detail in the next section.

2.1.2 Structure of aftermarket services

In general, Company X's products can be easily put into one of the stages of the product life cycle. Aftermarket products are in the decline stage: the focus is on delivering services, spare parts and occasionally extensions, retrofits and transition panels. For convenience, we will just name these types of services as 'extensions' from now on.

Company X has further divided the decline stage in three other stages: aftermarket stage 1, aftermarket stage 2 and obsolete, see figure 3.

[1] A schematic representation of these service types can be found in Appendix 2

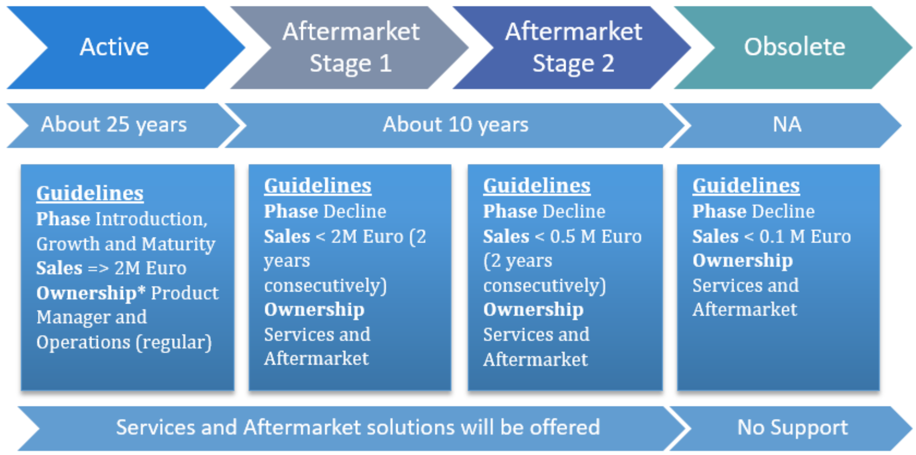

Figure 1 Aftermarket product lifecycle

Aftermarket stage 1 The product line ownership is transferred from the product manager and Operations to Services and Aftermarket. In this stage repairs and maintenance are offered. No new clients are accepted, but extensions and modifications, retrofits and transition panels, for existing customers are manufactured.

Retrofit solutions When technology of built-in switchgear becomes outdated, Company X offers its customers the possibility to replace old switches by new ones with modern technology. The new switch will have a longer lifetime and more functionalities.

Transition panel For modernized extensions that not fit with the standing system anymore, a transition panel is a solution.

Aftermarket stage 2 In the second aftermarket stage, extensions and modifications are not available anymore. The company keeps outdated spare parts in stock to offer all kinds of repairs and maintenance.

Obsolete / Aftermarket stage 3 In the last stage, Company X still offers specially trained technicians to conduct maintenance and repairs for which spare parts are not necessary. Availability of spare parts is not guaranteed, the situation can be described as a ‘best-can’.

At the end of the obsolete stage, the product can then be considered end-of-life. All service activities have then been terminated.

From the different stages in aftermarket, roughly three different service activities can be distinguished: the manufacturing of extensions, repairs and general maintenance. The first two categories involve the handling of spare parts, while the last only concerns the maintenance activities like greasing parts that are stuck, and checkups of how many times the installation has switched, which is an indication of the resting lifetime.

In order to get a more detailed view of what repairs involve, a field service engineer has been interviewed. From the interview 5 different types of repairs could be deduced:

1. Calamities – new installation required
   In very few cases, the power distribution system is involved in a calamity. These cases can for instance involve short circuit in main switches. If the service mechanic arrives at the site, he usually is only able to conclude that the whole installation needs to be rebuilt and replaced by a new one. Therefore, for these very unlikely situations no spare parts are stored.
2. Circuit breaker failures – new breaker required
   The second most urgent situation is when a failure occurs in a circuit breaker, as this will cause a system malfunction. If the malfunction isn't repairable by replacing spare parts, the customer's switch will be replaced by a spare. The defective switch will be returned to Company X and if possible, repaired. When not possible, Company X sometimes strips the defect switch to retrieve spare parts for other breakdown situations.
3. Item failure – spare parts required
   In some occasions a system- or switch malfunction can be solved by replacing a defective part. This usually concerns electric parts.
4. Planned or non-emergent service activities
   Some service activities, like extensions, can be planned. The customer asks for a quotation indicating a price and delivery time. Also non-emergent service activities are performed, for instance when a part breaks down that is aesthetic.
5. General maintenance – no parts required
   General maintenance involves checkups if the system is working properly, if all parts are in a good state and when needed some oiling to improve the system's functioning.

2.1.3 Stakeholders and information flows

Except for Service and Aftermarket, other stakeholders are involved as well in the process of delivering service. For the purpose of identifying stakeholders in the aftermarket processes, a flowchart with activities of stakeholders concerned with the order of an extension was constructed. The flowchart can be found in Appendix 6. As can be seen, the handling of materials starts with the prescription of department Work Preparation, from then on Supply Chain Analysts, Operational Buyers, Strategic Buyers and Warehouse are involved in materials management.

2.1.4 Warehousing

Services and Aftermarket is in the possession of its own warehouse and workshop, named CW3 in ERP system Baan. Therefore, when an item is also related to a product still in active production, it is probably stocked in more than one warehouse. If a service spare part is out of stock at the service warehouse, but when urgency is high, sometimes inventory is shared. Service mechanics working in CW3 indicated that they are not short of space. We will further limit our research by leaving this possibility of inventory sharing out.

2.2 ROOT CAUSE ANALYSIS

After analyzing the data of the E&O forecasts, we discovered that items belonging to aftermarket are divided into four different 'statistic groups', groups that describe to which category an item belongs. These are numbered 35, 36, 56 and 57. Groups 35 and 36 are corresponding to the ABC a first aftermarket stage product. Group 56 corresponds to DEF, an abbreviation for –confidential- , also a product in the first stage. While group 57 is an umbrella group for all items related to the products in the second and third stage/obsolete phase.

By selecting on these product groups, we have made an analysis of how E&O is distributed over the three different stages of aftermarket to gain insight in which stage most of E&O occurs. Table 2 was constructed for this research purposes, and shows that the majority of E&O occurs in the first stage.

Table removed for confidentiality reasons

Table 2 E&O in different stages of aftermarket

We are therefore especially interested in what is causing the high E&O level in the first stage of aftermarket. To determine wat actually is causing the E&O in both stages, we have conducted a root cause analysis on the top ten obsolete items with the highest total stock value. We chose to pick obsolete items, as table 2 showed that the vast majority of E&O in aftermarket is due to obsolescence.

The root cause analysis was conducted in the following way, we first made an overview of the item's characteristics: whether it is a purchase (ordered from a supplier) or manufacturing (produced by Company X itself) item, the availability of a supplier in case of a purchase item, the item lead time, safety stock level and minimum order size. This information was retrieved from the ERP system Baan. We then examined possible explanations as the last ordered amount being equal to the minimum order size, suggesting the minimum order size is too large, or if the current stock level was equal to the safety stock level, suggesting wrongly picked levels of safety stock. But none of the items had a safety stock level stored in Baan. The absence of a supplier could suggest the deliberately purchasing of a high amount to assure item availability in the future. From Baan it was also possible to retrieve notes stored in the system, which sometimes directly led to the root cause of an item. When uncertainty existed about the root cause, or the root cause was still unknown after assessing the available information in the ERP system, we proposed the items and their information to the manager of Service and Aftermarket. He was in some occasions able to confirm that stock was deliberately ordered in higher amounts, or provide us with a root cause that was not retrievable from information stored in Baan. After the analysis and the interviews with the manager, only four out of twenty root causes remained unknown. The root causes and their cumulative E&O impact (if found for more than one item) are presented in figure four.

At the first stage, root causes as 'Leftover stock from active stage' and 'Aborted R&D project' appear that are unlikely to occur in the second and third stage, because R&D projects are not beneficial for products that soon become end-of-life and the active stage is already over five years ago for the majority of products in stage two and three.

The root cause 'Overestimated demand in last time buy' only occurs once as root cause, but is definitely the largest contributor to the aftermarket E&O value. Root causes that occur more frequently are the deliberate stocking of higher amounts in order to reduce start-up costs for items with insufficient demand, the deliberate ordering of higher amounts than current expected demand for the upcoming year to guarantee availability in the future, minimum order sizes that are too high and incorrect prescriptions. The latter we will leave out of the scope of this research as they are human mistakes that can not be solved by improved forecasting or inventory models.

The root cause ‘High amount deliberately ordered to guarantee availability’ indicates that department Service and Aftermarket has instructed buyers or SCAs to store a larger quantity than recommended by applied inventory models or forecasts. These decisions are motivated by anxiety that the item will become more expensive or non-reproducible in the future. The same holds for items that are marked with the root cause ‘High amount stocked to reduce start-up costs but insufficient demand’, although these items will not become more expensive as Company X produces them itself, but still fear exists that the corresponding molds will become too old and unusable.

At the second stage we again find the deliberate ordering of high amounts to guarantee availability, but except for that, no root causes that are found that relate to how quantitative methods can help reducing the E&O value. PPAP order are initial orders placed to test the quality of a new item, which in this case was probably not sufficient as the item is now obsolete. The order size mistake includes an accidently ordered amount of items that was higher that the recommended order size mistake by the values stored in the ERP system Baan.

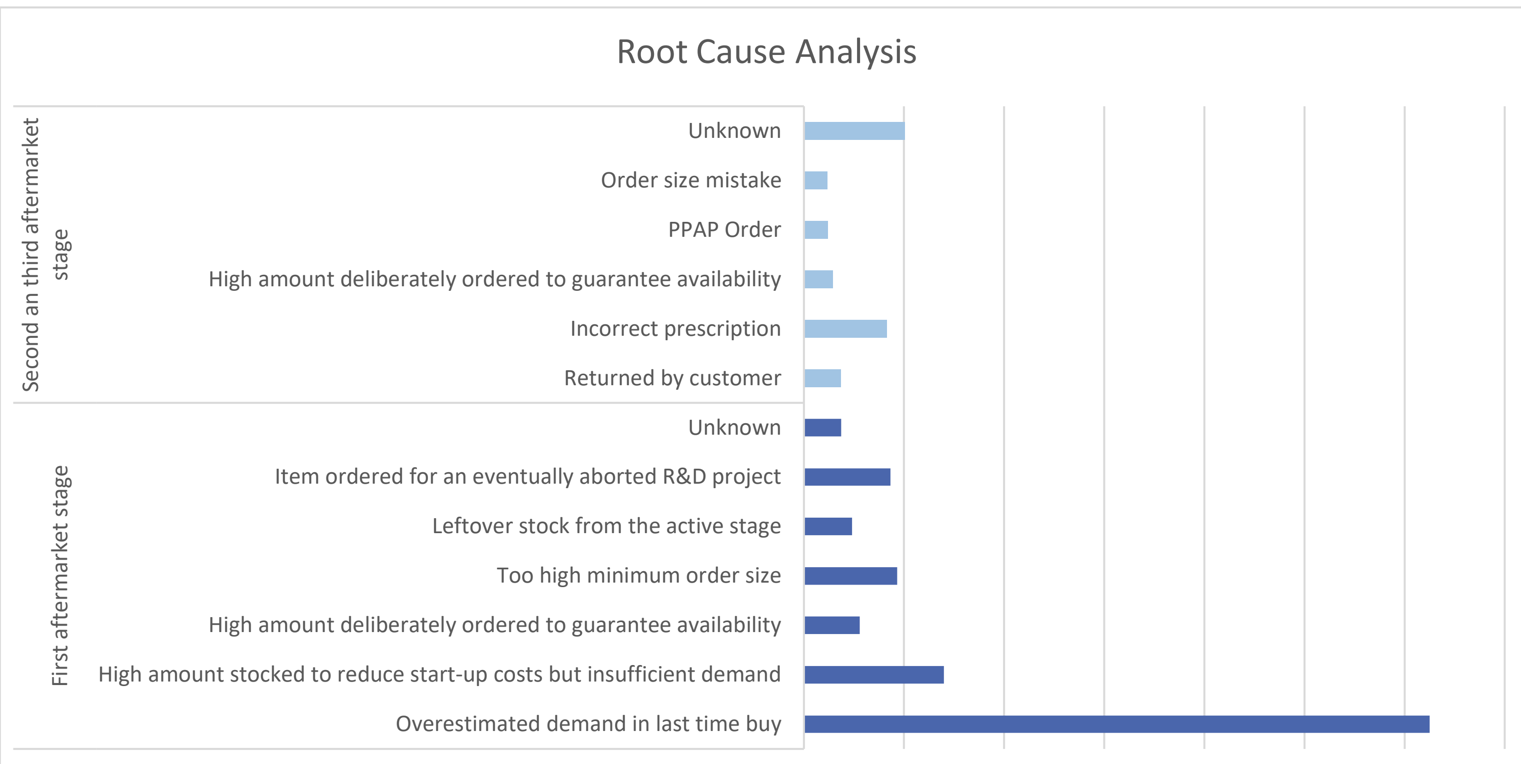

Figure 2 Root causes and E&O in different stages of aftermarket

2.2.1 Most important findings

The root cause analysis thus reveals that a relatively large share (7.5%) of aftermarket obsolescence is caused by one individual item, which root cause is an overestimated last time buy. Other root causes that were found and are responsible for the high obsolescence, are the deliberate stocking of high amounts, motivated by either the reducing of set-up costs or the guaranteeing of availability in the future, that did not match with the largely intermittent demand for that item and thus resulted in obsolescence.

It thus seems like Company X's high rate of obsolescence in aftermarket is for an important part due to troubles with order sizing. Amounts that have been ordered or produced, do not match with the intermittent type of demand and are consequently resulting in obsolescence. Availability is guaranteed with these high numbers, but Company X does not have insight in how risks of having no demand in a year relate to the risk of having a stock-out. We will thus proceed with providing Company X with methods describing how it can forecast demand, so that it is better able to adapt its order sizes to the flow of demand. We will therefore also include the root cause minimum order size.

The data retrieved from the ERP system that was necessary to determine the root causes is added in appendix 7.

2.2.2 Validity of the E&O guidelines

We determined oversized last time buys as a root cause for obsolescence, but one can question if the rules for marking an item as E&O are completely valid in each situation. When last time buys are placed, an amount is ordered to overcome demand in the remaining time until item end-of-life. When the remaining time is estimated to be over three years, the last time buy stock level is likely to be marked as excess. The complete stock level is marked as obsolete when demand lacks for a year, but this does not necessarily mean mistakes have been made when a last time buy was conducted, as lacking demand for a year does not directly means the item end-of-of life. For obsolete last time buys it would be more valid to only mark the part of the stock level as obsolete that exceeds the forecasted demand until item end of life.

2.2.3 Unexamined root causes

An important root cause that could not be examined are orders made for canceled projects. Sometimes, materials are prescribed in the ERP system for orders that are not certain yet. Consequently orders are triggered and likely to be executed by the Operational Buyers. When after a while the product order is cancelled, materials are left and likely to result in E&O.

2.3 General root causes retrieved from interviews with experts

The interviewed experts include Supply Chain Analysts, Operational- and Strategic Buyers, Manager Service and Aftermarket, Manager Materials Management and the Coordinator Service Aftermarket. Experts were asked what factors they thought are involved in a high rate of E&O for aftermarket. Their answers will be discussed per E&O category.

2.3.1 Obsolete

Decision-making Service Supply Chain Analysts remark that they get commands of Service to prevent obsolete items from being scrapped. They then register these items with the signal code 'S01'. This signaling code prevents the item inventory from being scrapped, as well as it prevents the item from being reordered. In this way, the obsolete stock will not further increase but also will never be scrapped until all inventory is gone by demand, which can take a very long while. Service argues that these items are usually very critical, i.e. a quick response is required and that they want to guarantee availability. On the SCAs side, the item is significantly contributing to E&O when it has a high cost price. This root cause relates to the deliberate ordering of high amounts that we found in the previous subchapters.

Leftover stock from active stage SCAs also argue that product transitions to aftermarket usually go in a rush, leaving insufficient time to examine what parts will be valuable for service and what stock levels will be appropriate in the aftermarket environment. This leads to insufficient reduction of stock, eventually resulting in obsolescence when the product is in aftermarket and demand is lacking.

High minimum order sizes Strategic Buyers remark that items in aftermarket are often old, outdated parts. Company X might be one of the few buyer left for such an item. From the suppliers' point of view, it might get unprofitable to still offer the item in low amounts. They therefore sometimes demand minimum order sizes. Leaving the unneeded items on the shelf, these might result in obsolescence when demand is low.

Last time buy Items bought in a last time buy, are purchased in lot sizes that are sufficient to overcome several years of service. Therefore these items are likely become obsolete when demand is very slow moving or nears end-of-life.

2.3.2 Technical Obsolete

Sudden transitions Just like the leftover stock resulting in obsolescence, introductions of new parts by R&D are often implemented quite sudden, leaving the remaining stock Technical Obsolete. SCAs argue that when Technical Obsolete needs to be reduced, more time to should be taken to decrease old stock before introducing new parts.

Unfitting releases Even though new releases on an item are based on Form Fit Function (FFF), sometimes several releases are made on an item. Having so many releases, more and more inventory adds up, as usually only the latest release is preferred to install.

2.3.3 Excess

Low cost price items Whereas the top obsolete items have a high cost price, at Excess items are usually just large in number. SCAs admit that large orders of a relatively cheap, fast-moving items are easier approved than large overs of more expensive items or slow-moving items. Therefore insufficient structure in stock-control can lead to Excess.

Unchanged control parameters When a move to aftermarket is announced, SCAs start to change stock control parameters to reduce stock and adapt to the aftermarket environment. Unfortunately it is hard to do this properly for all items. Stock parameters sometimes remain unchanged, resulting in stock levels that are too high for aftermarket demand.

Last time buy If a last time buy item has sufficient demand to not become obsolete, the high amount of inventory will cause high levels of Excess. Though, Materials Management argues that last time buys happen to a negligible part of inventory.

Minimum order sizes When minimum order sizes demand by suppliers are higher than the theoretical 3 year usage, buying a minimum order size will result in Excess

Declining demand As the theoretical 3 year usage is based on the past two years of historical demand, declining demand patterns form a problem when the forecasts are not accurate or not taken into account when buying.

2.4 The current E&O value

The introductory chapter showed that the E&O value of current stock on hand is € xxx This value is the sum of the E&O values for all of Company X's product lines. Each product line can be considered as the set of items related to one product that Company X sells separately from others. An exception on this definition is the aftermarket product line, which consists of multiple products that are not sold anymore, but still are serviced. Table 3 shows how the E&O value is distributed over the aftermarket- and the active product lines.

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Table 3 E&O in active and aftermarket products

The table shows that the majority of E&O results from active products. Yet, Company X still prefers to do further research in the category of aftermarket products, as the portfolio of aftermarket products contains less products than the active portfolio, but the aftermarket E&O value nears the value of the active products.

The table also shows that E&O costs in aftermarket are mostly due to obsolete items. Only a small part of the E&O items is considered Technical Obsolete. Therefore we will pay more attention to slow demand forecasting methods for avoiding obsolescence and order sizing strategies to avoid excess stock levels.

2.5 Conclusions

In this chapter we tried to find answers to the question 'How can the current situation and practices be described and what factors are involved in the high aftermarket E&O value?' We found out that the services that are offered in aftermarket are structured in three aftermarket stages, with the first stage offering extensions and modifications, while in the second stage only spare parts rest and the third phase nears the product end-of-life only obliged to offer generic maintenance.

We concluded that relevant stakeholders in aftermarket materials management are Work Preparation, Supply Chain Analysts, Operational Buyers, Strategic Buyers and Warehouse, but the decision-making about stocking an item or not is primarily done by the SCAs and Service and Aftermarket.

During the root cause analysis based on information retrieved from ERP system Baan, several root causes were identified. For obsolete items, the most important include:

- Overestimated demand in last time buys
- High minimum series demanded by suppliers for items with very low and intermittent demand
- Higher order series in order to reduce start-up costs for manufacturing items or guarantee availability

The latter is motivated by a fear of not being able to deliver in the future when demand occurs and the item needs to be serviced within the 4 hour time limit included in the service contract. The difference between a last time buy and the ordering of a high amount to guarantee availability is that the first is demanded by suppliers while the latter is motivated by Company X's employees itself, and therefore mainly concerns in-house manufacturing items.

From interviews with experts (SCAs, Service and Aftermarket, Buyers) additional root causes were retrieved for items becoming obsolete, as well as excess or technical obsolete. The retrieved root causes from the ERP system are recognized by the experts, although they do not all agree that obsolete items in stock to guarantee availability in the future, or large numbers in stock to reduce set-up costs, are having a bad effect on the company.

Analyzing Company X's data on E&O, the majority of E&O seems to occur in the active stage. Even though, Materials Management prefers to focus on aftermarket, as it is more complex to reduce E&O in this stage due to the increase of importance of decision making factors as criticality and the increased occurrence of slow demand. The latter is confirmed by the high degree of obsolete that occurs in aftermarket. To a lesser extent, also excess occurs in aftermarket, which is mostly due to the combination of large orders and declining demand, according to SCAs. Technical Obsolete items do not seem to cause major issues in aftermarket E&O.

As minimum order series also play a role in excess inventory levels, we will include this root cause in the decision model in the next chapter. Also a way of distinguishing critical items from non-critical needs to be defined, as Company X is now stocking too many of items it considers critical, for which it wants to guarantee availability, but has not a clear definition for criticality. We consequently need to gain insight in how many stock is sufficient to reach a certain service level for items that are critical. As the oversized last time buy also caused a lot of E&O, we will look at the conditions in which a last time buy really needs to be done or if alternatives are available, and when the one or the other is more beneficial for Company X.

3 How can Company X determine which parts should be- and which do not have to be stocked in aftermarket?

In the previous chapter, we identified several root causes for E&O items. In this chapter, a decision-making model will be developed to help Company X decide which items it shouldn't stock to avoid E&O, and if it should be stocked, then in which quantities. In this method, the identified root causes will be incorporated. The model is presented in figure 5 in the upcoming subchapters the structure and decisions of the model will be explained.

3.1 The developed decision-making model

The form of the developed decision model is a decision tree. A decision tree seemed appropriate as it is easy to understand. SCAs indicated that they are willing to use a decision model when they can fully understand it, and agree to how the model is established. Therefore, the Analytical Hierarchy Process was rejected as it is not transparent enough. Another decision making model that has been studied for usefulness is the 'Algemene Bedrijfskundige Probleemaanpak' (ABP). The ABP is easy to understand, but eventually got rejected by its nature of comparing several different possibilities by 'scoring' them on multiple criteria. Scoring criteria such as reproducibility, which is either yes or no, did not seem appropriate. An item must be able to follow a decision-making path, i.e. if the item is not reproducible, no form fit function is available but we still need it, then stock it. The AHP method was also rejected because it, just like ABP, uses scoring.

3.2 Item selection – what parts are necessary to stock?

From the interviews held with experts from Service and the examination of root causes, three main reasons for deliberately stocking an item were found, namely: non-reproducibility, criticality and long lead times. In this subchapter, we will further discuss these topics.

3.2.1 Non-reproducible parts

Sometimes, a supplier decides to stop offering an item that is necessary to conduct services agreed upon with customers. Another possibility is when Company X is manufacturing the item itself, but the mold becomes unusable. The item is then said to be 'non-reproducible', and Company X should decide if it wants to do a last time buy (LTB): placing a final order which quantity is sufficiently large to overcome the time until the products' end-of-life. Estimating this quantity is hard and thus prone to errors, but other options, like searching for a Form Fit Function (FFF), are available. Especially when the required financial investment in a LTB is high, FFFs can be an outcome. In agreement with Company X's service SCA, we decided that it is more beneficial to look for a FFF when the required financial investment in a last time buy is higher than € 2000.

The search for a FFF is not always necessary or placing an LTB. In case the current stock level is sufficient to overcome the time until the expiring of the service agreements or if the item is not really necessary to meet contract agreements. The latter can be the case when for instance the product is in aftermarket stage 3, but Company X still has some spare parts in stock.

3.2.2 Critical items

Another situation where Company X is obliged to keep items in stock is due to contract agreements in the case of system failures. Company X agrees to be present at the customers' location in four hours in case of a system failure. Service engineers remark that in a several cases the failure is easy to fix if the right spare parts are available. Therefore we make a distinction between these 'critical' parts that are involved in the functioning of the installed base installations and therefore need a high degree of availability, and cosmetic parts that are not.

3.2.3 Long Lead Time items (LLTs)

Breakdowns of parts that are not considered critical, still can cause severe damage to customers' installations. Service engineers remarked that for instance the breakdown of a simple LED can cause significant safety risks. For such items Company X should decide, depending on the lead time and demands of customers, whether it wants to keep some amount of (safety) stock, or if the lead time is considered to be sufficiently small to order on demand. Captured in a formula, Company X should still stock the item if the replenishment lead time exceeds the maximum response time allowed by customers:

$$Replenishment\ leadtime \geq Maximum\ response\ time\ allowed\ by\ customer$$

We will name items that meet this statement 'Long Lead Time' items, abbreviated as LLTs.

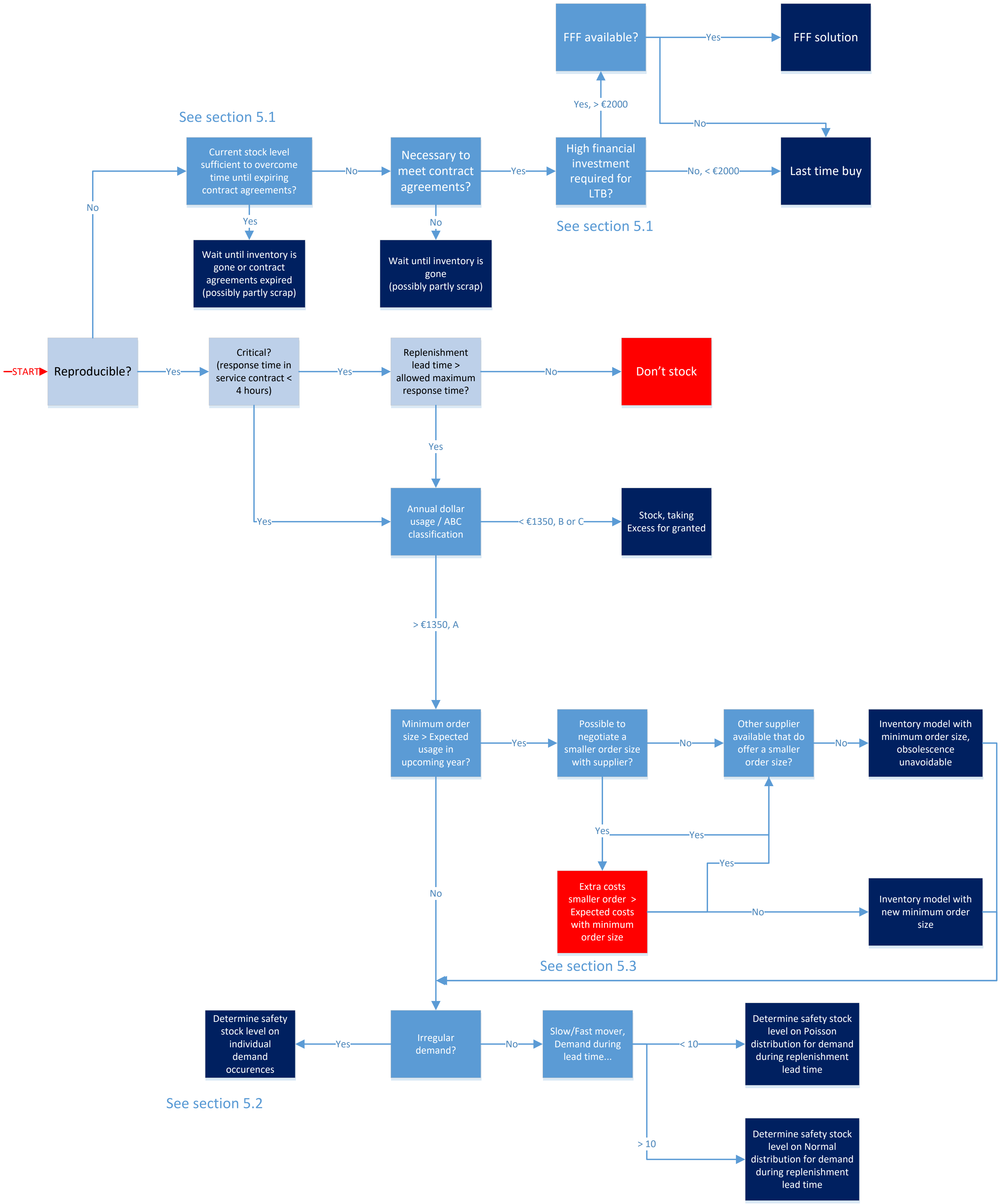

Figure 3 Decision model for stocking an item or not

3.2.4 Parts that shouldn't be in stock

In summary, we have found three situations in which Company X is advised to maintain inventory, even if considered E&O, for:

- Non-reproducible parts
- Critical items
- LLTs

Therefore, parts that shouldn't be in stock include parts that are solely related to the building of extensions, as Company X is then allowed to set the delivery time itself and therefore is able to plan the buying of involved materials. Examples include parts that are only used when building very specific extensions, circuit breakers or transition panels with low demand that are likely to result in E&O. Of course, also parts of which the lead time does not exceeds the allowed maximum response time limit, shouldn't be present in stock.

3.3 Materials management in case of non-reproducibility

Now that we have defined the characteristics of spare parts that are recommended to be kept in stock, we will go on to investigate how inventory can best be managed to avoid high levels of E&O.

3.3.1 For non-reproducible parts

When an item becomes non-reproducible, the decision whether to do a last time buy depends on the current stock level and the expected demand until the items manually set end-of-life, which is the end of the first or second aftermarket stage. If the current stock level is sufficient, there is no need to do a last time buy, Company X even might needs to scrap. But when the current stock level is not sufficient, Company X should consider the importance of the item. If the item is of low importance, Company X is best off with waiting for the left stock to be gone or the service obligation to expire.

When the item is considered important, Company X must secure the availability of the item. Placing a last time buy is only an attractive solution if the costs of the buy and the expected holding costs are not that large. If they are, Company X should look for an alternative FFF item.

Assessing item importance

When an item is critical, thus necessary to the functioning of the installations, it is obviously important and availability must be guaranteed. But in other situations the importance of an item is harder to determine. From interviews, another class between functional and cosmetic was derived: items related to safety. For most break downs of items enabling safe handling of the switchgear, service engineers usually can have a temporary solution on hand quite quickly. This will make the customer more willing to wait a while for the spare to arrive. But in the case of non-reproducibility a LTB or FFF still can be required, although the item is not functional. Therefore for these type of items must be classified by engineers with technical know-how as either critical, LLT or non-urgent.

Another case when items are not functional but a LTB or FFF is still required is when non-reproducibility occurs in the first aftermarket stage and the item is related to building extensions. Company X promises in its product support policy to offer extensions until a pre-set point in time, i.e. the end of aftermarket stage one. Consider for instance a very specific washer: it cannot cause a system failure or break down, but it is very important to the building of extensions. Company X should then still look for a FFF or LTB when there is not enough in stock to overcome the time until the end of the first aftermarket stage.

3.4 Materials management for critical items and LLTs

When Company X has decided an item should be kept in stock but the item is still reproducible, LTBs are not required. Company X must then decide about a suitable inventory policy and safety stock levels.

3.4.1 Simple and complex inventory models

In this part, the complexity of the applied inventory model and the level of safety stock depend on the importance of the individual item. For critical items a high level of safety stock is justified, as Company X does not want to have a high risk of running out of stock for these items and consequently losing customer devotion.

A complex inventory model is also justified for items with a high annual dollar usage: items that are concerned with a lot of money may be not that important to the customer, but the more to the company. To achieve a good financial performance in materials management, of which E&O is one of the parameters, expensive items require a more sophisticated inventory model.

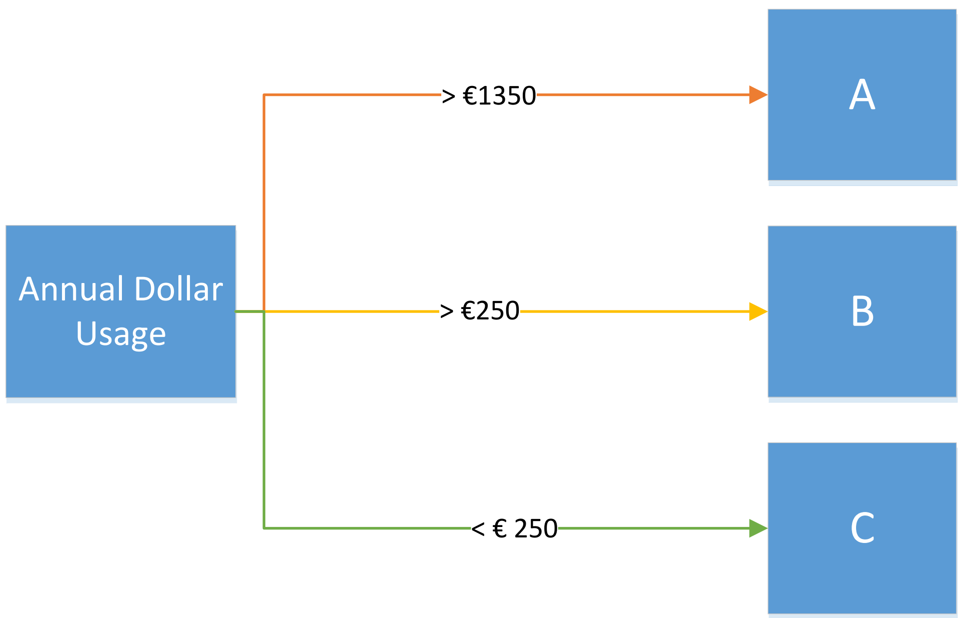

Figure 4 Decision model for ABC classification

Silver et al. (1998) write about ABC classification: based on annual dollar usage the upper 5% is named to be an A- item. Items with an annual dollar usage between the upper 5- and 20% are considered as B-items while the rest, 80%, is marked as a C- item. Figure 6 shows a schematically overview and exact cutoff values that were retrieved from Company X's aftermarket data. Appendix 9 shows a plot of Company X's annual aftermarket usages. Silver et al. also stress that items that are critical need to be directed to the A classification automatically, even when their annual usage is low. We decided to drop this rule, as in Company X's case it wants to guarantee availability for critical items, and if not much money is involved you would not want to take the risk of your safety stock level being insufficient if the keeping of a large amount guaranteeing an 100% service level is not that expensive.

In agreement with the Service SCA we decided that items classified as B or C can be held in stock directly, while for A items, that go with an annual usage of larger than € 1350, we will check upon the minimum order size and use a more sophisticated inventory model.

3.4.2 Check for minimum order size

Minimum order sizes exceeding the expected usage in the upcoming year were determined as one of the root causes for obsolete items. Therefore it was decided to incorporate an extra 'branch' in the decision tree model to create more attention of the analysts or buyers before they order the minimum order size if it exceeds the prospected usage in the upcoming year.

The impacts of minimum order sizes on obsolescence can be reduced by negotiating a smaller order size with the supplier or selecting another supplier that is willing to deliver smaller order sizes. As the order size gets smaller, suppliers usually demand a higher cost price per unit. Later on, in the literature section, methods will be proposed that enable Company X to examine which of the two options is more profitable.

3.4.3 Demand type

When examining the demand patterns of the top 10 obsolete items in the previous chapter, we discovered that it is not uncommon for items to have very few records of usage per year, or having no demand for a year at all. This is likely to result in items sometimes having no demand during lead time, making it unable to apply inventory models. Safety stock levels have to be determined for each demand occurrence individually. This sort of items will be named 'irregular demand items'.

3.4.4 Selection of demand distribution for inventory models

For items having regular demand and for which a more complex inventory model is justified, a distribution for demand needs to be selected. Silver et al. (1998) advise to use the Poisson distribution for items with less than ten units demand during lead time, and the normal distribution for items with higher demand.

3.4.5 Incorporation of identified root causes

The incorporation of identified root causes last time buys and minimum order sizes in the decision model is quite clear. Other root causes that are less obvious incorporated or not at all in the model are lot sizing, item cost prices, root causes for technical obsolete, negative trends and leftover stock from the active stage.

Lot sizing

The root cause analysis revealed that Company X employees disagree about quantities to be ordered. Although the real trade off seems to be between the ensuring of availability (Service and Aftermarket) versus the downside of high stock levels resulting in E&O (Supply Chain), there does not seem to be a method agreed upon how a lot size can be determined that satisfies both parties. In the next chapter methods found in literature will be presented for determining the optimal lot size.

Cost price per unit

Items with a high cost price per unit require a more sophisticated inventory policy than do items with a low cost price. But as demand for high cost price items sometimes occur only once a year in little quantities while low cost price items may occur every time time-unit in large quantities, it was decided that the annual dollar usage was a better criteria to decide about a high- or low control inventory model.

Technical obsolescence

One might have noted that both found root causes for technical obsolete items, sudden transitions and unfitting releases, are not incorporated in the model. Unfitting releases were not found to be a major issue in aftermarket: only two items were marked as technical obsolete. Furthermore we let it up to further research to change policy in sudden introductions of new items, as there is limited time for this research.

Declining demand patterns

Items showing a significant negative trend in demand need other forecast models and floating safety stock levels. Negative trends are not incorporate in the decision model as they do not influence the decision whether to stock an item or selecting an appropriate safety stock determination method by demand pattern. Methods will be presented in the next chapter for determining the last time buy quantity assuming negative trend.

3.5 Conclusions

In this chapter we tried to find an answer to the question: How can Company X determine which parts should be- and which parts do not have to be stocked in aftermarket? From the interviews with the manager Service and Aftermarket and a service engineer, we found three main criteria:

- Non-reproducibility
- Criticality
- Long lead times (LLTs)

Where criticality is defined as a spare part that can repair a system failure, and the being of an LLT needs to be determined for each item individually.

If a service spare part meets one of these criteria, the part must be held in stock. The three criteria exclude most items that are related to first stage of aftermarket activities like the building of extensions, retrofit refurbishments and transition panels.

Options that are considered to overcome the problem of non-reproducibility include placing a last time buy and looking for a form fit function. Taking the decision not to place a last time buy for an item is justified if it is not critical/functional, the on hand stock is sufficient to overcome the time until expiring of the service contract agreement or if the investment is high. In these cases a FFF solution or not even placing a LTB at all is more attractive.

When the decision is made to stock an item for being critical or an LLT, we recommend to stock the item if its annual dollar usage is less than €1350. When it is more than €1350, a more sophisticated model is justified, and a check on the minimum order size to decrease the E&O consequences in case the item becomes obsolete.

To apply inventory models, regular demand items need to be split into slow- and fast movers. Slow movers have on average less than 10 units demand during lead time, while fast movers have more. The Poisson distribution is more suitable for slow movers while the normal distribution is a better fit for fast movers. We named items for which it is likely that no demand occurs during lead time irregular demand items.

Now that the decision model is constructed, we need to determine which of the model outcomes is concerned with the most of E&O. As we unfortunately are not able to assess the influence of last time buys, we will focus on whether demand is irregular or not, and if most demand is considered regular, if E&O is centered in models using the Poisson or normal distribution. We will thus going make an analysis of how demand behaves in aftermarket.

4 What are frequently occurring demand patterns in aftermarket and which of them are involved in the high E&O level?

In this chapter we will assess what demand patterns occur most frequently in aftermarket, so that we can look for suitable inventory management methods in the next chapter. For classifying demand we will use the Boylan & Syntetos model. Boylan & Syntetos (2009) remark that intermittent demand patterns, characterized by sequences of zero demand observations interspersed by occasional non-zero demands, are common among spare parts. When demand occurs, it may be of a highly variable size, generating ‘erraticness’. If an item is both intermittent and erratic, it is said to be ‘lumpy’.

4.1 Demand classification

Syntetos et al. (2005) propose a classification system aiming at the selection of the most appropriate demand forecasting models. In this system, four quadrants are determined based on two dimensions: demand size variability, measured by the coefficient of variation CV^2, and average demand inter-arrival (I). The coefficient of variation is calculated as $\frac{\sigma}{\bar{X}}$, an thus relates variance to the mean. In this way variabilities can be compared for different items. The system is showed in figure 6, including the cut-off values $CV^2 = 0.49$ and $I = 1.32$, which were mathematically determined and are expected to have general validity for a wide range of realistic control parameters (Bucher and Meissner, 2011). The approach was applied to a system for automotive spares by Boylan et al. (2008), who found the performance of the system to be robust to the exact choice of cut-off values.

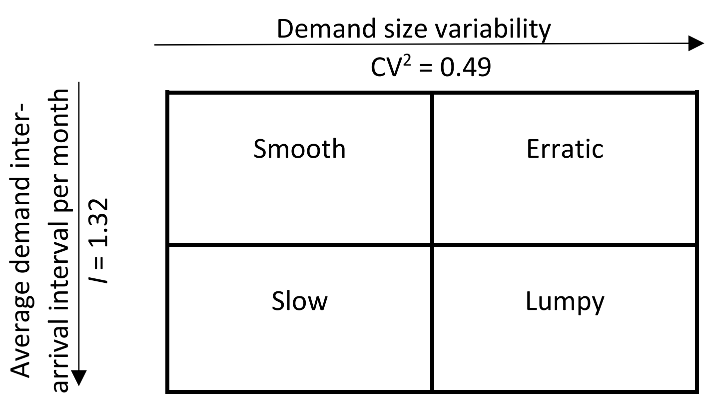

Figure 5 Syntetos and Boylan classification system

Syntetos and Boylan hereby define irregular demand as having an average demand inter-arrival of larger than 1.32, which does not always match with our applied definition of irregular demand for items that not always have demand during their lead time. Therefore the model needs to be slightly modified, which we will do later on.

4.2 Study on the demand patterns in Product ABC

To determine what forecasting and inventory models to focus on, 1807 items of Product ABC were analyzed on demand pattern by Syntetos' framework. It revealed that most of the items have a slow demand pattern, followed by a lumpy pattern. Only a small part (8%) can be considered as fast moving and therefore was classified as erratic or smooth. 19% of the leftover items could not be classified, due to having only one record of usage making it impossible to calculate the variance of demand size.

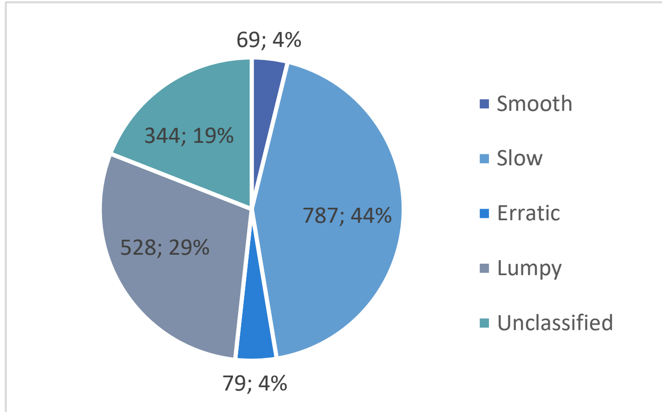

Figure 6 Demand patterns distribution

To gain insight in to what extent the demand patterns are related to E&O, items that had an E&O value were assigned to their corresponding demand pattern. We saw that largest proportion of E&O in the product line comes of slow moving items, even when compared to the total stock value. Lumpy and unclassified or non-moving patterns also take up a considerable amount of the E&O value. A negligible part of E&O is due to fast moving demand patterns as smooth and erratic. Although this seems logic as obsoletes will not occur in these classes of demand patterns, it is remarkable that even excess does not seem to play a role at all in these demand patterns.

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Figure 7 E&O and demand patterns

As can be seen in figure 8 unclassified parts are responsible for 13.5% of the total amount of E&O in the product line. For unclassified parts, all having just one record of usage in two years, it is likely that their E&O is due to a minimum or overestimated order sizes, as Company X retains the policy to only order the amount requested by the customer for these kinds of very slow moving items.

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Figure 8 Excess and obsolescence in lumpy and slow demand patterns

Items with a slow demand pattern suffer more from obsolete items in stock whereas at unclassified and lumpy patterns excess is more of a problem. Although both require a slightly different approach, with a focus on demand forecasting for obsolete and a focus on order sizing strategies for excess, we will pay attention to both in the upcoming subchapters.

Adapting the Syntetos and Boylan model to Company X's situation

Previously we have made distinction between items that do have irregular demand, and items that have not. Irregular demand depends on the occurrence of demand during replenishment lead time, indicating if an inventory model can be applied or not. The average demand interval in Syntetos and Boylans model was therefore replaced with the average demand occurrences during lead time. When every lead time at least one demand occurs on average, we classify the item as having regular demand, depending on the demand size variability consequently classified as smooth or erratic. When lead times with no demand occurrence are likely, having an average demand occurrence during lead time smaller than one, we classify the demand as irregular, and slow or lumpy depending on its variability. See figure 11.

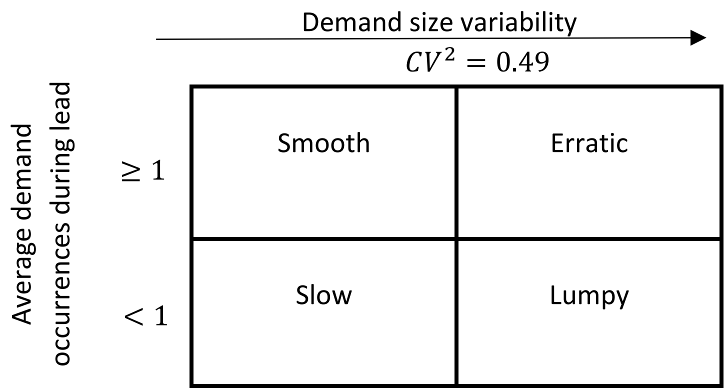

Figure 9 Modified classification system

Applying our new cut off value on the historical demand dataset, it causes even less items to be marked as smooth or erratic: only 37. The average demand occurrences during lead time was calculated by taking the ratio of the average demand inter-arrival time in months divided by the lead time in months. Therefore we remain at our conclusion that methods suitable for irregular demand have a higher priority than those for regular demand when we will search for literature in the next chapter.

4.3 Conclusions

From the conducted data analysis we can conclude that the occurrence of E&O in aftermarket is going hand in hand with slow and lumpy demand patterns. A negligible part of E&O occurs in smooth and erratic patterns, so we have to focus on intermittent demand patterns when looking for suitable methods in literature. Even when we assess the demand during lead time we find that regular inventory models cannot be applied to the aftermarket demand, as for most items have lead times in which no demand occurs are not uncommon

5 WHAT METHODS ARE AVAILABLE FOR SERVICE SPARE PART MANAGEMENT IN LITERATURE?

Once the service spare parts that need to be stocked are selected, proper inventory policies need to be selected to determine safety stock levels. This process starts with examining how demand behaves on individual SKU basis. Cohen et al. (2006) argue that for after-sales services supply chains demand is largely sporadic and unpredictable. Therefore it is not hard to imagine service spare parts having different demand patterns than parts related to manufacturing. Often, due to their different behavior of demand, standard inventory policies do not fit (in case of slow moving intermittent demand). In this chapter methods for demand forecasting for spare parts will be assed and several stock control policies will be proposed. We will zoom in on how appropriate (safety) stock levels can be determined for each branch of the decision tree.

5.1 LAST TIME BUYS FOR NON-REPRODUCIBLE PARTS

Estimating the size of a LTB is very hard. Moore (1971) provides a relatively easy model for estimating demand until item end-of-life. The model uses curve fitting and is especially suitable for aftermarket items, as it incorporates the effects of non-stationary decreasing demand.

The forecast function can be determined according to the following five steps:

1. On basis of actual annual or monthly sales data, the year of peak demand is determined.
2. For parts exhibiting sales decay, a plot of sale after the peak year against the index number of the year of those sales is obtained on a fully logarithmic (base 10) scale.
3. Consecutively, the ellipse, parabola and straight line which best fit the transformed sales data are each determined.
4. From these three 'best fits' the single best fitting curve is selected as a forecast of future service part demand.
5. The curve is transformed from the logarithmic to an arithmetic scale to provide yearly sales forecasts.

Stated in formulas, the parabola, ellipse and linear curve can be described as follows:

Parabola:

$$\hat{\delta}_t = \delta_1 - \frac{\delta_1 \lambda_t^2}{\lambda_n^2}$$

Ellipse:

$$\hat{\delta}_t = \delta_1 \sqrt{\left(\frac{\lambda_n^2 - \lambda_t^2}{\lambda_n^2}\right)}$$

Linear:

$$\hat{\delta}_t = \delta_1 - \frac{\delta_1 \lambda_t}{\lambda_n}$$

Where with $j = 1$ the peak demand period is appointed with d_j, the items usage in year j. From here, δ_j was determined, the logarithm of the usage in period j, and λ_j the logarithm from indexed year j. Then δ_j can be described as:

$\delta_j = \log(d_j)$ for j = 1,2,...K where K is the last year for which data is available
$\lambda_j = \log(j)$ for j = 1,2,...N where N is the expected year of item end-of-life

Moore discovered in his case study conducted in the automotive industry that the parabolic function usually describes demand for moderately priced essentials and several cosmetic items for higher priced vehicles. Linear decay functions were associated with a wide range of general maintenance parts while the elliptical decay function characterizes the sales decay patterns of major engines and transmission parts that are related to very expensive repairs.

5.2 Forecasting methods for critical parts and LLTs

Croston (1972) showed that exponential smoothing for items with intermittent demand results in excessive stock levels. These lumpy and slow moving parts, whereby no inventory models can be applied, require a different demand forecasting method where the two components, the time between consecutive transactions and the magnitude of individual transactions, are estimated separately. Based on Croston, Silver et al. propose

$$x_t = y_t z_t$$

where

$$y_t = \begin{cases} 1, if\ a\ transaction\ occurs \\ 0, \qquad\qquad\qquad otherwise \end{cases}$$

and z_t is the size of the transaction. Furthermore, the quantity n is defined as the number of periods between transactions and if demands in separate periods are considered independent, then the occurrence or nonoccurrence of a transaction in a period can be considered as a Bernoulli process with probability of occurrence begin $1/n$:

$$prob\ (y_t = 1) = \frac{1}{n}$$

and

$$prob\ (y_t = 0) = 1 - \frac{1}{n}$$

The following updating procedure can be applied if $x_t = 0$:

$$\begin{aligned} &1.\ transaction\ size\ estimates\ are\ not\ update \\ &2.\ \hat{n}_t = \hat{n}_{t-1} \end{aligned}$$

and if $x_t > 0$:

$$\begin{aligned} &1.\ \hat{z}_t = \alpha x_t + (1-\alpha)\hat{z}_{t-1} \\ &2.\ \hat{n}_t = \alpha n_t + (1-\alpha)\hat{n}_{t-1} \end{aligned}$$

where

$$n_t = number\ of\ periods\ since\ the\ last\ transaction$$
$$\hat{n}_t = estimated\ value\ of\ n\ at\ the\ end\ of\ period\ t$$
$$\hat{z}_t = estimate, at\ the\ end\ of\ period\ t, of\ the\ average\ transaction\ size$$

Then, after each transaction, the new forecast can be calculated by:

$$\frac{\hat{z}_t}{\hat{n}_t}$$

In contrast to exponential smoothing, in Croston's method parameters only gets updated each time demand occurs. As in the case of large inter arrival times a lot can change in demand. Our focus will be on Croston's forecasting method as the vast majority of demand is irregular.

Inventory policies for irregular demand

According to Rego, J. R. et al. (2011) the Base Stock model is one of the classic inventory models that is suitable for items with irregular demand. Base Stock (B) states that at each withdrawal from a predetermined inventory level, an order of the same amount is made to replenish the baseline, keeping the inventory position constant and equal to B. The Base Stock model is suitable for items having a low dollar usage and for which consequences are not significant when the complete base stock level would be marked as obsolete.

A special case of the Base Stock model is when the safety stock and base stock level is 1 and when variability of demand cannot be determined or is not present. Company X should then decide, if the item is critical or LLT, and to always stock the amount of one demand occurrence. Then, when demand occurs, demand can be satisfied from shelf while a new replenishment order is made.

Determining safety stock levels for irregular demand

As for irregular demand items no demand occurs during lead time and therefore no re-order point can be calculated, we define the irregular service level (ISL) using the base stock inventory policy to be:

$$ISL = 1 - \ Prob(Occuring\ demand \geq average\ demand + safety\ stock)$$

In case of irregular demand we will maintain the service level of 0.95 for critical items and a service level of 0.60 for LLTS, as a significant part of irregular demand items are 'unclassified' items, having negligible demand, of which uncertainty exists if it will ever return.

5.3 Determining optimal order quantities

For stationary demand, the optimal lot size can be calculated by the formula for the Economic Order Quantity (EOQ):

$$Q^* = \sqrt{\frac{2DS}{hC}}$$

Where

$$D = Annual\ demand\ of\ the\ product$$
$$S = Fixed\ cost\ incurred\ per\ order$$
$$C = Cost\ per\ unit$$
$$h = \ Holding\ cost\ per\ year\ as\ a\ fraction\ of\ product\ cost$$
$$Q^* = Economic\ order\ quantity$$

Unfortunately the EOQ formula cannot be applied to Company X's situation, as they deliberately do not take fixed cost incurred per order into account. Moreover it is also not known in Baan how suppliers calculate the price of an order: exact quantity discounts and set-up costs cannot be retrieved. Therefore it was decided to leave order set-up costs out of account. Consequently we assume that Company X will place one order to meet demand in the upcoming year. The total cost function, of which the EOQ formula is derived, leaving start-up costs out becomes:

$$TC = CD + \left(\frac{D}{2}\right) hC$$

In this case, D is the expected demand in the upcoming year, which can be deduced from exponential smoothing. The derivative of this formula becomes independent of D, and therefore an optimum lot size cannot be determined. When the problem is approached stochastically, an optimum must exist between the expected increase in holding costs when ordering an amount Q, and the approximate costs of running out of stock:

$$TC = CQ + \left(\frac{Q + \sum_{i=0}^{i=Q} Prob(demand = i) * (Q - i)}{2}\right) hC \; + \; kC * \sum_{j=Q}^{j=\infty} Prob(demand = j) * (j - Q)$$

Where k is the cost per stock-out unit as a fraction of product cost. In agreement with Company X's manager Materials Management and manager Service and Aftermarket it was decided to estimate k at 0.5. Stock-outs are then more than twice as expensive as keeping an item in stock for a year, as holding costs are estimated at 0.196 times the cost price a year. The formula can also be used to compare minimum order sizes with a specific cost price to a smaller order with a higher cost price per unit, as for the formula only C and Q need to be known. It is important to note that a Poisson distribution must be used for this formula, as negative demands are not allowed to occur. Only for large numbers, negative demands have little influence when a normal distribution is used. In these cases it is better to use the normal distribution instead of Poisson, as the variance can then be set based on the historical demand data, making the distribution better adapted to the real behavior of demand.

5.4 Conclusions

In this chapter we tried to find an answer to the question: What methods are available for service spare parts management in literature? We first addressed this question to non-reproducible parts, and found Moore's method of curve fitting to estimate demand until item end-of-life.

We secondly looked at forecasting methods for irregular demand items, and found Croston's method to forecast when the next demand occurrence will happen and what its size is expected to be.

At last we developed a formula that enables Company X to compare different order sizes and quantities, taking historical demand into account to retrieve a probability distribution for the next size of demand occurrence.

In the next chapter we will apply these methods to a few of Company X's in stock spare parts. to items known to be non-reproducible we will apply Moore, while Croston can be applied to any irregular demand item and the total cost function for comparing order sizes- and prices to any item stocked deliberately in high amounts.

6 ARE THE PROPOSED MODELS AND METHODS VALID FOR COMPANY X´S SITUATION?

In this chapter we will address the validity of the proposed methods found in literature for Company X's situation. The financial and E&O implications of decisions with current decision-making-, versus proposed decision-making methods will be compared. As previously mentioned this will only be done for irregular demand items, and therefore concerns Moore's method, Croston's method and the modified EOQ formula. But we will start by examining if there are differences in what items the new decision model recommends to stock, and what items are actually stocked by Company X.

6.1 VALIDATION OF THE DECISION MODEL

Before going in depth about order sizing strategies and forecasting methods, we will first validate the decision model proposed in chapter 3. To do this, we have taken 20 aftermarket items that are currently stocked and partly marked as E&O. Ten of them are first stage of aftermarket items and ten second and third stage. They all have been assessed on the three key indicators for stocking: non-reproducibility, criticality and LLTs. The results are presented in table 5 and 6, but first will be explained how non-reproducibility, criticality and long lead time-ness have been assessed.

6.1.1 Assessing non-reproducibility, criticality and LLTs

Reproducibility of an item depends on the availability of drawings, suppliers and molds. Usually when a supplier announces to quit production, buyers will search for another supplier. When they do not find one, the supplier field in Baan is cleared. After then it becomes very uncertain if the item is reproducible, as no supplier is available, capacity may not be present, and old drawings or returned molds tend to get lost. Therefore we took an empty supplier field as an indicator for non-reproducibility.

The factor criticality was harder to measure, as it had to be retrieved from service engineers with technical know-how. It eventually became clear that most consequences of critical breakdowns are system failures or a loss of control or safety on the switchgear. As mentioned in chapter two, system failures have direct consequences to the consumer(s) of power management. A loss of control is very undesirable as the end-user will not be able to for instance stop the production process. Another option that we will define as critical is when an item breaks down, that is concerned with significant safety risks for which no temporarily solution is available. This includes for instance surge arresters, when these break down, the system cannot be used anymore due to significant safety risks.

But for safety risks a temporary solution is usually on hand, making the item more suitable as LLT. This includes for instance indicator LEDs that signal if the door can be opened safely to conduct maintenance. Service engineers remark that experienced engineers even without the LED working, can deduce if it is safe to open the door, but without experience or technical know-how it is unsafe. He remarked that putting on a warning for non-engineers that they are not allowed to open the door is for most customers a satisfying solution until the ordered new item has arrived. We assign safety-risk items with temporarily solutions available therefore to the LLT class, while assigning significant safety risk items without temporarily solution to the critical class. The LLTs category therefore only contains those items that cause temporarily solvable safety issues or a decrease the user-friendliness of the system (cosmetic damage), i.e. door clinks.

Safety-risks and user friendliness are thus indicators for assessing an item as LLT. Therefore LLTs were determined depending on their application. A maximum of five working days was taken as reasonable for safety-risk LLTs while for items with decreasing user-friendliness fifteen working days was determined as upper bound.

6.1.2 Key findings for current stocking strategy for second and third stage aftermarket items

Table 5 presents that except for non-reproducible items, all items are recommended to be stocked by the decision model. Therefore the conclusion can be drawn that Company X is managing their second and third aftermarket stage inventory well. Except for the items that have an application in the product XY, for which all product support should have ended in December 2015, therefore also last time buy inventory is not recommended to maintain.

Item no.	Description	Application	Repro-ducible?	Critical?	LLT item? (lead time in working days)	Decision by model	Average stock level ´15/´16
1	Item A	Confidential	Yes	No	Yes (20)	Stock	16,5
2	Item B		Yes	Yes	Yes (20)	Stock	2
3	Item C		Yes	Yes	Yes (20)	Stock	1
4	Item D		Yes	Yes	Yes (20)	Stock	1
5	Item E		Yes	Yes	Yes (20)	Stock	1
6	Item F		No	No	No (6)	Depends	18,5 1)
7	Item G		Yes	Yes	Yes (15)	Stock	1
8	Item H		No	No	No (7)	Depends	0,5 1)
9	Item I		No	No	No (1)	Depends	1 2)
10	Item J		Yes	No	Yes (30)	Stock	1 1)

Table 4 Random sample of second and third stage aftermarket spare parts

1) XY items that should not be in stock due to expired product support
2) Item related to planned service activities

Inconsistent product support policy

Writing this thesis in July 2016, XY spare parts are still in stock, even though product support has ended. Company X mentions in the policy's notes that until the end of 2015, it has retained a limited amount of spare parts in the third stage. When examining usages of the past two years on these XY items, we found that item number 6 and 10 did not had any usage. Item eight however had 16 records of usage, but this item is used by service engineer's to conduct generic maintenance, making it a suitable item to be in stock at the third aftermarket stage.

Additional notes are not rare in Company X's policy. According to the policy, Product XYX and YXY's are second stage of aftermarket, yet planned service activities as transition panels and retrofits (refurbishments) are still offered. The XYX second stage should also have been ended in December 2015, but we still found 3 spare parts in our randomly generated selection that should have been scrapped already. At the end of July 2016, Company X published a new product support policy, where it suddenly has extended the second stage for XYX's and YXY's until January 2027. Due to these inconsistencies, it is hard for SCAs to estimate if and when items can be scrapped. Also, it hardens the last time buy calculations, as it is unclear what time interval needs to be covered.

6.1.3 Key findings for current stocking strategy for first stage aftermarket items

When we look at the results in table 6, there is less correspondence in the decision model's advice and the parts that Company X has currently stocked. For just two items inventory can directly be justified by the model. Items marked with 2) also suffer from inconsistent policy, as they are specifically needed for planned service activities, which Company X has decided to end to offer since the beginning of this year (2016).

Item no.	Description	Application	Repro-ducible?	Critical?	LLT item? (lead time in working days)	Decision by model	Average stock level ´15/´16	Excess, Obsolete or Courant
1	Item A	Confidential	Yes	Yes	Yes (40)	Stock	8	C
2	Item B		Yes	No	No (40)	Don't Stock	0,5 2)	C
3	Item C		No	No	No (8)	Depends	1 2) 3)	C
4	Item D		No	No	No (9)	Depends	0,5 2)	C
5	Item E		Yes	No	No (15)	Don't Stock	3,935 2)	O
6	Item F		Yes	No	No (25)	Don't stock	4,5 2)	E
7	Item G		Yes	No	No (8)	Don't stock	37 2)	E
8	Item H		Yes	No	No (5)	Don't stock	7 2)	O
9	Item I		Yes	No	No (20)	Don't stock	5,5 2)	C
10	Item J		Yes	Yes	Yes (40)	Stock	986,125	E

Table 5 Decision model validation for first stage aftermarket items

2) Item related to planned service activities

3) Item contains a signaling code of ended usage

Although washers and braces are very general parts that can also be used in other systems, XYXX must be their main customer as they are all registered under XYXX's statistic group. Furthermore we found one item marked with 3) that contains a signaling code dictating that the item is ended and therefore is not allowed to be used anymore. Therefore it should have been scrapped. From table 6 we draw the conclusion that in the first stage of aftermarket a lot of unnecessary stock occurs. Apparently, including planned service activities makes it harder to manage stock effectively.

6.1.4 SCA's feedback on decisions by model

When the results of the decision model were discussed with Company X's service SCA, he announced that he agrees to the majority of the model's outcomes. Most items that were marked as critical by the decision model, were also marked as critical by the SCA that has installed the item parameters. The SCA could recognize this by an installed safety stock level. But still some problems arise with the decision model.

The service SCA did not agree with our used definition of a manufacturing item being non-reproducible when no supplier was entered in Baan. He argued that for the majority of manufacturing items no stand by supplier is available, and that it depends on the underlying parts from which the item is manufactured if the item is non-reproducible. Therefore, he argues, it is not good to take an empty supplier field as a sign for non-reproducibility. This changes decision-model outcomes for FASEVERGEL.STOK+KOKER KR and PRIM.GEL. 1 WIND IC16 to both being critical instead of non-reproducible.

Therefore we will redefine non-reproducibility as: 'An item is non-reproducible when, in case of a purchasing item, no supplier is willing to make the item, or in case of a manufacturing item, at least one of the underlying parts cannot be ordered at a supplier anymore or produced by Company X itself.'

Another remark of the SCA is that, for B and C items, he tends to act different when the annual usage consists of the sell of one, very expensive item, than when the item has several usages over the year. He argues that the risk of demand collapsing in the next year is higher for the first case than the latter. Therefore he is less likely to stock still stock another item for the upcoming year. But as the annual dollar usage already provides an upper bound for which items can be stocked directly, so Company X does not care if stock becomes obsolete in the next year when its value is below €1350, we decided not to further modify the model.

6.1.5 Non-reproducible items

Here we will further determine what advice is retrieved from the decision model for non-reproducible items.

The first item Item AA is not considered to be able to break down at all. As for the product XY all product support is ended, the current on hand stock of 10 is all ready for scrap.

As the XYXX item Item BB is not allowed to be used anymore, it ends in the decision model as scrap. The Item CC is an ´extension item´. Extensions for XYXX are offered until 2021, therefore the decision model concludes that a FFF has to be found or a last time buy should have been done, depending on the size of the investment.

The current stock level of 1 gives the impression that no last time buy has been done. We also were not able to check if Company X has sought for FFF.

6.2 Validation of Moore for non-reproducible items

Moore will be validated by analyzing its implications for the 'Item AAA', the item we found that causes a lot of E&O in the root cause analysis of chapter two due to its performed last time buy. When the situation occurred that Company X had to do a LTB, there were 16 Item AAAs in stock. Company X then decided buy four extra, even though the demand in the previous year was only one.

We will compare the last time buy size recommended by Moore to the size Company X has bought. The second item that Moore's theorem will be applied on is the ITEM AA. The last replenishment lot will be taken as last time buy size.

6.2.1 Item AAA

The last time buy on Item AAAs has been done at 2013. Unfortunately data could only be retrieved until January 2010. It appeared that the year of peak demand occurred in 2011, having sold 35 Item AAAs. The next year only demand for one unit occurred. As only two data points are quite easy to fit a curve on, we also included the 4 units sold in 2013, even though this data was not known at the time. Other methods considered to make a better fit include the use of quarterly data, but that was no possibility as demand then becomes intermittent, causing problems with taking the logarithm. We only used the Ellipse as forecasting curve, as fitting three different types of curves would not make a significant difference when numbers are small and only three data points are available. Figure 11 shows how the forecasted demand decreases and eventually forecasts the demand in 2014 to be zero. Following this forecast. No extra Item AAA's would have been bought.

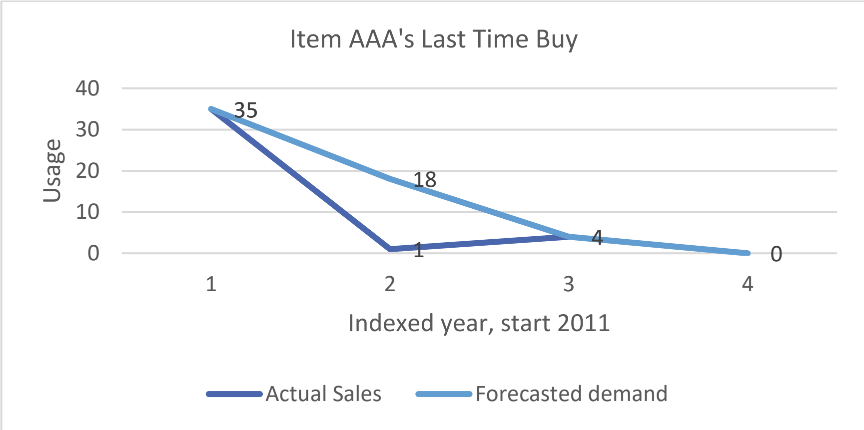

Figure 10 Moore's forecasting method applied to Item AAA

Demand actually was zero in 2014, just like in 2015. Only recently new demand occurred for Item AAA, which exact amount has not been processed in Baan yet. The unit cost price of one Item AAA is €3907, therefore Company X incurred €7657,72 (4*3907*0,196*2,5) more costs on holding- and carrying costs for buying the four extra units, than it would have done if the Moore's forecast had been followed or the decreasing nature of demand had better been taken into account. Also four times the cost price, €15.628, of E&O could have been avoided.

Company X sells its aftermarket spare parts and products with a 40% margin. The margin is assumed to cover at least all costs incurred with handling an order: man-hours, tax, carrying costs and etcetera. But selling one of the 16 Item AAAs as a spare part now, which is possible as it is a switch, after being in stock for 2,5 years, considering carrying costs alone already exceeds the 40% margin.

6.2.2 ITEM BBB

Moore has also been applied to the ITEM AA, but the same problem of having limited demand information available from peak year arose. An almost perfect fit was established through the two available data points, also resulting in a forecast of zero demand for the upcoming year.

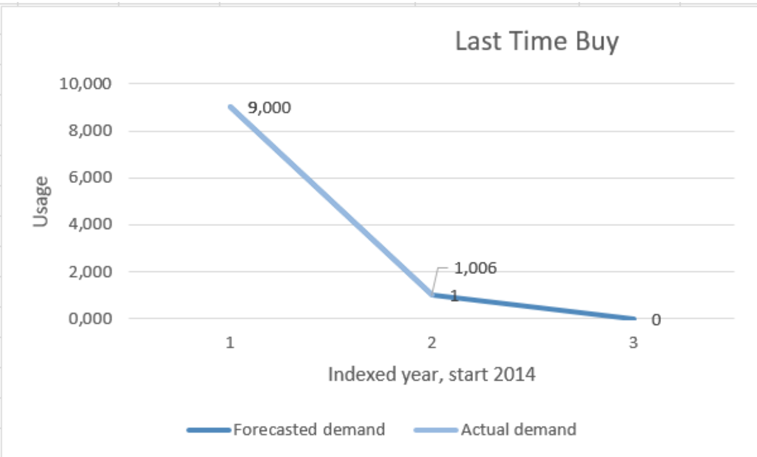

Figure 11 Last time buy ITEM BBB

Company X might also have expected demand to decrease, and therefore not placed a last time buy, but it is more likely that they did not notice the supplier field being cleared, and just waited for all stock to be gone before placing a new order.

6.3 VALIDATION OF NEW MINIMUM ORDER SERIES POLICY

In this section we will check whether the proposed calculation for comparing minimum order sizes to new negotiated order sizes with also a new cost price will be of use to Company X. For this purpose the items of the second chapter with minimum order size or decision-making determined as root cause were selected and analyzed. They include the ITEM CCC and ITEM DDD. An excel tool has been developed in which Company X is able to easily estimate expected costs at the end of the year, and compare it to other options with different order sizes and unit prices. The tool is shown in figure 14.

A	B	C	D	F	G	H	L	M	N	O	Q	R
	Historical Demand input			Calculation Shortage Costs			Calculation Obsolescence Costs					
Year 1	40	Expected demand in the upcoming year	10	Expected shortage costs			Expected obsolescence costs	/ units obsolete			EXPECTED YEARLY COSTS	
Year 2	24	Average demand (mu)	16									
Year 3	36			€		0.00	€	1,869.00	84.00		€	10,455.00
Year 4	0	Ordered amount Q_n	100	UNITS SHORT	CHANCE	SHORTAGE COST	UNITS TOO MANY	CHANCE	OBSOLESCENCE COST	UNITS OBS		
Year 5	0	Cost price per unit in €	€ 85.00	1	4.93E-46	€ 0.00	100	1.13E-07	€ 0.00	1.1E-05		
Year 6	0	Shortage cost per unit	0.5	2	7.74E-47	€ 0.00	99	1.8E-06	€ 0.00	0.00018		
Year 7	12	Inventory carrying cost per unit per year	0.25	3	1.2E-47	€ 0.00	98	1.44E-05	€ 0.03	0.00141		
Year 8		(Cycle) service level	1	4	1.85E-48	€ 0.00	97	7.68E-05	€ 0.16	0.00745		
Year 9				5	2.82E-49	€ 0.00	96	0.000307	€ 0.63	0.0295		
Year 10				6	4.25E-50	€ 0.00	95	0.000983	€ 1.99	0.09342		
Year 11				7	6.36E-51	€ 0.00	94	0.002622	€ 5.24	0.24649		
Year 12				8	9.42E-52	€ 0.00	93	0.005994	€ 11.85	0.55742		
Year 13				9	1.38E-52	€ 0.00	92	0.011987	€ 23.44	1.10285		
Year 14				10	2.01E-53	€ 0.00	91	0.021311	€ 41.21	1.93931		
Year 15				11	2.9E-54	€ 0.00	90	0.034098	€ 65.21	3.06879		
Year 16				12	4.14E-55	€ 0.00	89	0.049597	€ 93.80	4.4141		
Year 17				13	5.87E-56	€ 0.00	88	0.066129	€ 123.66	5.81934		
Year 18				14	8.23E-57	€ 0.00	87	0.081389	€ 150.47	7.08088		
Year 19				15	1.15E-57	€ 0.00	86	0.093016	€ 169.99	7.99941		
Year 20				16	1.58E-58	€ 0.00	85	0.099218	€ 179.21	8.43349		
Year 21				17	2.16E-59	€ 0.00	84	0.099218	€ 177.10	8.33427		
Year 22				18	2.93E-60	€ 0.00	83	0.093381	€ 164.70	7.75064		
Year 23				19	3.94E-61	€ 0.00	82	0.083006	€ 144.64	6.80645		
Year 24				20	5.25E-62	€ 0.00	81	0.069899	€ 120.31	5.66185		
Year 25				21	6.94E-63	€ 0.00	80	0.05592	€ 95.06	4.47356		
Year 26				22	9.11E-64	€ 0.00	79	0.042605	€ 71.52	3.36582		
Year 27				23	1.18E-64	€ 0.00	78	0.030986	€ 51.36	2.41688		
Year 28				24	1.53E-65	€ 0.00	77	0.021555	€ 35.27	1.65976		
Year 29				25	1.96E-66	€ 0.00	76	0.01437	€ 23.21	1.09213		

Figure 12 Tool for comparing order quantities

6.3.1 Minimum order size: ITEM CCC

The ITEM CCC, which from now on will be referred to as 'CCC', is an obsolete service item that is contributing € 4055.00 to the E&O value. Its cost price is €40.50 per unit and therefore currently a hundred units are in stock. The CCC is not unfamiliar with scrapping, and the high stock level is mostly due to the high minimum order size, which demands 100 units to be bought.

Based on item demand history and our proposed calculation of expected costs at end of year, a new order of 100 units will incur € 4780.30 on purchasing- and holding costs. Zero stock outs are expected to occur but 84 units are expected to remain at the end of the year, establishing a 100% service level.

Assuming the CCC is critic, a 96.3% service level is accomplished when 23 units are ordered. The break-even point is then at a unit price of €183.91, which means that there is a profit when a unit price can be negotiated that is lower. When the item is considered a LLT, a 65,9% service level is achieved when ordering 17 units. The corresponding break-even point is at €245.73. By ordering smaller amounts, the consequences are less heavy if the item becomes obsolete, and will not be seen as excess just after receiving the order.

6.3.2 Decision-making: ITEM DDD

The item ITEM DDD is a manufacturing item which is marked with the root cause 'Start-up costs' in chapter 2, is now contributing an amount of €7136.20 to the E&O value. The item, which costs € 237.87 per unit, has a current stock level of 30. The last order was placed on the 23rd of January 2012, Service then decided to manufacture 40 units to decrease start-up costs, after only having one demand record of four in the previous year.

Unsurprisingly, manufacturing an amount of 40 establishes a service level of 100%. The expected costs at the end of the year are €11,286.46. Ordering 7 units, equal to a service level of 94.88%, would have incurred €1,910.26 on costs in the first year. As the rest of demand is known until 2016, we have assumed that Company X will replenish its stock level each year to 7 units (base stock model) to keep up the 94.88% service level.

		Company X's policy		Proposed base stock policy	
	Demand	Purchasing costs	Carrying costs	Purchasing costs	Carrying costs
Beginning 2012		€ 9,514.80	€ -	€ 1,665.09	€ -
End 2012	4	€ -	€ 1,771.66	€ -	€ 233.11
2013	0	€ -	€ 1,678.41	€ 951.48	€ 326.36
2014	6	€ -	€ 1,538.54	€ -	€ 186.49
2015	0	€ -	€ 1,398.68	€ 1,427.22	€ -
Estimated stock out costs		€ -		€ 10.08	
Total		€ 15,902.09		€ 4,799.83	
E&O		€ 7,136.10		€ 1,665.09	
Total difference		€ 11,102.25			
E&O difference		€ 5,471.01			

Table 6 Comparing policies

Table 7 calculates the difference between Company X's and the proposed policy. From 2012 we have calculated how much purchasing- and carrying costs Company X would have had when it bought all 40 units at one time, or replenish up to 7 each time an amount was withdrawn. Considering only purchasing and carrying costs, the difference is € 11,102.25 over three years time, (2012 to 2015). As in the proposed policy start-up costs are incurred, we can conclude that Company X's policy only is more beneficial if the start-up costs exceed €11,102.25/3 = € 3,700.75, which is very unlikely.

6.4 Validation of Croston for irregular demand items

At last we will validate Croston's forecasting method for irregular demand items. As we have proposed Croston as a forecasting method for both slow- and lumpy items, we will apply the theorem to one lumpy demand item and one slow demand item of our random selection. These include the XY's Item A and Item B, or as we will name it from now on 'A' and 'B'. The forecasts will be compared to the forecasts conducted by Company X's service SCA Ronald, who four times a year conducts a forecast on the expected demand in the upcoming year. Although his forecasts are only used as an indicator for buyers, we will treat them as if each month an 1/13 (Company X counts thirteen 4 week periods in year) amount if his yearly forecast is ordered. After three or four months the forecast then might change. Company X's forecast is conducted in a fuzzy, unclear way, that cannot be explained shortly, but applies some exponential smoothing. The excel calculations of Croston's method compared to Company X's can be found in Appendix 8 Errors are measured by the mean square error:

$$MSE = \frac{1}{n}\sum_{i=1}^{n} E_t^2$$

For Croston, the parameter α was determined by minimalizing the MSE for Croston's forecasts on historical demand. This makes the estimates a bit biased, as in a real life example the best value for α is updated after each demand occurrence. We let both forecasts start from the same point, namely the SCA's forecast after the first demand occurrence.

6.4.1 Slow patterns - ITEM B

Croston's forecasts are slightly better predictors of demand than Company X's current forecasts. They result in a 27% smaller MSE than Company X's method, as can be seen in Appendix 8. However, when rounding off both Company X and Ronald's forecasts, the error becomes significantly in favour of Mr. Y's forecasts: an MSE of 7 for Croston, while 4 Mr. Y. This might be because of the fact that we weren't able to determine the best fitting alpha with the constraint of the forecast begin an integer number, but a more likely explanation is that Ronald is better able to estimate when demand significantly sets in.

6.4.2 Lumpy patterns - ITEM A

When examining a lumpy demand pattern, we see the same happening: Ronald's rounded forecasts achieve a 48% percent less MSE error than Croston's. Even using unrounded numbers Ronald's estimates perform better than Croston's, almost twice as well. A simple plot with trend line on the actual data revealed that a declining demand pattern has set in. Ronald's forecasts, although performed just four times a year, were better able to adapt than Croston's method.

6.4.3 Necessity of making adjustments

From both examples we conclude that experience is essential for successful forecasting in aftermarket. Croston might get useful to Company X when its forecast are adjusted by a SCA with relevant experience, who can timely recognize decreasing demand patterns or adjust for management decisions or data errors. Croston's is less easy to build in Excel than the current forecasting method, and therefore more time-consuming.

6.5 Conclusions

The purpose of this chapter was to check if applying the proposed methods will establish better financial performance or less E&O. We started by examining if the items that Company X is currently stocking, would also have been in stock if the constructed decision model was applied. We found that for second- and third stage Company X's stocking decisions largely correspond to those of the model, but we did find an opportunity for Company X to reduce E&O by being stricter on what items it is obliged to stock.

Examining stock in the first stage of aftermarket revealed four E&O items out of the ten selected that would not have been in stock if our decision model had been applied. These items were all related to the building of extensions. We conclude that Company X should be more careful with ordering a higher amount than requested by the customer.

This brings us to our model for comparing order size costs. We found that Company X could have saved € 11,102.25 over three years by applying a base stock strategy with the calculated order size for achieving 95% service level. The model is able to calculate specific boundaries for renegotiating order- sizes and prices, which Company X definitely can profit from.

Although we did not find any cases for which Moore could properly be applied, the model would have made a better recommendation than Company X has acted on in case of Item AAA. A weakness of the Moore is that is not applicable on intermittent demand, and therefore many historical data needs to be present to cluster usages in larger time intervals to avoid intermittence. Moore needs to be applied to items with better fitting demand than to fully validate its usefulness.

At last, we applied Croston to two items having intermittent demand. Unfortunately Croston's method did not produce better forecasts than currently done by the SCAs. We expect this to be due to the limited response abilities to changes in demand of the method. As we have only applied Croston's method to two items, we need more examples to draw a general conclusion on its usefulness.

7 How should the redesigned processes be implemented?

In this chapter we will design an implementation plan for the developed decision model, order sizing tool and Moore's theorem. For each we will determine which divisions of the company are involved, what information is needed to apply- and enable the methods to be effective.

7.1 Decision model

For a successful implementation of the decision model it is necessary that all employees of both parties involved, service and materials management, agree to the three criteria for stocking. Once support is created, service engineers can be monitored to gain better insight in what types of items, i.e. electrical, or mechanical parts, cause what kind of defects, i.e. system failure or inconvenience, to the system. For instance: In this way a more generalized description of critical items can be established, which will make it easier to assign each service spare part to a category or for instance: all types of coils are critical. When all spare parts are classified, their class needs to be documented. We propose to do this in the ERP system. In this way SCAs can consult the importance of obsolete items, and take the decision to scrap more easily.

For items that are in stock due to a last time buy we suggest to create a new signalling code. Necessary information about last time buys needs to be stored in one place. It should include information about the size of the last time buy, the date the last time buy has been done and the expiration date of the product support it is concerned with. Remark that this requires a consistent support policy.

7.2 Order sizing tool

The order sizing tool in its current form is only of use to supply chain specialists, as the total costs are largely based on carrying costs, which Company X's Services and Aftermarket manager is not fully convinced of to exist. Employees at Service need to be convinced that carrying costs also have large impact on the plant's profits, but more important, can oppress the margin at which they sell their products. We recommend to create more awareness on what factors play a role as well in the eventual contribution of a customer order to the plant's profit.

So the tool might not be ready to implement at the department of Services and Aftermarket, but it can have a positive effect when used by buyers and supply chain analysts. Every time they get a request from Services and Aftermarket to put a certain quantity in stock, both the tool and the decision model help to create awareness and stimulate buyers and SCAs to be more critical. Historical demand on usages needs to be easily accessible, which is now not the case.

7.3 Moore

The most important thing that is needed to create accurate last time buy forecasts is a lot of historical demand. The farther away in time the peak year of demand can be retrieved, the more accurate the forecast will be. As Company X has started to use Baan somewhere around 1995, the data is expected to be stored somewhere. So first, historical demand data should be extended. Second, more examples must be find that endorse the benefits of quantitative last time buy forecasting to convince management of its benefits.

8 Conclusion and recommendations

In this chapter we will draw a general conclusion to the main research question: *'What determines if an item is necessary to stock and what methods of demand forecasting and order-sizing can be applied to reduce E&O in aftermarket?'* We will proceed to address factors that could have influenced the research and its outcomes in the discussion section and end with recommendations for further research.

8.1 Conclusions

The research started with examining E&O in the current aftermarket situation. We saw that E&O is centered in the first stage of aftermarket, having a level of €xxx, while only about one third originates from the second and third stage. In the validation step we discovered in a random selection that in the first stage Company X is keeping items stock that are not necessary in stock, which probably is an important factor in the large share of E&O in the first stage.

In the root cause analysis we selected the top four of most to E&O contributing root causes that might can be improved by applying quantitative methods: overestimated demand in last time buys, responsible for about €xxx in the first aftermarket stage, deliberately high amounts stocked to guarantee availability (€xxx in all three aftermarket stages) or reduce start-up costs (€xxx in first stage) and too high minimum order sizes (€xxx, first stage).

The research continued to examine how a method could be provided to assess whether the stocking of an item is justified, and found three key factors that justify (E&O) service spare parts to be kept in inventory: non-reproducibility, criticality and LLTs. In case of non-reproducibility, the method provides steps to determine whether a last time buy is necessary, or if another solution is available. In case of criticality and LLTs, the item will be classified as either A, B or C, and depending on its classification assessed for being suitable to apply an inventory model or just held in stock in an amount high enough to guarantee availability for a longer period of time. In the other case irregularity needs to be assessed, which we have done in chapter 4. We found only 37 out of 1807 items to have sufficient demand during lead time to apply an inventory model, and therefore focused on forecasting for intermittent demand patterns.

Croston's demand forecasting method was found to be suitable for intermittent demand patterns. But we unfortunately were not able to proof Croston's benefits as we only examined the consequences of the method for two items, for which the current by Company X applied forecasting method provided better predictions than Croston's method.

To help gaining insight in whether it is more beneficial to order a lower amount against a higher unit price, or to order a larger amount with a lower unit price, we have developed a method for comparing yearly financial consequences for specific order quantities and unit prices, so that a comparison can be made. Two decisions to deliberately stock a higher amount of items were analysed and both established a 100% service level, which Company X does not find necessary to pursue. So Company X could have saved money by ordering less items for a higher unit price, or renegotiating the minimum order size.

At last, we have applied Moore's method to a last time buy situation. Unfortunately, after selecting the year of peak demand, only two other data points rested, which makes the forecast very unreliable. More previous last time buy situations need to be tested to get a better idea of the benefits of Moore's method.

8.2 Discussion

There are some factors that decrease the reliability of this research. First, we have based the root causes of all parts in aftermarket on a study conducted on only the most E&O expensive items. This selection very likely to not be representative for the whole aftermarket population. Moreover, only a root cause study has been conducted on obsolete items.

Another weakness occurs in the modified EOQ calculation, which does not takes order set-up costs into account. Even though Company X preferred to leave these costs out of scope, they do start to play a role when order quantities decrease significantly. Moreover, the developed tool is not suitable for replenishment quantities when the stock on hand is not zero. Besides we have used the Poisson distribution for large quantities, which is not biased as not the correct size of variation is taken.

The maximum response time differs per customer. We have made a very general assumption that was not based on any measures, just on service engineers' opinions. It will therefore be very hard to generalize the criteria long lead time-ness.

The validation conducted on Moore's theorem is highly unreliable, as almost any curve can be fit into two or three data points. More data points are required for accurate forecasts so that a difference between the three types of curves of Moore's theorem can occur and the best curve can be selected.

As we have recommend to stock all B- and C- items in large quantities to minimize the review costs but guarantee availability, this will almost certainly result in an increase of excess. Company X should be aware of this.

Moreover we have not checked what part of items having regular demand are A items. Around 90 items are marked as A items (0.05*1807), if all of the items suitable for regular inventory models (37) would fall into the A class, then regular inventory models would have been a good point to focus on as well.

8.3 Recommendations

This research has to some extent provided insight in what could be done to reduce E&O in aftermarket, but there are still a lot more research opportunities left on this topic. Company X can for instance reconsider if it wants to charge the same percentage of the cost price for aftermarket E&O items as for items that are still in active production. We have seen that aftermarket demand patterns only for a tiny part behave as regular demand. Charging the same percentage to an aftermarket items becoming E&O therefore seems not logical.

Moreover, for items bought in a last time buy it is almost certain that they will be in stock for over a year, and therefore shouldn't be marked as excess or obsolete at all.

Furthermore we recommend Service and Aftermarket to maintain a consequent policy. When a product is transferred to aftermarket, applying Moore's forecasting method on product level might give good estimates on how many years in the future there will still exist demand.

In the first chapter more root causes were discovered than addressed in this research. Therefore Company X is recommended to do further research on these identified root causes, as they come with high rates of obsolescence.

9 REFERENCES

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10 APPENDICES

APPENDIX 1

Company X's financial policy

- Confidential

APPENDIX 2

Representation of different offered service types

- Confidential

APPENDIX 3

Product support policy – Confidential

APPENDIX 4

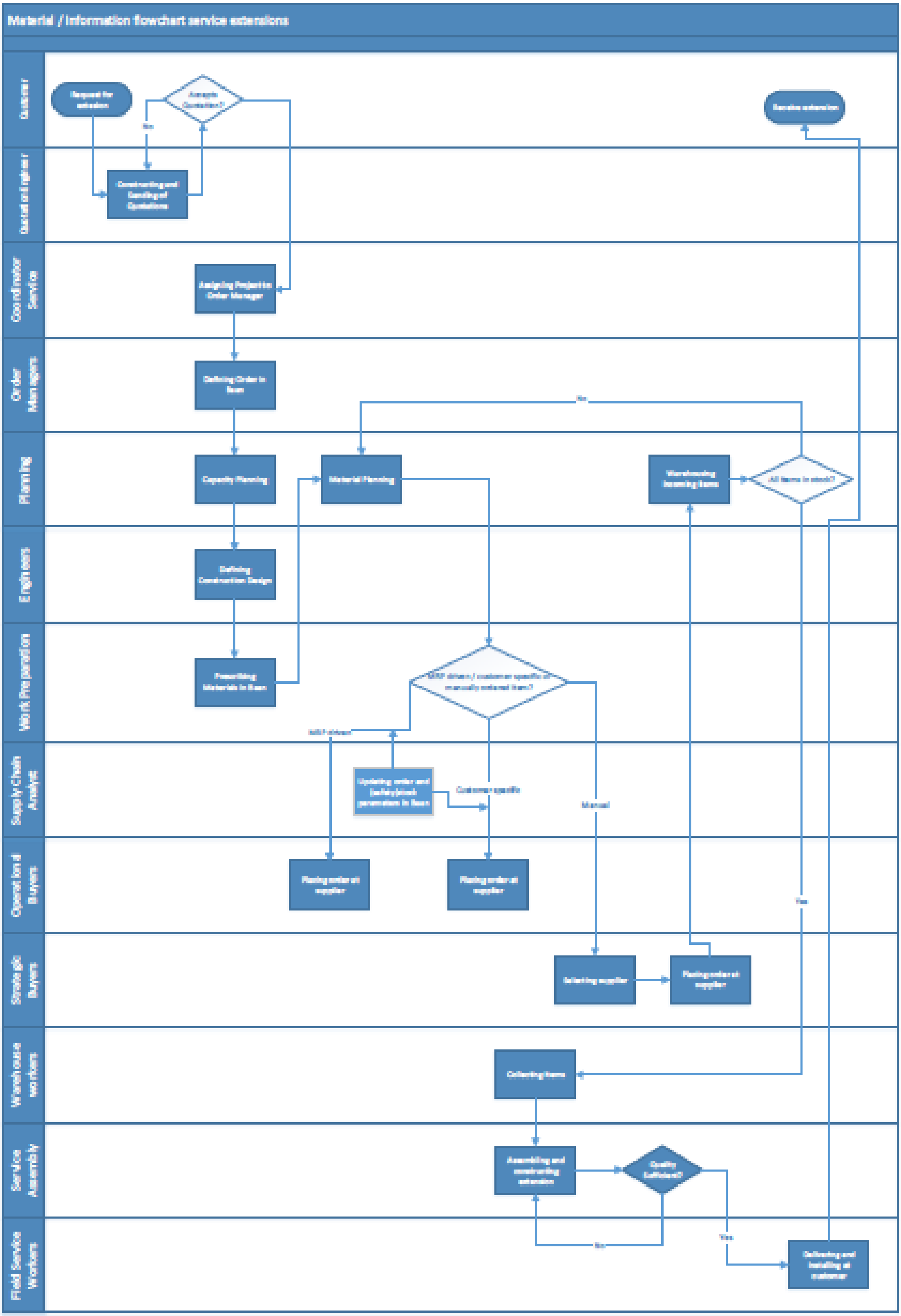
Product support policy – Confidential

APPENDIX 5

Most important agreements in service contract – confidential

APPENDIX 6

Flowchart – Extension order


Material / Information flowchart service extensions
Coordinator Service
Assigning Project to Order Manager
Order Managers
Defining Order in Baan
Planning
Capacity Planning
Material Planning
No
Warehousing incoming items
All items in stock?
Engineers
Defining Construction Design
Work Preparation
Prescribing Materials in Baan
MRP driven / customer specific or manually ordered item?
MRP driven
Supply Chain Analyst
Updating order and (safety)stock parameters in Baan
Customer specific
Manual
Operational Buyers
Placing order at supplier
Placing order at supplier
Yes
Strategic Buyers
Selecting supplier
Placing order at supplier
Warehouse workers
Collecting items
Service Assembly
Assembling and constructing extension
Quality Sufficient?
Field Service Workers
No
Yes
Delivering and installing at customer

APPENDIX 7

Root cause analysis

Kritieke items

Statistiek groep 56,		Most likely root cause	kitm	supplier	item grp	lead time	csig	2012 (Verbruik)	2013	2014	2015	2106	Veiligheidvoorraad, (heeft er een veiligheidsvo	Serie (Stonden er minimale series in?)	Signalering (heeft er een signaleringscode opgestaan?)	Artikeltekst	huidige voorraad ingekocht	Current stock level
		Last time buy	In		830011	50	S01	1	4	0	0	0	Nee	Nee	Naleververplichting s01	Artikel niet meer leverbaar, en wordt vervangen	31-10-2010 (20st) 29-1-2013 (4st)	16st
		Start-up costs	Ma	0	560022	4	S01	4	0	6	0	0	Nee	Voor 01-02-2012, stond er een serie in van 6	Naleververplichting s01	Nee	23-01-2012 (40st)	30st
		Start-up costs	Ma	0	560022	2	S01	8	0	0	0	0	Nee	Voor 13-03-2013, stond er een serie van 6 in	Naleververplichting s01	Nee	23-01-2012 (20st)	20st
		Decision-making	In		800011	35		12	-10	18	0	0	Nee	Nee	Nee	alleen specificaties	29-7-2011 (30) & 08-04-2013 (10st)	26st
		Minimum serie	In		830011	40		30	36	25	1	0	Nee	Ja minimale order serie van 100, ten tijde van aankoop van de voorraad (100 minimaal, inkoper heeft 80 ingekocht)	Nee	alleen specificaties	8-1-2013 (80st)	45st
		Leftover Active	Ma	0	560022	4	S01	0	0	0	0	0	Nee	Tot 1-2-2012 stond er een serie van 8 in	Naleververplichting s01	Nee	23-1-2012 (16st)	10st
		Aborted R&D project	Ma		860011	30		3	12	0	0	0	Nee	Stond een minimum serie van 12 in tot t/m 2-10-2013	Nee	Nee	Inkoop: 6-2-2012 (7st) 17-11-2011 (10st) Maak: 18-10-2011 (39st) voor R&D project/ NPD ER7070	23st
		Aborted R&D project	Ma		860011	30		3	12	0	0	0	Nee	Stond een serie in van 40 op 25-10-2010	Nee	Nee	Inkoop: 6-2-2012 (5st) 18-11-2011 (10st) Maak: 18-10-2011 (39st) voor R&D project/ NPD ER7070	22st
		Minimum serie	In		800011	20	S01	36	0	0	0	0	Nee	Op 27-6 is de serie verlaagd van 100 naar 15, toch ingekocht met 100 waarschijnlijk minimaal van de leverancier	Naleververplichting s01	Ja gedeelte voorraad weggegooid 2008	5-9-2011 (100st)	100st
		unknown	In		800011	50		0	0	0	0	0	Nee	Nee	Nee	Nee	Niet terug te vinden; ook niet in archiefbedrijf. Voorraad voor 2007	10st

Statistiek groep 57, 3e fase prod

[illegible]	unknown	In	[illegible]	800011	30		23	2	11	0	0	Nee	voor 4-3-2011 was de optimale serie 2, (&minimale serie 1)	Nee	Nee	07-05-2009 (75st)	80st
[illegible]	unknown	Ma	0	570022	6	UF2	0	0	0	0	0	Nee	Nee	UF2, uitgefaseerd voor reguliere productie	Nee	Niet terug te vinden; ook niet in archiefbedrijf. Voorraad voor 2007	21st
[illegible]	Returne by Customer	Ma	0	470024	4		3	-9	13	-2	0	Nee, pas na april 2015 (3st)	Nee	Nee	Nee	9st teruggekomen van project WD3022	9st
[illegible]	Incorrect prescription	Ma	0	470024	20		18	-4	0	0	0	Nee	Geen series, werd lot-for-lot geproduceerd, *i.e.* 1 stuks wanneer er 1 nodig is	Nee	Nee	In October 2012 (14st) geproduceerd & verbruikt. Vervogens 9 st teruggevonden in het magazijn met voorraadcorrectie	9st
[illegible]	Decision-making	Ma	0	570022	6		0	0	0	0	0	Nee	Optimale serie van 10	Nee	Nee	Niet terug te vinden; ook niet in archiefbedrijf. Voorraad voor 2007	10st
[illegible]	Incorrect prescription	In	0	530	50		0	0	0	0	0	Nee	Nee, standaard op een rol van 100m/5000kg	Nee	Nee	Continu voorraad correcties, geen bijboekingen. Waarschijnlijk wordt materiaal onjuist voorgeschreven, of handmatig gecontroleerd (of verbruiksartikel)	40kg
[illegible]	Incorrect prescription	In	[illegible]	860011	50		280	0	0	0	0	Nee	Op basis van van de artikeltekst is af te leiden dat er een minimum order serie op heeft gestaan. Hoeveel is onduidelijk.	Nee	Ja, in de tekst staat: op 2-03-2012 is op verzoek van Maurice Hetem de minimale orderhoeveelheden aangepast voor de artikelnummers B954286 in 300 gram.	Continu voorraad correcties, geen bijboekingen. Waarschijnlijk wordt materiaal onjuist voorgeschreven, of handmatig gecontroleerd (of verbruiksartikel)	399st
[illegible]	unknown	Ma	0	570022	6		0	0	0	0	0	Nee	Nee alleen een optimale serie van 10	Nee	Nee	Niet terug te vinden; ook niet in archiefbedrijf. Voorraad voor 2007	6st
[illegible]	PPAP Order	In	[illegible]	800011	30		0	0	0	0	0	Nee	Nee	Nee	Nee	PPAP order (99 serie); inkooporder 02-11-2011 (1st)	1st
	Order size mistake	In	[illegible]	830011	75		0	9	0	0	0	Nee	Optimale serie van 3	Nee	alleen specificaties	inkooporder 07-06-2013 & 15-07-2013 (6st)	4st

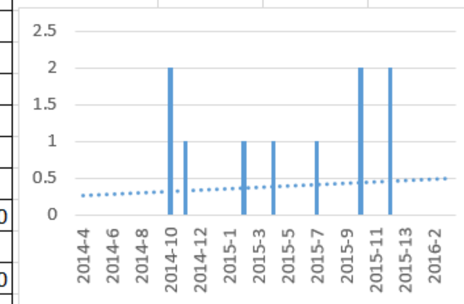
APPENDIX 8

Excel calculations Croston

Croston applied to item with slow demand pattern

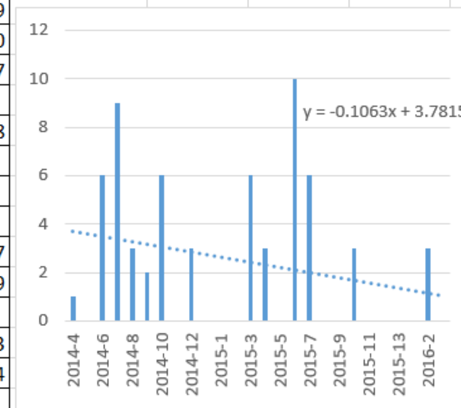
A	B	C	D	E	F	G	H	I	J	K	L
Period	**Usage**		**Ronald**	**x_(t+1)**	**n(t)**	**z^(t)**	**n^(t)**	**Error_croston**	**EC^2**	**Error_Ronald**	**ER^2**
2014-4	0	Q2-2014	0.000								
2014-5	0		0.000								
2014-6	0		0.000								
2014-7	0	Q3-2014	0.000								
2014-8	0		0.000								
2014-9	0		0.000								
2014-10	2		0.000								
2014-11	1	Q4-2014	0.000	0.00000	1	0.00000	1.00000				
2014-12	0		0.000	0.00000	1	0.00000	1.00000				
2014-13	0		0.000	0.00000	2	0.00000	1.00000				
2015-1	0	Q1-2015	0.000	0.00000	3	0.00000	1.00000				
2015-2	1		0.000	0.24088	4	0.86842	3.60527	1.00000	1	1.000	1.000
2015-3	0		0.000	0.24088	1	0.86842	3.60527				
2015-4	1	Q2-2015	0.000	0.44441	2	0.98269	2.21122	0.51825	0.268581	1.000	1.000
2015-5	0		0.000	0.44441	1	0.98269	2.21122				
2015-6	0		0.000	0.44441	2	0.98269	2.21122				
2015-7	1	Q3-2015	0.769	0.34449	3	0.99772	2.89621	-0.33323	0.111043	1.000	1.000
2015-8	0		0.769	0.34449	1	0.99772	2.89621				
2015-9	0		0.769	0.34449	2	0.99772	2.89621				
2015-10	2	Q4-2015	0.769	0.62556	3	1.86812	2.98634	0.96652	0.93417	-0.308	0.095
2015-11	0		0.769	0.62556	1	1.86812	2.98634				
2015-12	2		0.769	0.93092	2	1.98265	2.12978	0.74889	0.560835	0.74889	0.561
2015-13	0		0.769	0.93092	1	1.98265	2.12978				
2016-1	0	Q1-2016	0.385	0.93092	2	1.98265	2.12978				
2016-2	0		0.385	0.93092	3	1.98265	2.12978				
2016-3	0		0.385	0.93092	4	1.98265	2.12978				

M	N	O	P
Alpha	0.868423		
MSE_Croston	0.574926		
MSE_Ronald	0.731102		
Difference	0.156176		



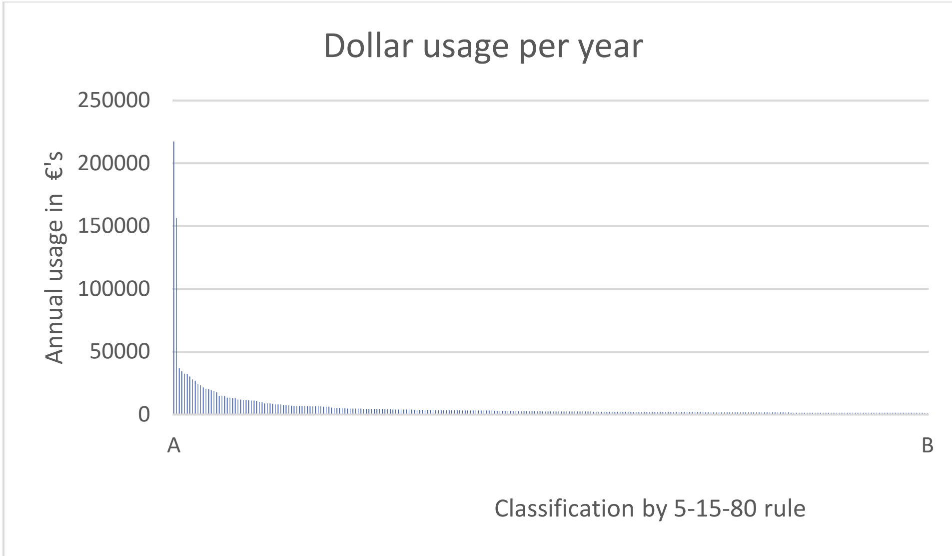
Croston applied to a lumpy demand pattern

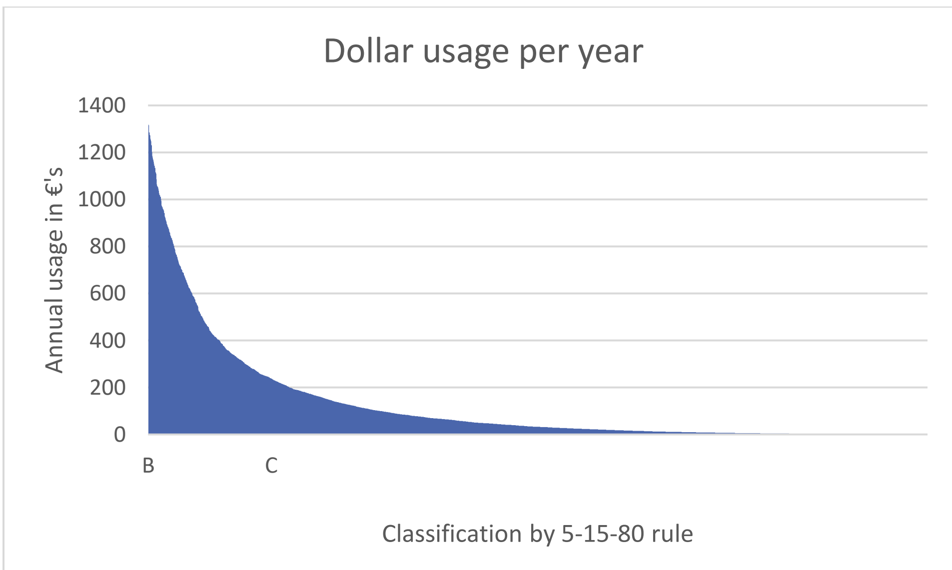
	A	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Period**	**Usage**		**Ronald**	**x_(t+1)**	**n(t)**	**z^(t)**	**n^(t)**	**Error_croston**	**EC^2**	**Error_Ronald**	**ER^2**		
2	**2014-4**	1	Q2-2014	4.615									**Alpha**	0.417414
3	**2014-5**	0		4.615	4.61538	1	4.61538	2.00000					**MSE_Croston**	27.78792
4	**2014-6**	6		4.615	2.59667	2	5.19334	2.00000	1.38462		-3.231		**MSE_Ronald**	13.70737
5	**2014-7**	9	Q3-2014	4.615	4.28558	1	6.78229	1.58259	6.40333	41.00262204	4.385	19.225	**Difference**	14.08055
6	**2014-8**	3		4.615	3.88494	1	5.20351	1.33941	-1.28558	1.652704527	-1.615	2.609		
7	**2014-9**	2		4.615	3.22803	1	3.86632	1.19773	-1.88494	3.552990794	-2.615	6.840		
8	**2014-10**	6		4.615	4.26557	1	4.75695	1.11520	2.77197	7.683809092	1.385	1.917		
9	**2014-11**	0	Q4-2014	3.077	4.26557	1	4.75695	1.11520						
10	**2014-12**	3		3.077	2.71034	2	4.02357	1.48453	-5.53114	30.59346694	-4.692	22.018		
11	**2014-13**	0		3.077	2.71034	1	4.02357	1.48453						
12	**2015-1**	0	Q1-2015	3.077	2.71034	2	4.02357	1.48453						
13	**2015-2**	0		3.077	2.71034	3	4.02357	1.48453						
14	**2015-3**	6		3.077	1.91301	4	4.84856	2.53452	-4.84137	23.43887998	-6.308	39.787		
15	**2015-4**	3	Q2-2015	3.077	2.15257	1	4.07695	1.89399	1.08699	1.18154659	-1.615	2.609		
16	**2015-5**	0		3.077	2.15257	1	4.07695	1.89399						
17	**2015-6**	10		3.077	3.37900	2	6.54931	1.93824	5.69486	32.43142141	3.846	14.793		
18	**2015-7**	6	Q3-2015	1.538	4.08638	1	6.32002	1.54661	2.62100	6.86964816	2.923	8.544		
19	**2015-8**	0		1.538	4.08638	1	6.32002	1.54661						
20	**2015-9**	0		1.538	4.08638	2	6.32002	1.54661						
21	**2015-10**	3	Q4-2015	1.538	2.29149	3	4.93420	2.15327	-9.25914	85.73173721	-1.615	2.609		
22	**2015-11**	0		1.538	2.29149	1	4.93420	2.15327						
23	**2015-12**	0		1.538	2.29149	2	4.93420	2.15327						
24	**2015-13**	0		1.538	2.29149	3	4.93420	2.15327						
25	**2016-1**	0	Q1-2016	2.308	2.29149	4	4.93420	2.15327						
26	**2016-2**	3		2.308	1.23501	5	4.12684	3.34154	-8.45744	71.52831618	-5.462	29.828		
27	**2016-3**	0		2.308	1.23501	1	4.12684	3.34154						
28										**305.6671429**		**150.7810651**		



APPENDIX 9

ABC Classification


Dollar usage per year
Annual usage in €'s
250000
200000
150000
100000
50000
0
A
B
Classification by 5-15-80 rule


Dollar usage per year
Annual usage in €'s
1400
1200
1000
800
600
400
200
0
B
C
Classification by 5-15-80 rule