Spare-parts costs and process management optimization

Bachelor Thesis Industrial Engineering and management

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Preface:

Dear reader,

The paper I've produced includes the research I conducted for my senior thesis for the University of Twente's Industrial Engineering and Management program. The report was written between March and October 2021 at the Abbott pharmaceutical facility in Olst.

Since I got the opportunity to gain valuable experience at such a sizable organization as Abbott, this research project was enjoyable and interesting for me It was also a pleasure to work and interact with so many employees from Abbott. I also particularly valued the opportunity to put the knowledge I had acquired during my studies to use since it helped me see how the theory could be used in a real setting and with a genuine business.

I would want to sincerely thank everyone who supported me throughout my research, gave me advice, and provided me with comments and helpful criticism, as without the help I could not have produced such a report. I'd like to thank my supervisors, Timmy Labeodan from the company and Engin Topan from the university. Since this is my graduation project, I'd also like to thank my friends and family for their tremendous support over the course of my academic career.

Aldayeh, Alaa

Enschede, October 2021

Management summary:

Introduction:

This paper explains in detail the research done at Abbott which is a core component of the study of industrial engineering and management at the university of Twente. The company manufactures drugs and health-related devices and has multiple sites around the world. The thesis focuses on the site Olst, this site has multiple manufacturing lines with many machines therefore spare parts are crucial at the site to guarantee that all the machines are working in good shape. The site mainly focuses on preventive maintenance and has a full department that is responsible for maintaining the machines, however, there are times were corrective maintenance is needed, for that case, an optimal ordering policy is needed to guarantee that the spare parts are always in stock. This is mainly to limit the downtime of the machines and save costs and be more efficient in general. This brings us to the following main research question: "how can spare part management be improved to minimize the cost of materials?"

After looking at the current situation it has been determined that the company is working on improving the spare part management process and one of those improvement strategies is that they are trying to increase the capacity of the technical warehouse and this is by introducing revolving shelves in the technical warehouse that will increase the capacity through making the usage of the space in the technical warehouse more efficient, this is a beneficial step towards improving the spare part management process and it is one of the recommendations that are given to the company. The capacity problem however, is not the only problem in the process there are some problems with the safety stock and ROPs of the SKUs, also another problem with the way technical specialists take out spare parts from the technical warehouse therefore this thesis will try to propose solutions and recommendations for these problems.

Methods/approach:

To answer the research, question a design for the research framework has been made specifically for this research using the MPSM as a guide to creating the steps of this research. Firstly we needed to understand the current situation and understand the current process then look at the problems that are happening and analyze the data but to make the data analysis process time efficient we should figure out the focus of this research, this was done with ABC classification, then we needed to forecast the demand and finding what is the expected demand in a random month so that we can calculate the safety stock levels and order up to levels to find the improved reordering policy which has been found and given in the results section of this summary.

Results:

The results of this research were the new safety stock levels and order up to levels which have been found from the parameters that were recalculated, Figures 1 and 2 give the calculated SS levels and OUT levels of a random sample of the SKUs that were in this research's focus, and the tables in the appendix will give the recalculated levels for all the material numbers. These new values are recommended to save the costs on the site and to use the money that is being spent much more efficiently, and the OUT levels are now being proposed for the company as a replacement for ROP because in this research we are ignoring economic order quantity as spare parts are slow-moving items and we are presenting this policy as OUT policy. There are other recommendations that this research is also giving for

the company which can be found in the last chapter of this research, but the summary of these recommendations is given in the next section.

Figure 1: Recalculated safety stock level for a sample of SKUs

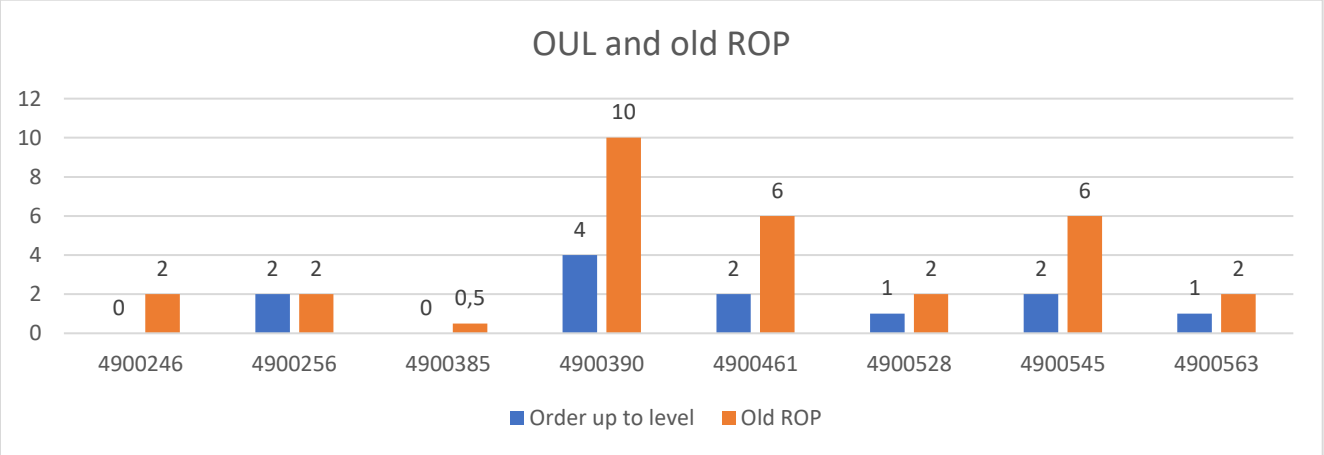

Figure 2: Calculated OUL for a sample of SKUs

The results were then tested by analyzing a sample of 5 different SKUs to see if the new reordering policy is better than the old situation and also testing them against the KPIs and see if they improved these indicators or not.

Recommendations:

From this research we can recommend the company to firstly continue with the process of getting the vertical carousel which are the shelves that the company will introduce, as it will help with the capacity limitation problem in the technical warehouse, then also change and improve the process of checking in and out the parts in the technical warehouse by introducing barcodes and scanners that directly registers these movements into SAP so that the system will have the correct stock use and stock ordered so that the company will benefit with the decisions that SAP is designed to give. Also, the site can benefit from using these recalculated safety stock levels and order up to levels that have been given in the results and implementing them into the OUT policy, the site could also use the same approach of this thesis and recalculate the levels for all the SKUs if the data has been updated to make the actual stock match the stock in SAP which is not the case right now, but even with this difference, these new values that are calculated in this paper will also help improve the process and save costs.

Contents

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List of terms and abbreviations:

MPSM Managerial Problem-Solving Method

ROP Reorder point

SS Safety stock level

LT Lead time

LTL Linear trend line

Stdev Standard deviation

SKU stock-keeping unit

KPI Key performance indicator

BPM Business process management

SPM Spare part management

OUT Order up to

Reader's guide:

Chapter 1: Introduction

Chapter one is the introductory chapter that explains the research problem, the current situation, and the approach that will be done for this thesis.

Chapter 2: Research focus

This chapter explains the method used to find the research focus of the thesis and the findings of that method.

Chapter 3: Literature review

The third chapter contains the prior knowledge and the research findings that are used to make this thesis and answer its research questions.

Chapter 4: Solution design

This chapter has the model of steps that were undertaken to provide the solution and explains each step.

Chapter 5: Solution testing

The solution is tested to find if it is valid, reliable, and optimal in this chapter.

Chapter 6: Conclusion

Chapter 6 gives the conclusion, limitations, and recommendations.

Chapter 7: Standard operating process (SOP)

One of the deliverables of this research is given which is the SOP it will include a guide that explains how to implement the new inventory control policy.

Chapter 8: Further research

This chapter shows the possible research that could be done further to build on this thesis and improve it.

1. Introduction:

The study is being conducted for the international company Abbott Biologicals B.V., more precisely at the Olst location in the Netherlands. This project's goal is to evaluate and improve the site's current spare part management system. A little background on the company will be given in Section 1.1. Following that, Section 1.2 will present and discuss the problem definition while Section 1.3 addresses the research approach.

1.1. Company

An international pharmaceutical firm called Abbott Biologicals B.V. produces medicines for millions of people. The thesis will focus on the company's location Olst, one of its several locations in the Netherlands. The facility was established in 2008 and consists of a few buildings housing the various departments, production lines, and warehouses. The business essentially produces all types of medications, selling them primarily to other distributors. Only a small portion of the medications are sold with the Abbott label directly to patients.

1.2. Problem Identification:

1.2.1. Current situation:

The current situation can be divided into multiple parts and this section will explain the details of each part of the current situation. These findings were the result of having multiple open-ended interviews with employees from the company in which they seem to agree on the same information.

- *Data entry:*

Firstly, the employees from many departments agree that because of some data entry problems, SAP is not aware of how much stock is in the warehouse of the company this causes SAP to let the company know that they need to order some more parts or not order parts but in real life, this information could be incorrect. According to the technical warehouse manager Edwin Henssen, the count that happened at the end of the year 2021 corresponded to a 78% match between actual stock and the stock in SAP. Edwin also commented that the target is to reach 97% or higher in the future and that is by taking some measures he listed (Labeling, Barcoding, Scanning, Direct entry into SAP after leaving the warehouse, and Controlled entrance).

The reason behind these data entry problems is that normally the standard process of using anything from the warehouse is to fill in a form after taking a certain part and this sometimes does not happen for various reasons like an employee might be in a hurry and needs the part as soon as possible, a sort of slack from the employee, needing the parts in some late at night times, etc.

This difference between the actual stock and the stock results in ordering parts when not needed therefore increasing not needed costs which can be easily eliminated therefore making the process a lot more cost-efficient. When comparing the actual stock used and the stock ordered we found out that there were some SKUs that have been used less than ordered and vice versa, to see how much money was used when not even needed we needed to look at the SKUs that were ordered more than used. In the period from Jan 2018 – May 2022 there were a total of 3556 different parts that were ordered but not used and the value of these parts is a total of € 212.526,11 (Appendix 2) this is money that has been spent just because the reordering policy is not optimal and or the data entry problem that was mentioned earlier.

- *Ordering policy:*

According to Rob de Neef who is the team leader of maintenance engineering the agreement in Olst is that an order of parts is only placed in the occurrence of a breakdown, this policy is not optimal and leads to a stockout of spare parts which makes fixing the machines in the manufacturing lines slower, because you need to wait for the lead time. Also, this leads to less manufacturing since the machines will be unable to work until the part is fixed therefore it limits the profit generated by the site.

- *Safety stock levels:*

After looking at the safety stock levels from the data given it was determined that all the safety stock levels were 0, this means that the safety stock levels are not determined which corresponds to the ordering policy and makes the issue mentioned in the previous paragraph more vital as without the safety stock it increases the chance of a stock out.

- *Storage capacity:*

Another problem that the site is facing is not having a harmonized storage point and as not all the spare parts are in one warehouse but the site is using other buildings as storage points and which is not good as some parts could be lost that way, this, unfortunately, happens because of the lack of storage capacity in the technical warehouse.

- *Reorder points:*

The reorder point of the materials in Olst is determined however it will be replaced with OUT levels and that is because the policy that will be made in this research is the OUT policy and that is reasoned by having the data that was given since after analyzation we had to ignore economic order quantity and since the spare parts are slow moving items and for these reasons the OUT policy is a better option for us than the reordering policy.

1.2.2. Action problem:

The action problem for the research project is “How can the spare part management process be improved to save costs by 10%”. The action problem was also identified in the problem cluster in Figure 3. As said above an action problem must include both the norm and reality and that is to become an action problem. The norm is the goal or what needs to be happening however the reality is what is happening. The gap between the norm and reality is the action problem and is what needs to be solved for this research project, the reality is that the costs of the site are very high, and the reality is to save the costs by 10% from the spare part management process. This 10% is the goal set by the company’s supervisor and what I will try to do is to make the process optimal therefore if it saves more than 10% then that is not a problem.

1.2.3. Core problem:

A core problem is identified by creating a problem cluster and seeing which problem is considered the main problem and which can be influenced. Looking at Figure 3 it shows the problem cluster that I created, and it can be identified by looking at the problem cluster that all the problems are caused by the main or core problem which is having high spare parts inventory. The problem is, in fact, a core problem as it is related to all the smaller problems and can also be influenced for example by creating a new more optimized spare part management ordering policy. Looking at the different problems because the data in SAP is outdated and because of the non-harmonized storage, parts are ordered even if they are not needed, and this is also a cause that increases the spare part inventory. This is a loop that would not end

unless some other policy is implemented or an improvement to the existing policy is made. The core problem in this company is the main problem because it is affecting the cost of the company as it is not maximizing its use and is not utilizing the spare parts that are bought by the company.

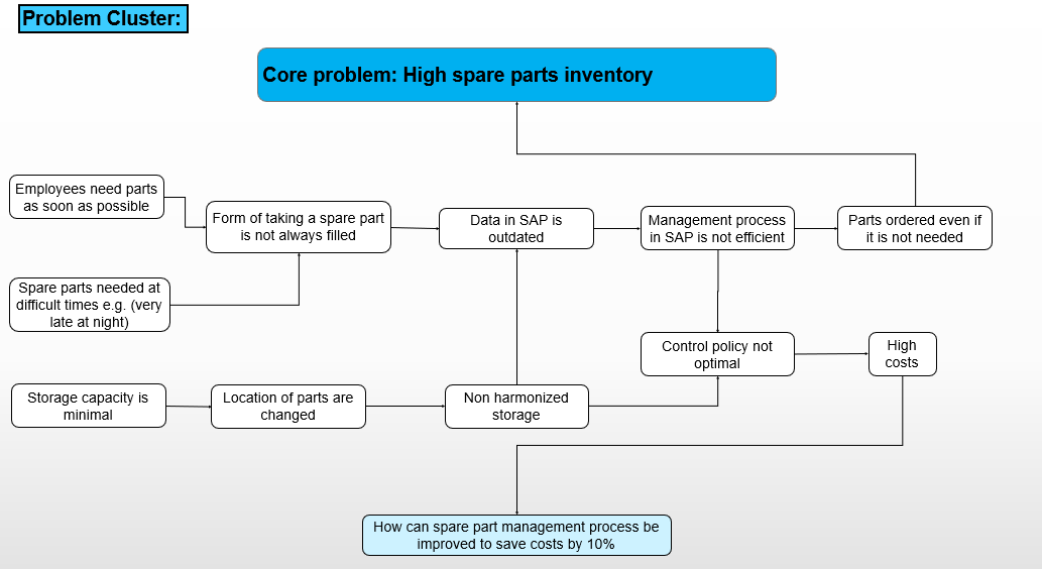

Figure 3: Problem Cluster

1.2.4. Research questions:

To become able to solve the core problem of this research project the research question must be answered:

"How can spare part management be improved to minimize the cost of materials?"

This research question's type is an evaluative study question because it is questioning the effectiveness of the current spare part management and finding out how to improve this process therefore it evaluates and checks how well it's working.

To solve the research, question a list of sub-questions must be answered:

1. Which items should be focused on so that it impacts the cost the most when improving the OUT policy?

The type of this question is an exploratory study and that is because an insight is gained by answering this question which is the SKUs that should be focused on to get the most change on the cost of the company.

To answer this question an ABC classification needs to be done so that we can determine which parts exactly affect the cost of the company the most and that way those parts will be focused on and try to come up with a new optimal reordering policy and this way it will be easier to save costs and reach the goal of 10%.

2. *What is making the spare part inventory control inefficient?*

This question is an explanatory study that focuses on what caused the spare part inventory control to become inefficient and what is the relationship between the variables that are linked to how the company orders parts and what policy they use.

Many different problems that can make a process inefficient and for Abbott, this ranges from managerial issues to actual strategy issues. The site in Olst has some problems with data entry regarding the forms that must be filled when parts are taken out of the warehouse, this is one of the main reasons why SAP is not giving the right orders to the company thus making the policy not optimal because the software does not always know what the stock level of the parts is making the whole process inefficient. Also, it just seems to be that the spare part management strategy does not exist or that it is not being followed.

3. *Is there an existing policy for spare part management and if it does is it being followed?*

The question has the type of exploratory study this is because the policy for spare parts is being explored and studied to see if it is being followed and these are insights and knowledge that are gained when answering this research question.

After meeting with many people from different departments it seems like the inventory control policy that is implemented is not very formal, so it is not always followed. The strategy that is related to preventive maintenance is more formal and it is a risk-based strategy, but it was only recently implemented at the site. This means that the parts are mostly ordered only when needed but it is still unknown whether that strategy is optimal or if it can be changed to improve and save some costs.

4. What is the demand for the SKUs? How can it be forecasted?

This question is of type exploratory study as the demand of the SKUs will be determined by answering this question.

To answer this question multiple methods will be used to find the best answer this will be done by first making or attempting the methods that will be reviewed in the systematic literature review and excluding any methods that fail to be done correctly, then we can apply statistical tests for example to test the reliability of the results, then to finally have a method to stick with and use its result to determine question 5.

5. Are the safety stock levels and OUT levels optimal? if not how can they be changed?

The question's type is an evaluative study as it tests the safety stock levels and reordering points for optimality and studies this gained knowledge further to see how these numbers can be changed to become optimal if the answer to this question turns out to have a non-optimal safety stock and OUT levels.

It seems like SS levels are not optimal however a lot of analysis of data must be made to truly figure out if they are optimal and how exactly they can be adjusted if it is not optimal. For the OUT levels these will all be calculated in this thesis and replaced instead of the ROP as this paper will be proposing an OUT policy for the company.

6. *How can the solution be implemented, validated, and assessed?*

This question is an exploratory study as it studies and explores the methods that one could follow to implement, validate, and asses the solution of this thesis which is the inventory control policy.

Firstly, for the new strategy to be implemented, there must be a plan so that everything is done in shape and organized. This can't be done alone as I need to speak to multiple people in different departments including my supervisor from the company just to make sure that the implementation process is done correctly. Also, the solution can be tested by looking at a sample of the data like 5 different SKUs, and analyze the data to figure out whether the improved levels of SS and OUT are better than the old situation.

1.2.5. Problem solving approach:

A problem-solving approach that we have been learning at the university of Twente for the last two and a half years is called: The Managerial Problem-Solving Method (MPSM). This approach has seven steps that guide anyone in solving a problem. The steps are shown in Figure 4.

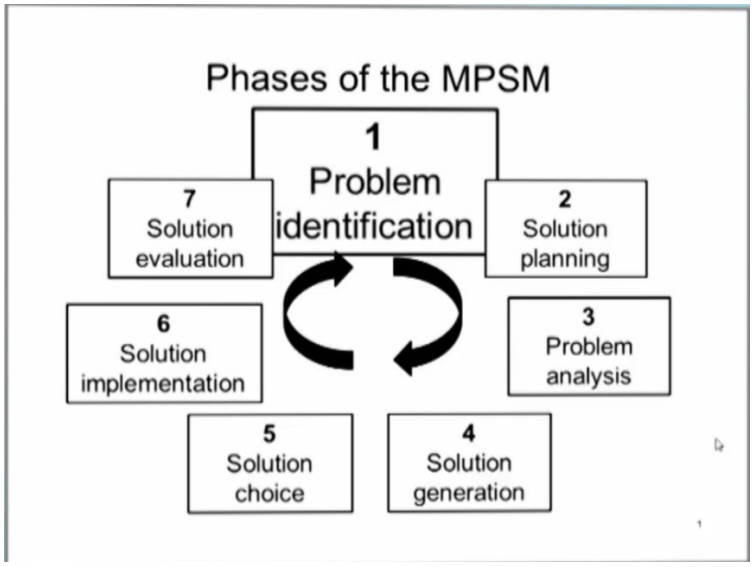

Figure 4: The phases of the MPSM[1]

Step one is the problem identification in the case of this research and defining the problem that the company has which is related to spare part management. Is to first understand the current policy and strategy that the company is following. Only after that and after talking and having many open-ended interviews with people from different departments then data must be analyzed so that the problem can be identified.

The next step is solution planning this is basically when the approach is formulated which is how the solution will come up and what steps will be taken.

Then comes the problem analysis phase this is where all the computations are made. In this phase, more analysis of the data is done, and this is to plan for the next phase which is the solution generation.

In the phase of generating solutions even more analysis of data is done but also all these analyses are compiled to generate a solution, these solutions concerning the project could be like adjusting the inventory control policy or ordering policy and testing out how this would affect the company and whether it gives us a solution.

[1] ITC E-Learning. (2022, 1 april). *mpsm phase 01*. Vimeo. Geraadpleegd op 5 april 2022, van https://vimeo.com/101271073

After generating comes the selection phase where the solution choice is made, this is done based on making a comparative analysis between each of the solutions generated to find out which one is the most optimal and that is defined by multiple criteria that must also be defined e.g. (cost and revenue) so basically what is most important for the company. The solutions will be found by firstly figuring out which approach of forecasting the demand is best, which is done by analyzing the approach's results to choose the best one. The policy that will be obtained through this research is an order up to policy of spare parts and the parameters are mainly the safety stock levels and the OUT levels. The solution will then be tested by choosing a sample of the SKUs and analyzing it to figure out if the new values of the parameters are better than the old ones.

Step 6 is solution implementation, and this is where the solution is considered and implemented in the company. This only happens after the past steps and a lot of testing of the solution.

The last and final step is solution evaluation, in this phase, the solution has already been implemented so it is also important to assess this solution and make sure that everything went to plan, and that the solution was up to what was expected. If this was not the case then that must be evaluated further and see what is making it fail to reach expectation, this is what makes the MPSM a cycle as it can be repeated if for instance, a new problem arises after implementing and evaluating the solution.

1.2.6. Deliverables:

The deliverables that this chosen approach will give are several outcomes. Firstly, analysis of data and breakdown of problems found using the analysis. Secondly, a new or improved standard operating process (SOP) for spare part management. Also, the second deliverable implies that there would be some changes made to the safety stocks and inventory control policy. Implementation of the solution/ strategy. Lastly, analysis and assessment of the new strategy after implementation.

1.3. Research approach:

1.3.1. Research type and scope:

The research type of this thesis is prescriptive research this is because an improved strategy will be advised to the company from this research. The research will provide this strategy as a solution to the problem that exists in the company. Two subjects are involved in this research the first one is the data from the company on how they handle spare parts, what is it exactly they do to manage them, and so on. The second subject is the employees that are related and have access to or use any spare parts. That is because it is also important to see the process of spare parts in real life and see how everything is done and also analyze if there are any problems with their work.

1.3.2. Key variables:

- Safety stock levels and order up to levels of spare parts

The key variables for creating an improved policy we needed to get some data for the current SS, ROP and the stock use for all the SKUs so that we will be able to recalculate SS and calculate the new OUT levels then compare it to the old situation to see if the strategy/policy improved.

- Costs of parts and Total costs

To analyze the efficiency of the current situation we needed to find the price of the parts and from the historical stock use, we could determine the total cost. We can also find the amount of money that was used without needing it when comparing the total cost of ordered parts with the actual stock use.

- Demand and lead time of ordering parts

The demand for the company will also need to be forecasted using many approaches and then choosing the best approach, this will be used to calculate the SS and OUT levels of the SKUs combined with the lead time for all the SKUs.

As we can see all these key variables are vital to come up with a solution and improve the inventory control strategy of the spare parts. They are all linked to each other and without these key variables nothing can be determined, and an improvement will not be created.

1.3.3. Theoretical perspective:

In this research, the theoretical perspective that is chosen must be spare part management inventory control strategy and standard operating procedure. To be able to provide these deliverables there must be a lot of research, and analysis of data. The failure rates of machines can be considered to see when a part must be replaced, but in this research we can focus on safety stock levels which are also vital levels that has to be considered when improving an inventory control strategy.

1.3.4. Research framework:

Figure 5: The research framework

As seen in Figure 5 the first step of the research framework is choosing the focus. The focus will be on improving the spare part management process by mainly recalculating the safety stock levels and OUT levels for a group of SKUs (the most important SKUs which are found through ABC classification) also we will be trying to figure out solutions for the other gaps and problems found in the process. After specifying the focus comes the step of asking and finding the needed data from the company. Thirdly I will have to analyze the data to distinguish problems with how the process of spare part management flows and alongside this step we make the ABC classification method. After that step, some recalculations must be made to optimize the process. If the past steps have been completed, then an improved or new standard operating procedure will be written so that the process can be followed even after I and the company could keep using the improved strategy. After that, the whole research will be presented to the team in the company and hopefully could implement, and only after implementation, we could assess and validate the process and see if the results correspond closely to that of the theoretical strategy.

2. Research focus:

In this chapter, the research focus of this thesis will be presented and explained including an analysis of the current system that is being followed in the company.

2.1. What is this research's focus?

This thesis will be focusing mainly on changing and improving the process of spare part management in Olst one of Abbot's sites, this will be done by improving the physical process of how things run in the company and also improving the parameters of the inventory control strategy of spare parts by recalculating the safety stock levels and calculating OUT levels of the SKUs.

The SKUs that will be chosen to make this recalculation of the SS and OUT levels could not include all the material numbers that exist in Olst and that is because there are way too many different SKUs and will take us more time to be able to recalculate the parameters, therefore, an ABC classification method will be used to choose the most important SKUs and the ones that will affect the cost significantly and the explanation of the ABC classification is given in chapter 4.1.

2.2. Current system analysis:

This section is an analysis of the current system and that has been determined throughout all the interviews that have been done with people from various departments on the site. To start, the best way to understand the current system is by drawing and creating a business process management chart that explains and shows clearly how spare parts are managed and what tasks are made in the process. The figure below does that.

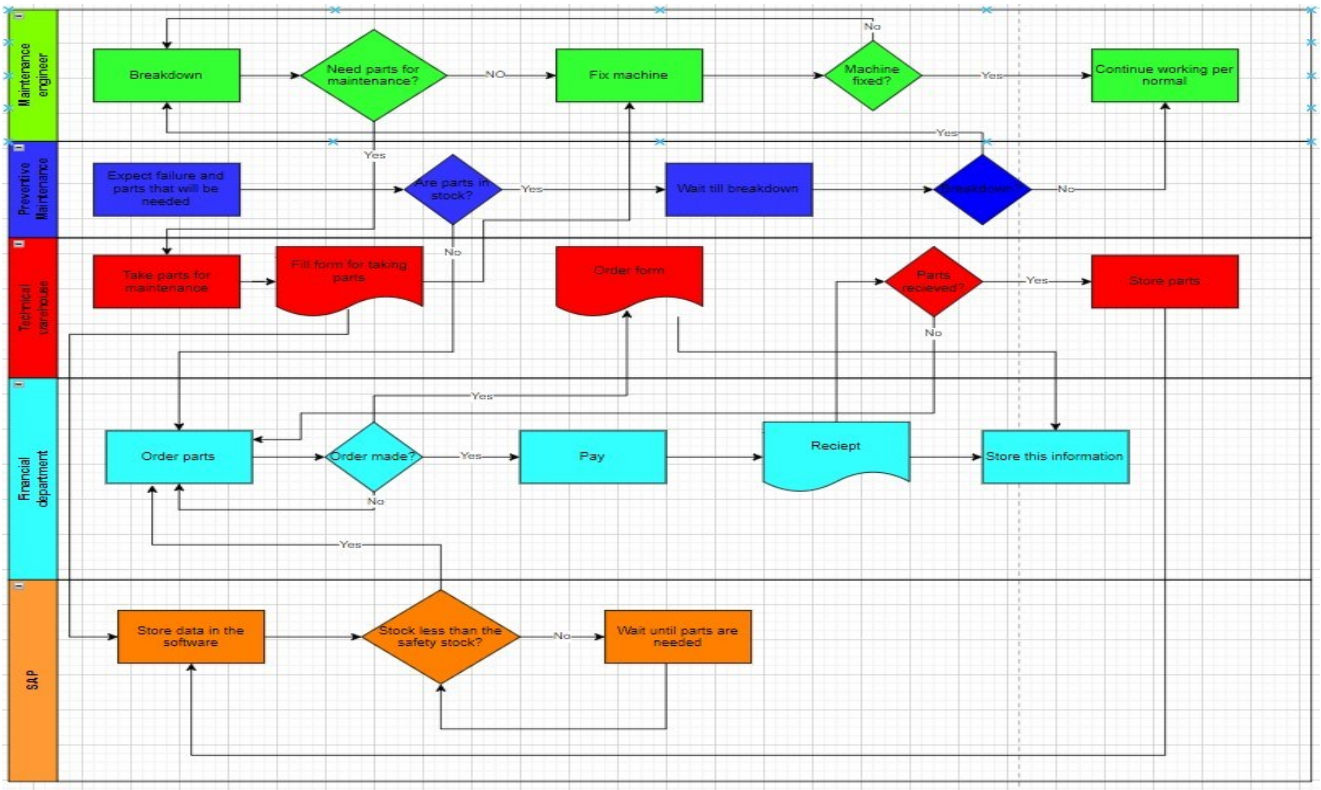

Figure 6: BPM of SPM

As seen in Figure 6 the process of spare part management has been created and the gaps in the process have been identified in yellow comment boxes which are the capacity limitation in the technical warehouse and the forms that are not always being filled that corresponds to the differences between actual stock count and the stock count in SAP.

2.2.1. What parts are involved?

The parts involved in this research are the spare parts that are used as backup when a machine breaks down and parts ae needed to get the machine fixed, however the focus of this research will not include all the spare parts as mentioned before an ABC classification method will be done in order to narrow down the research's focus so that is fits with the time window of this research.

2.2.2. Who are the customers?

The customer of the spare parts is the company it elf where it purchases spare parts so that it can be used when a failure in a machine happens.

2.2.3. How is the ordering process?

The current ordering policy of spare parts are to only order when the parts are needed and all the safety stock levels for SKUs are set to 0 and OUT levels will be calculated in this research paper which will help us to recalculate the SS levels. So the results will provide an OUT policy which is an improved inventory control strategy.

2.2.4. What are the demand and supply figures?

The demand and supply figures are the stock used and stock ordered respectively and in the current systems these values for many of the SKUs are problem were some SKUs are ordered in amounts more than what is actually needed and other SKUs have more demand than what was actually ordered and this is mainly because the reordering policy of the company is not optimal and parameters of this policy like the SS level and ROPs are not computed correctly. Therefore the OUT policy will be an improvement of the old situation.

2.2.5. What costs are involved?

The costs that are included in the spare part management process are the costs of the parts, the break down costs of machines, holding costs and stockout costs. However, in this research the only cost that will be focused on is the cost related to the price of the part, this is mainly to the limited availability of data for the other costs and limited time scope of this research therefore narrowing down the results will give better results and more detailed results.

2.2.6. Key performance indicators (KPIs)

The KPIs of this research are the average inventory cost and the amount of money spent when not needed meaning the money that was used on parts that we did not need because we ordered more than the demand, this is the key performance indicator because if this can be avoided then we will have better liquidity in the company that way this money can be saved to use for other purposes. The other KPI is the service level availability as we aim to have a service level of 95% therefore we can limit the probability of having a stock out.

3. Literature review:

In this chapter, an explanation of some terminology and the literature that was reviewed to create and write this thesis will be given.

3.1. Spare part management:

Spare part management is the management process that handles anything related to the use, ordering, and planning of parts that are used for the maintenance of machines in a production line. This management process is vital in a company and crucial because it affects the production lines of a certain manufacturing company as it tries to reduce the downtime[2] of the machines which cut potential lost revenue. Spare part management has a strong bond with the maintenance department and that includes both the preventive maintenance planners and the corrective maintenance planners.

Spare part management is responsible for many decisions this is including inventory or reordering policy as it gives the company the decision on whether to stock a certain spare part or to just order it when needed. An optimal spare part management process should always be the goal of a company especially if the company wants to maximize its revenues and prevent any potential losses.

3.2. Demand forecasting:

Demand forecasting is when a company uses historical data and or an evaluative study of the market to make predictions and estimations of the future levels of demand.[3] Most companies invest time, effort, and money to make reliable predictions and estimations for the demand and this is due to multiple reasons in general. For example, it is financially beneficial as the company could get some knowledge on how profitable a certain product is, and an estimation of their sales. Also, on the logistics side of the company, it is great to determine how many products to manufacture. For spare parts a company could also benefit from demand forecasting, this is because knowing how many spare parts will be needed in the future will make inventory control much easier and the company would order just the right amount of spare parts this way it prevents stock outs from happening but also prevents spending more money on spare parts when it is not needed. In this research we will be trying to use 3 different methods in order to find the expectation of demand for the purpose of recalculating the safety stock levels and calculating OUT levels of the SKUs.

3.2.1. Fitting a distribution:

Fitting a distribution is when the historical data is assumed to be coming from one of the standard distributions like normal, lognormal, binomial, etc. The method of making this approach is provided below and it consists of three parts: histogram, choosing a distribution, and running chi-square goodness of fit test.

3.2.1.1. Histograms:

Histograms are a representation of the frequency that a certain number is repeated throughout the data set. The histogram in this thesis specifically shows for each made purchase of a spare part the frequency that this same amount of order was made throughout the whole period of data which

[2] Zhang, S., Huang, K., & Yuan, Y. (2021). Spare parts inventory management: A literature review. *Sustainability*, *13*(5), 2460. https://doi.org/10.3390/su13052460

[3] Wikimedia Foundation. (2022, July 15). *Demand forecasting*. Wikipedia. Retrieved July 29, 2022, from https://en.wikipedia.org/wiki/Demand_forecasting

corresponds to 53 months. These histograms can also be used to find out the SS level of the SKUs as explained in chapter 3.3.1 specifically in method 2.

3.2.1.2. Choosing the distribution to test on:

Using the histogram and through looking at it a distribution could be assumed, and this distribution could be any of the following: Normal, Lognormal, Binomial, Poisson, Geometric, Hypergeometric, etc. When this is determined the next step will be to statistically test the assumption that has just been made. Further the statistical test is given below.

3.2.1.3. Chi-squared goodness of fit test:

The chi-square goodness of fit test is used to determine if a variable could be expected to be coming from a specific distribution or not.[4] The method contains identifies two hypothesis H_0 which is the null hypotheses and H_1 which is the other hypotheses. The expected values are then computed depending on the distribution assumed, then those expected values are used with the actual values that were determined from the histograms to compute the Chi-square value.

Chi square:

$$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad [5] \tag{1}$$

Where X_c^2 is Chi-square, O_i is the observed value that was computed from the histogram, and Ei is the expected value that was computed from the general distribution. If the test statistic was lower than the chi-square value, then the null hypothesis is not rejected and is rejected if the test statistic was higher than the value of chi-square.[5]

3.2.2. Linear regression:

Linear regression is well-known and widely used in many companies to forecast demand the idea of this method is based on the assumption that if a linear line was drawn from the historical data of demand then using the same formula of this linear line we can determine the future demand. The method is done by firstly computing the slope and Y-intercept of the data and then computing the future demand with the same formula of the line. the method is then tested to see whether the actual demand followed this linear regression line or not.

Formula of a line:

$$y = a + bx \tag{2}$$

Where y is the demand that will be computed/ forecasted, a is the y-intercept, b is the slope, and x is the stock use.

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[4] *Chi-square goodness of fit test*. JMP. (n.d.). Retrieved July 29, 2022, from https://www.jmp.com/en_sg/statistics-knowledge-portal/chi-square-test/chi-square-goodness-of-fit-test.html#:~:text=The%20Chi%2Dsquare%20goodness%20of%20fit%20test%20is%20a%20statistical,representative%20of%20the%20full%20population.

[5] Taylor, C. (2019, March 23). *Chi-square goodness of fit test*. ThoughtCo. Retrieved July 29, 2022, from https://www.thoughtco.com/chi-square-goodness-of-fit-test-3126383

Computing the slope:

$$b = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad [6] \tag{3}$$

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4}$$

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{5}$$

Where b is the slope, x_i is the period, y_i is the stock use, $\bar{x}$ is mean of all values of x, and $\bar{y}$ is mean of all values of y.

Computing the Y intercept:

$$a = \bar{y} - (b\bar{x}) \quad [5] \tag{6}$$

Where a is the y-intercept, $\bar{y}$ is mean of all values of y, b is the slope, and $\bar{x}$ is mean of all values of v.

Also, note that these two formulas are only considering one SKU and there is an easy formula in excel that could be used to determine the slope and y-intercept which will be beneficial and time-saving to use when making the method and it provides the same results.

3.2.3. Moving average:

Moving averages is a method that uses subsets of historical data to compute averages of the demand and is used to forecast demand.[7] The method also has a statistical test to calculate the error of the estimate (forecast) that came out from the moving average.

Mean absolute deviation (MAD):

$$AD_i = |Moving\ average - Stock\ use_i| \tag{7}$$

$$MAD = \frac{\sum_{i=1}^{n} AD_i}{n} \tag{8}$$

Mean squared error (MSE):

$$SE_i = AD_i^2 \tag{9}$$

$$MSE = \frac{\sum_{i=1}^{n} SE_i}{n} \tag{10}$$

Mean absolute percent error (MAPE):

$$APE_i = \frac{AD_i}{Stock\ use_i} \tag{11}$$

$$MAPE = \frac{\sum_{i=1}^{n} APE_i}{n} \tag{12}$$

[6] Wikimedia Foundation. (2022, May 3). *Simple linear regression*. Wikipedia. Retrieved July 30, 2022, from https://en.wikipedia.org/wiki/Simple_linear_regression

[7] Wikimedia Foundation. (2022, July 10). *Moving average*. Wikipedia. Retrieved July 30, 2022, from https://en.wikipedia.org/wiki/Moving_average

3.3. Order up to policy:

An inventory control strategy is the basis of the spare part management process, and it consists of a type of policy that has all the measures that are taken which are related to the inventory in the company. The policy if followed correctly it should solely be responsible for all the decisions that are taken regarding inventory[8]. Having an inventory control policy does not mean that this policy is optimal, and a company should be aiming to reach an optimal policy, this is so that it can maximize profit, minimize costs, and prevent any potential losses. The policy that will be proposed for the company in this research paper is the order up to policy and this policy gives the order up to levels and that safety stock levels for the SKUs, more explanation on these parameters are given later if the literature review.

3.3.1. Safety stock levels:

This section will be reviewing the literature for the fifth research question: "Are the safety stock levels and OUT levels optimal? if not how can they be changed?" To answer this question there had to be some general review of safety stock level.

Safety stock levels are the level of the additional stock that exists in the warehouse of the company to ensure that there will not be many stock outs[9] and in the spare part management process, it means that it is minimizing the downtime of the machines.

To calculate the safety stock levels, two methods were researched one assumes that the data of demand is coming from a normal distribution and the other method uses the frequency table from the histogram.

Method one:

The formula is the following:

$$SS = Z * \sigma_{demand} * \sqrt{L}\ ^{10} \quad (13)$$

Where SS is the safety stock level, Z is the Z-score of the chosen service level from the normal distribution, σ_{demand} is the standard deviation of monthly demand, and $\sqrt{L}$ is the square root of the lead time in months.

Method two:

To calculate the safety stock using the histograms we needed to calculate the OUT levels first which is given in method 2 of section 3.3.2.

Then we can use the following formula:

$$SS = OUT\ level - (E(D) * L) \quad (14)$$

[8] SorenGP. (n.d.). *Design details - handling reordering policies - business central*. Design Details - Handling Reordering Policies - Business Central | Microsoft Docs. Retrieved July 27, 2022, from https://docs.microsoft.com/en-us/dynamics365/business-central/design-details-handling-reordering-policies

[9] Wikimedia Foundation. (2022, March 13). *Safety stock*. Wikipedia. Retrieved July 27, 2022, from https://en.wikipedia.org/wiki/Safety_stock#:~:text=Safety%20stock%20is%20a%20term,proceed%20according%20to%20their%20plans.

3.3.2. Order up to levels:

Order up to levels are the levels that indicates to the company to order to that level as soon as the stock level goes below this level. These levels are required to calculate for the purpose of creating out order up to policy and to also recalculate the safety stock levels. The method of calculating this level is given below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Period	Demand			1	11/05/2022		# of bins	Bin width	Max	Count	*Bins*	*Frequency*	Freq/count	Cummulative
2	01/01/2018	0			1	19/04/2022		10	1	7	82	0	47	0,573171	0,573171
3	21/01/2018	4			1	08/04/2022		91	91	TRUE		1	10	0,121951	0,695122
4	10/02/2018	1			4	13/01/2022						2	10	0,121951	0,817073
5	02/03/2018	3			2	20/10/2021						3	4	0,04878	0,865854
6	22/03/2018	7			1	09/10/2021						4	8	0,097561	0,963415
7	11/04/2018	2			2	19/07/2021						5	2	0,02439	0,987805
8	01/05/2018	2			2	19/07/2021						6	0	0	0,987805
9	21/05/2018	0			1	10/06/2021						7	1	0,012195	1
10	10/06/2018	1			2	19/05/2021						8	0	0	1
11	30/06/2018	2			2	07/05/2021						9	0	0	1
12	20/07/2018	0			2	02/03/2021							0	0	1
13	09/08/2018	2			2	20/02/2021								0	1
14	29/08/2018	1			2	12/08/2020									
15	18/09/2018	0			2	22/07/2020									
16	08/10/2018	0			4	08/07/2020									
17	28/10/2018	0			2	13/05/2020									
18	17/11/2018	5			1	01/05/2020									
19	07/12/2018	0			1	28/04/2020									
20	27/12/2018	0			2	05/02/2020									
21	16/01/2019	0			3	05/02/2020									
22	05/02/2019	0			1	11/10/2019									
23	25/02/2019	0			2	04/10/2019									
24	17/03/2019	1			1	16/09/2019									
25	06/04/2019	0			1	09/09/2019									
26	26/04/2019	4			1	30/08/2019									
27	16/05/2019	0			1	26/08/2019									
28	05/06/2019	2			2	02/08/2019									
29	25/06/2019	0			1	02/08/2019									
30	15/07/2019	4			4	28/06/2019									
31	04/08/2019	3			2	27/05/2019									
32	24/08/2019	0			2	10/04/2019									

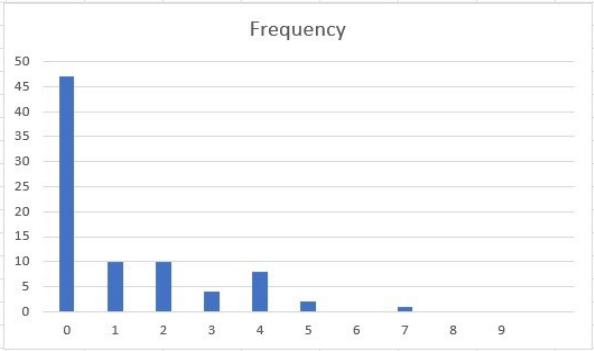


Figure 7: Excel screenshot of OUT level calculation

The first step of this method is creating a bucket for each leadtime cyclas seen in column A the dates increase in increments of 20 dayswhich is the lead time for this SKU and in column B the total stock use during the 20 days is given. The we create a histogram for the SKU so that we can have a frequency table for the part. Then the service level must be chosen and for the purpose of this research the service level that was chosen to calculate the OUT levels for all the SKUs was 95%. This service level was chosen to be the most commonly used and gives a good result to avoid stock out of spare parts 95% of the time. As seen in Figure 7 the frequency table is in columns L and M, the next is dividing the this frequency by the number of periods we have which is in cell K2 and is 82 for this SKU. In column O we see the cumulative sum of column N and in this column we need to identify the first cell with a value that is $\geq 0{,}95$, Then we can say that the bin on that same row as this cell will be the OUT level of this SKU. In Figure 7 the OUT level of this part is clearly highlighted in yellow which is 4.

4. Solution design:

This chapter will be explaining the model that was used in order to provide the solution and also the information about every step and provide the corresponding results and findings.

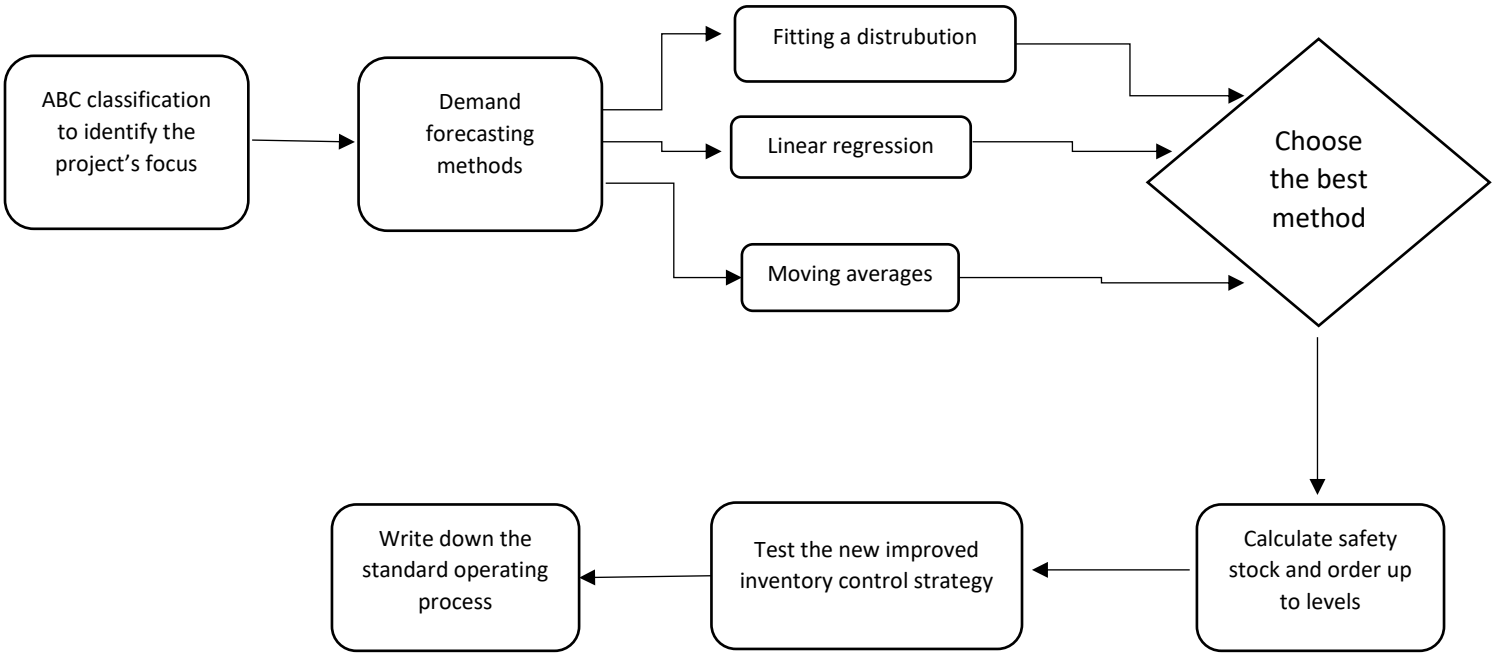


Figure 8: Flowchart of the solution design steps

4.1. ABC classification:

In this chapter, we will determine the research focus of the thesis project. The findings in this chapter will be an answer to the first research question that questions the following "Which items should be focused on so that it impacts the cost the most when improving the OUT policy?" It will be answered by making an ABC classification for the SKUs of spare parts. The section will contain an explanation of ABC classification, the reason for using this classification method, and finally the results of taking this approach.

4.1.1. What is ABC classification? How to make it?

The ABC classification method is a ranking system that clusters SKUs into three categories depending on the importance of the SKU.[10] The importance of the SKU is the ABC classification system is based on the value it has and for spare parts, this value is the cost therefore if a certain item costs a lot and the ordering quantity of it is also large and then compared to another item that does not cost as much and/ or the ordering quantity is smaller than the first Item is put at a higher category/placement than the second item.

The way of making this ABC classification is to create a table and it is best to use excel, the first column is a list of the SKUs, then the second column must have the part's price, and the third column will contact the order volume or quantity (in the case of this research I summed all the quantities ordered from that specific SKU throughout the whole period of data I have which is from Jan 2018 – May 2022). This is all

[10] Contributor, T. T. (2011, August 24). *What is ABC classification? - definition from whatis.com*. SearchERP. Retrieved July 28, 2022, from https://www.techtarget.com/searcherp/definition/ABC-classification#:~:text=ABC%20classification%20is%20a%20ranking,C%20%2D%20relatively%20unimportant

the given information that is needed and the rest of the columns will be computed and formulas will be explained below.

Column 4:

This column is the total cost and is computed using the formula below.

$$Total\ SKU\ cost = Part\ price * Quantity \quad (15)$$

Column 5:

This column is the cost share which is the percentage of the cost of the SKU from the total cost of all the SKUs and the formula is:

$$Cost\ share = \frac{Total\ SKU\ cost}{Total\ cost\ of\ all\ SKUs} \quad (16)$$

Note: This column must be sorted out from the largest number to the smallest one.

Column 6:

This column is the quantity share and it is the same concept as the previous column but only concerning the quantity, the formula for it is shown below.

$$Quantity\ share = \frac{SKU\ quantity}{Sum\ of\ all\ SKUs' quantity} \quad (17)$$

Column 7:

This column is the cumulative cost share percentage and is computed using the formula below.

$$Cumulative\ cost\ share = cost\ share\ of\ SKU + sum\ of\ all\ the\ shares\ of\ SKU\ previously \quad (18)$$

For the first SKU the sum is equal to zero.

Column 8:

This column is the category column, and it looks at the cumulative cost share, and depending on the number reached the SKU is put in a certain category. The criteria of each category are defined by the percentage and in this ABC classification category A is 70% category B is 20% and Category C is 10%, this means that the system will accept SKU in category A until the cumulative cost share reaches 70% then it starts grouping SKUs in category B until the percentage reaches 90% and finally in category C until the end of the SKUs. Because the 70 -20 -10 percentages are only corresponding to the cumulative cost share this means that the number of SKUs in each category is not equal.

A screenshot of the excel sheet will be in appendix 1.

4.1.2. Findings of the ABC classification method:

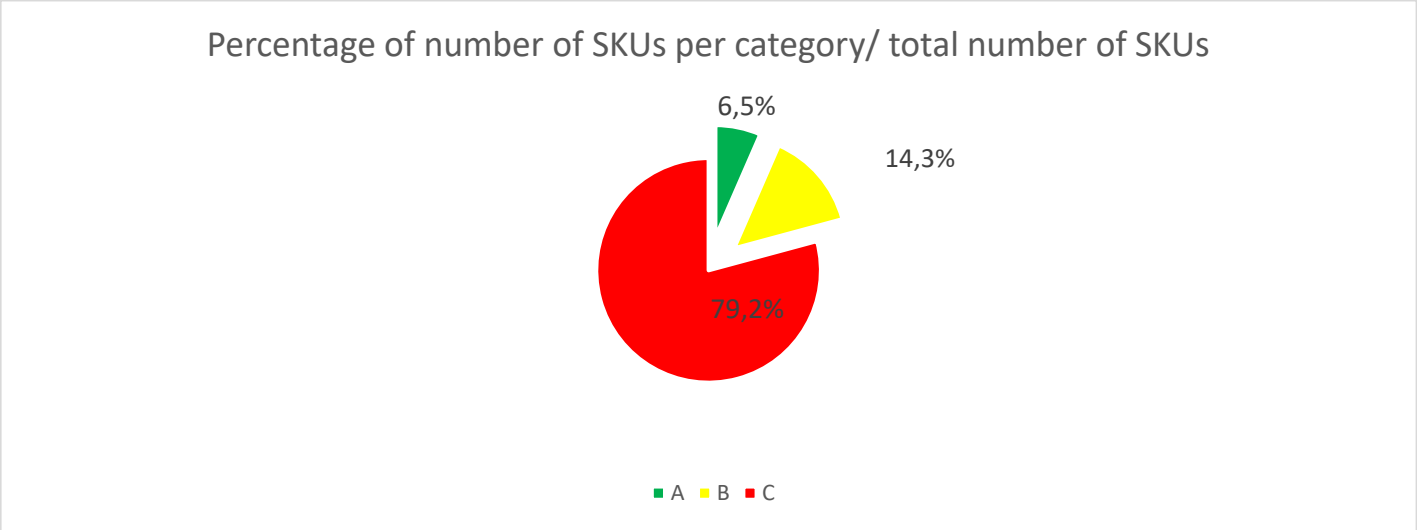


Figure 9: ABC classification results

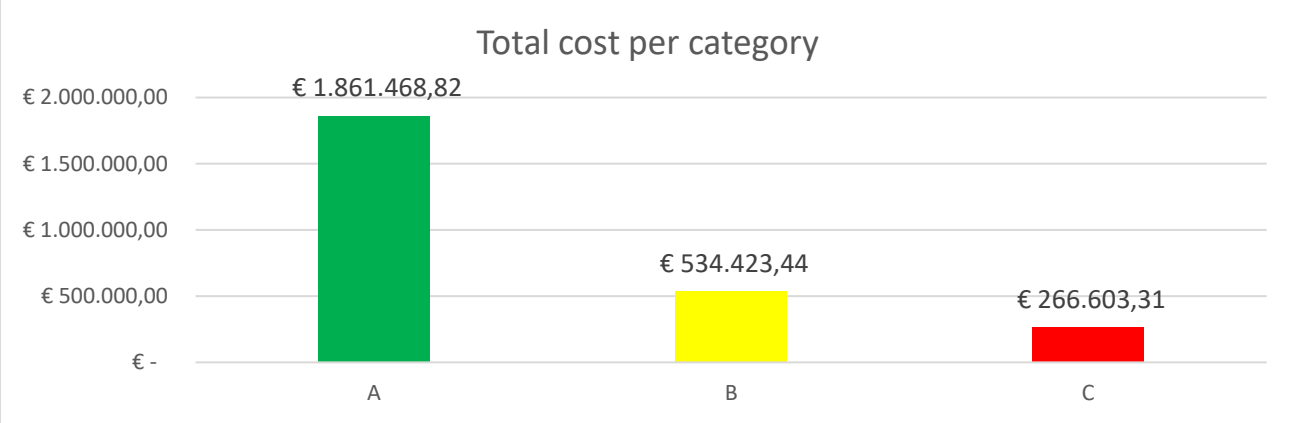


Figure 10: Cost value of each category for the past 5 years

The results of the ABC classification as shown in Figure 9 the percentages correspond to the number of SKUs in a category divided by the total number of SKUs. This explains the difference in the percentages between Figure 9 and the 70 -20 -10 categorization, as they correspond to different things. The percentage of the number of SKUs in categories A, B, and C divided by the total number of SKUs are 6,5%, 14,3%, and 79,2% respectively. Also, from Figure 10 we can see the total cost that comes from each category, and category A has the largest value. This means that the ABC classification is valid, and the approach was followed correctly.

For answering the first research question the focus of this thesis will be containing the categories A and B this is because they impact the cost of the site in Olst the most and it gives a total of 623 unique SKU's which will be more reasonable to focus on regarding the time restriction of this research. The rest of the SKUs are still important and can also benefit the company however it is best if they are disregarded for the time being and could be investigated further later.

As explained in chapter 2 the ABC classification needed to be done to focus on a smaller number of SKUs and the best way to do that is by using the most important items from the list of SKUs in the company to complete the research. The complete explanation of making this classification system is also written in chapter 2 and as a conclusion, the remaining steps of this solution design will only be considering the SKUs that are in categories A and B which are a total of 623 unique material numbers.

4.2. Demand forecasting:

To improve the inventory control strategy and to finally calculate the safety stock and OUT levels an identification of the demand must be made and this is also one of the research questions, specifically the fourth question which is: "What is the demand for the SKUs? How can it be forecasted?". Therefore, in this section, the answer to this research question with an explanation of how the answer was found and what methods were used to come up with the findings will be included.

4.2.1. Method 1: Fitting a distribution

Chapter 3.2.3 explains the method that was attempted to fit a distribution for the SKUs however not all the steps were undertaken this is mainly because after the histograms for all the 623 SKUs were made, we have realized that the data does not show relevance for any of the standard known distributions this can be seen in the figures below. Therefore, we stopped this approach and disregarded it as it will be giving unreasonable results.

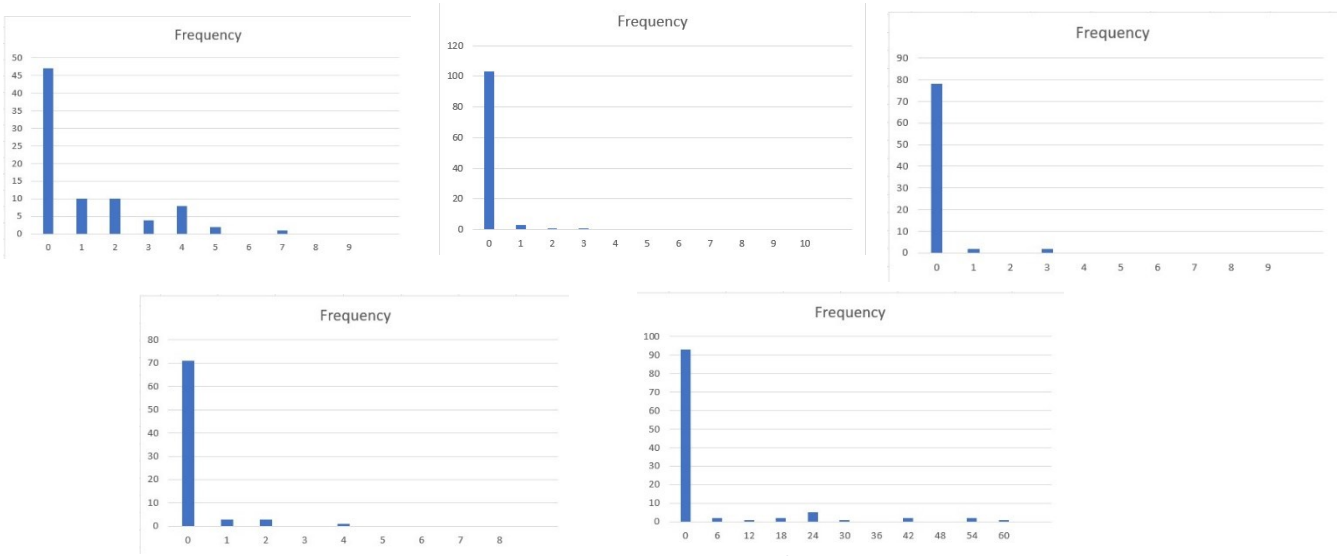


Figure 11: Histogram examples

As seen in Figure 11, five histogram examples of five different SKUs do not show any relevance to a singular distribution and these 5 examples basically shows the same kind of histograms for all the 623 SKUs. The histograms however show relevance to a mixed distribution which is identified by seeing that there are 2 significant modes and this means that a mixed distribution can be used to forecast the demand however with the knowledge that I currently have and also respecting the time scope of this research this method can't be done in this research therefore it can be done in further investigations. However this method can still be done as we can fit the data we have for demand to an empirical distribution and we can use the histograms that were made for this method to figure out the OUT levels and then calculate the SS levels as explained in chapter 3.3.1. & 3.3.2.

4.2.2. Method 2: Linear regression

For linear regression, an explanation of the steps of making it can be found in chapter 3.2.2, these steps were applied to the data that we have and the findings that we came up with in conclusion, linear regression is not the best method for forecasting the demand of spare parts and especially for Abbott. The reason is that linear regression simply just stretches the linear trend line and assumes that the demand will follow this trend line and future demand can just be plotted on that stretched-out trend line as points. This is unreasonable because the demand for the spare parts in Abbott is never constant nor has a trend. With linear regression, if the slope of the trendline has a negative value like in Figure 12 below we see that the trendline has a slope of -0,33, this means that the demand for this part will reach zero at a certain point if the line was stretched enough. This does not make sense because this slope only became negative because there are a lot of months that this part was not used that is because it is not always needed which is reasonable because this is how spare parts behave as they are only needed when a machine fails. To conclude we can say that the linear regression method has failed to give us the right assumption for demand and the method can be disregarded.

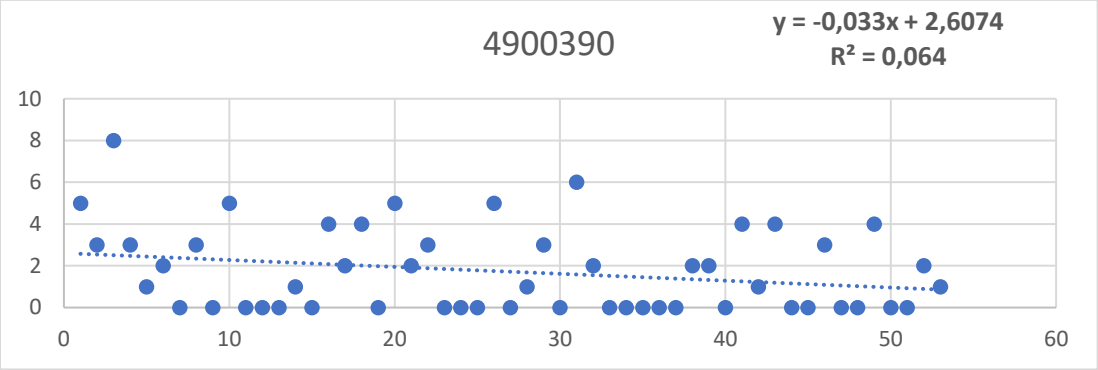


Figure 12: Linear regression line for one of the SKUs

4.2.3. Method 3: Moving average

The steps in chapter 3.2.3 were followed to make the method of forecasting the demand, the method worked fine and with no issues, however, this method only forecasts the demand for one period i.e., one month that comes after our historical data. This means that we can't use this approach as it will also not help us with calculating the safety stock levels and the reordering points.

4.3. Trend and seasonality

After looking at the 3 different methods and before deciding on the method that best resembles the expectation of demand we needed to look at the variability of the data and try to find a way that explains this variability, therefore the method that was used was by looking at the trends and seasonality of these demand data, to do this we needed to find the seasonal indices to test whether there is any seasonality in the data, also the demand will be plotted as graphs to look if there are any trends that happen regularly. These trends and seasonality if found it would explain the variability of the demand and that way the demand forecast would be adjusted to match this seasonality and trends.

After careful consideration and analyzation of demand plots and seasonal factors it was determined that these factors do not show relevance to the variability of the demand and that can be shown in Figure 11 and as we see the R^2 value is very low and therefore this shows that there aren't trends in the demand

of this data. Regarding the seasonal factors the figures below will show how that these factors do not show relevance to the variability of the demand.

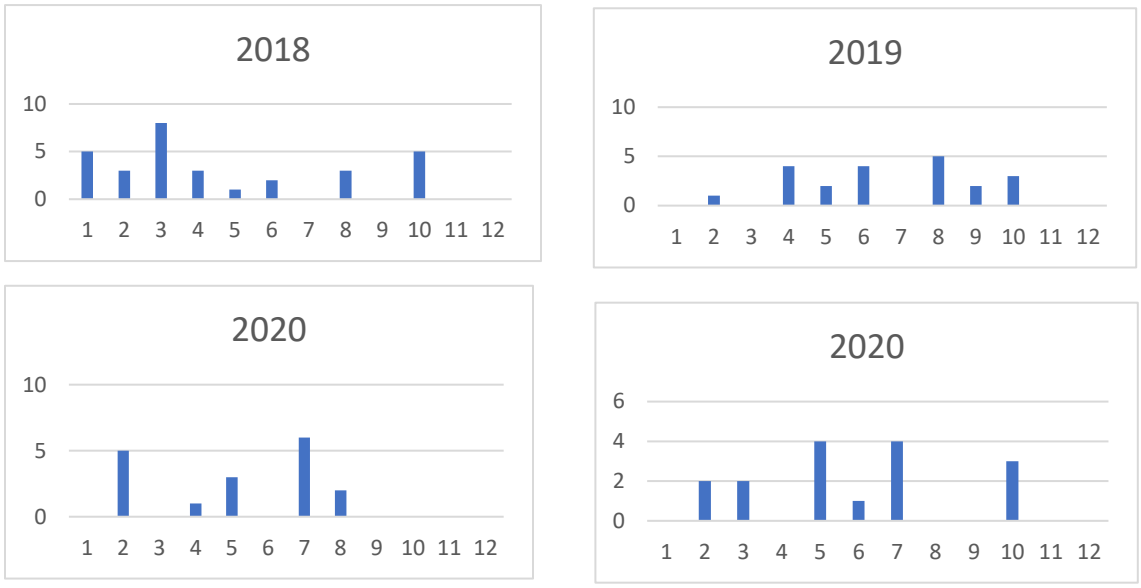


Figure 11: Stock use of SKU 4900390 of 4 full years

As we see from Figure 13 all the different years show different demand variability and although the seasonality factors were computed however in our case we can't explain any variability through seasonality because we do not see a certain season that the demand is similar to the rest of the years. This was the same case as the rest of the SKUs and because of that we assumed that the variability of demand is explained by random demand models and probability distributions and we use the histograms alongside the method of demand expecting that will be chosen in the next section in order to recalculate the SS levels and ROPs of the SKUs.

4.4. Choosing the best method of forecasting demand:

From all the forecasting methods in section 4.2 we have determined that the best method for forecasting demand and that will help us determine the safety stock levels and reordering points for the improved policy is method one (Fitting a distribution), however, we will use this method by fitting the distribution to an empirical distribution and we will use the histograms in order to recalculate the safety stock and OUT levels as explained in chapter 3.3.1. and 3.3.2. The method is not the best method that can be done for solely forecasting the demand but for the purpose of calculating the improved values of our parameters in the new OUT policy it is the best method we can use. Because of the mentioned data problems it will be better if this study is made again with the fixed data and with more time to find exactly how much demand will be needed in the future using the approach of fitting the data to a mixed distribution, also these methods can be merged with a study of the failure rates of the machines to see which parts are needed for each machine and when are they needed. This unfortunately was not possible in the time scope of this thesis so we can just get the OUT levels from the histograms assuming an empirical distribution then we can calculate the SS levels. This is also an improvement as the OUT policy in the results will work better that the current situation.

4.5. Order up to policy improvement:

In this section a description of the new recommended policy that will be given in this research paper for the site is given and mainly a description of the two most important parameters are given which are the safety stock level and OUT level.

4.5.1. Safety stock levels:

The safety stock levels have been computed using method 2 that was explained in chapter 3.3.1. This is mainly because the first method assumes that the demand is coming from a normal distribution which after careful analyzation and looking at the histograms the SKUs clearly did not show any significance to the normal distribution, therefore the second one was used as an approach for calculating the safety stock levels assuming an empirical distribution. Therefore we reject the first method and we test validity and optimality only on the second method which will be done in chapter 5 of this thesis. The values of the safety stock levels can be found in appendix 4.

4.5.2. Order up to levels:

From the data given it was identified that the reorder points of the SKUs are set but however we needed to calculate the order up to levels as we are providing an OUT policy then we test their validity and optimality meaning we will be testing both the new OUT level and compare it to the old ROPs. When computing the OUT levels, we used the method explained in chapter 3.3.2. Although the ROP levels and OUT levels have different meanings but we can just compare the different situations and see if there is an improvement between the old and the new situation.

5. Solution testing:

5.1. Safety stock levels Order up to levels:

To test the calculated safety stock and OUT levels we can provide five different case studies where we will be analyzing the old situation and whether the new values are better or not. These cases have been chosen at random and they just form a small sample of all the SKUs but the purpose of looking at these case studies is to test if the new values are really better than the old situation and if they change anything regarding the KPIs that we are trying to improve.

Case study 1:

This case study will be focusing on the SKU "4900390" this material is PNEUMATIC SEAL ISOLATOR L=2750 which is one of the spare parts of Abbot. The part is priced at around € 1.360,80, after the ABC classification results this part was in category A and in fact the top one in category A. This means that this part has a huge part in the total cost of the site and has the largest cost share out of the rest of the SKUs. In the period of the data which is around four and a half years the part was used 91 times which corresponds to a value of € 123.832,8. With a monthly mean of around 1,72. The safety stock, OUT levels, and old reordering point is shown below.

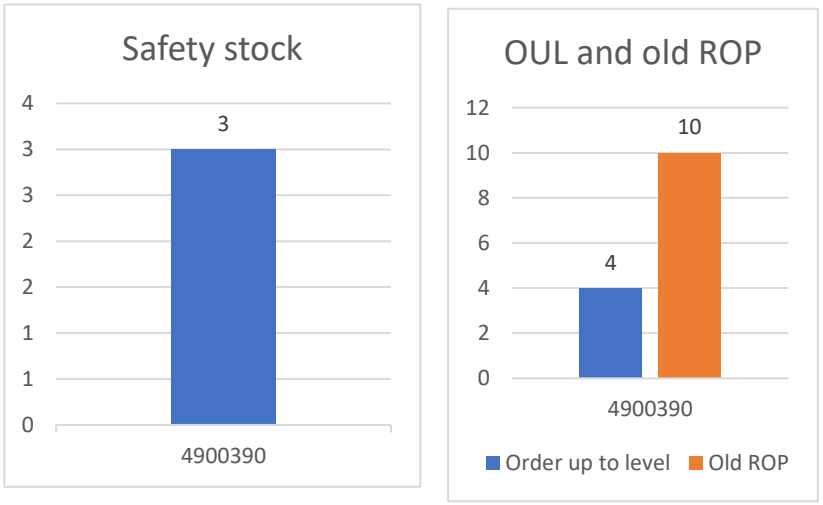


Figure 12: Safety stock, OUT, and Old ROP for case study 1

So as it clearly states in the figure the safety stock is determined to be around 3. The old ROP is set to 10 but the OUL is 4. The lead time for this part is around 20 days and considering the average that it was used we can definitely say that we don't need such a high reordering point of 10 since this number is very large the company will keep reordering even when the part is not even needed so using an OUT level of 4 parts so that we keep having a maximum of 4 parts in stock is much better for the cash flow of the business and will even save costs because we won't be ordering more than what we actually need. The figure below also helps with visualizing how much was used for each month.

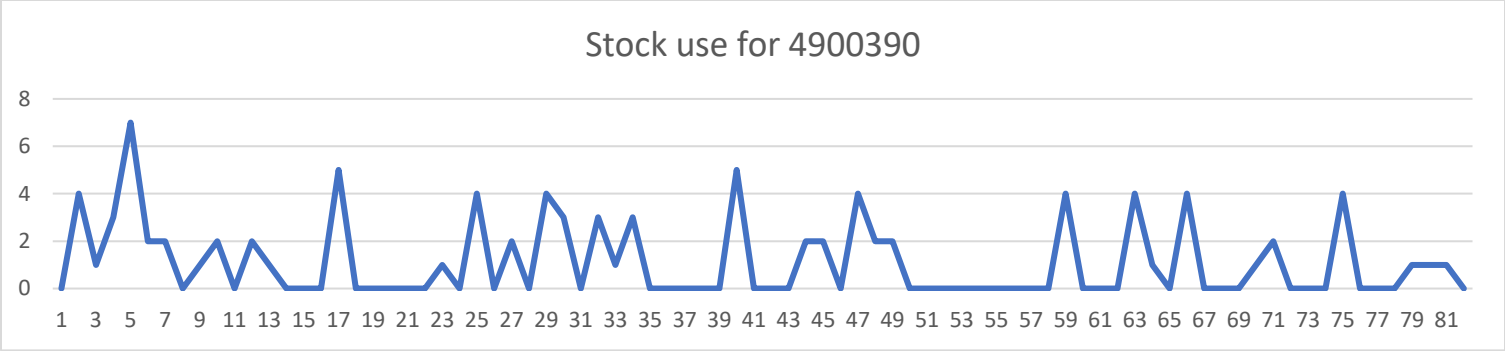


Figure 13: Stock use for case study 1

To conclude this case study is a perfect example of how the new ordering up to policy can help improve the KPI of having less inventory cost as we will be ordering closer to what we need and not ordering more parts which will not be used for a long time, therefore money is spent efficiently. Also there won't be a tradeoff of having a bad service availability because the safety stock and OUT level should guarantee a 95% service level.

Case study 2:

In this study the part that will be analyzed is "4909570" which is a ZUIGNAP D=8MM WIT Hypak and this part had an average monthly use of around 140,7 and it is also in category A according to the ABC classification. The price of this part is € 4,56 and although this might look cheap, but it does have a large cost share on the company and that is because it is used more and in bigger quantities than the material in case 1. In the past four and a half years the total stock use was 7457 which is a total value of € 34.003,92. The lead time for this part is around 10 days.

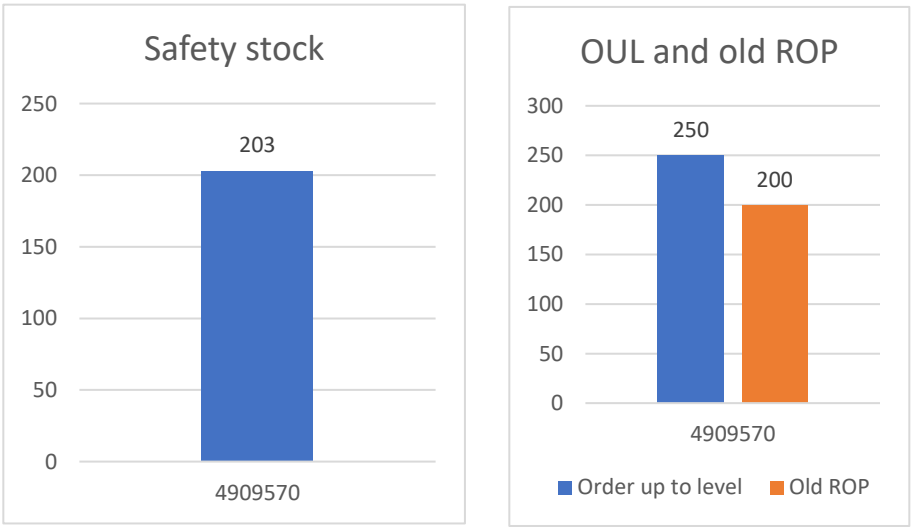


Figure 14: Safety stock, OUT, and Old ROP for case study 2

For this part the problem was not with the reordering point as the computed OUT level is very close to the one that was already set but the problem is that there is no safety stock and since the part is

used a lot at the site for example the maximum use for one month was 500 and if we look at the figure below:

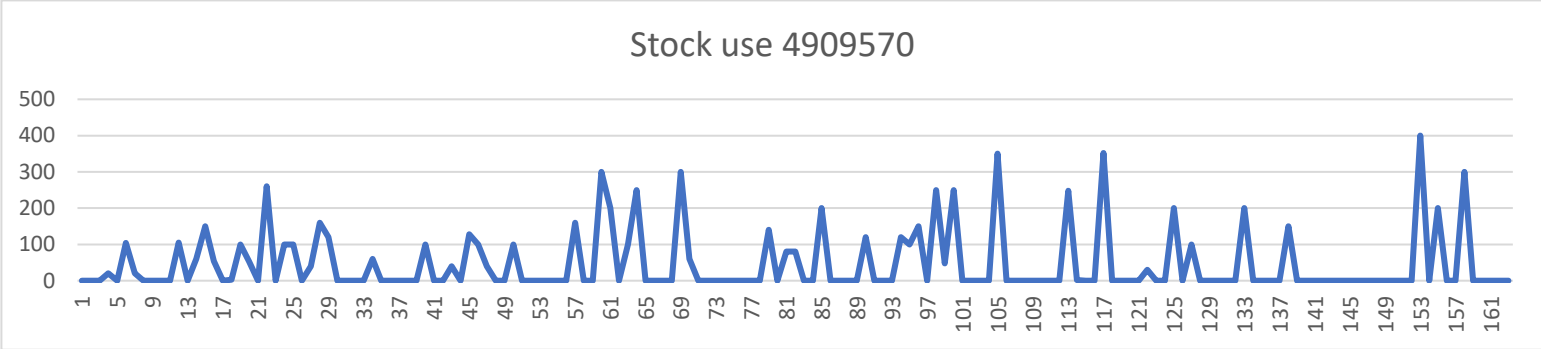


Figure 15: Stock use for case study 2

From this we can see that the safety stock level is very much needed as there are many months where the stock use is high and therefore applying these values to the policy can limit the loss that comes from the stock out of this part this way the company will generate more revenue.

To conclude this case study shows that the new OUT policy will improve the service level availably with the tradeoff of having more inventory cost but it will be needed based on the demand and past stock use of this part so it will also help with limiting any stock out costs.

Case study 3:

For this case study we will focus on material number "4900593" and the description is VERNAUWDE BUISJES PLUNJER this part's average monthly stock use is approximately 1,9 and the part price is € 181,55 it was used at a total of 100 parts which is a value of € 18.155 and it is also in category A according to the ABC classification system. The lead time for this part is 35 days, the safety stock, OUT levels and old ROP are given below:

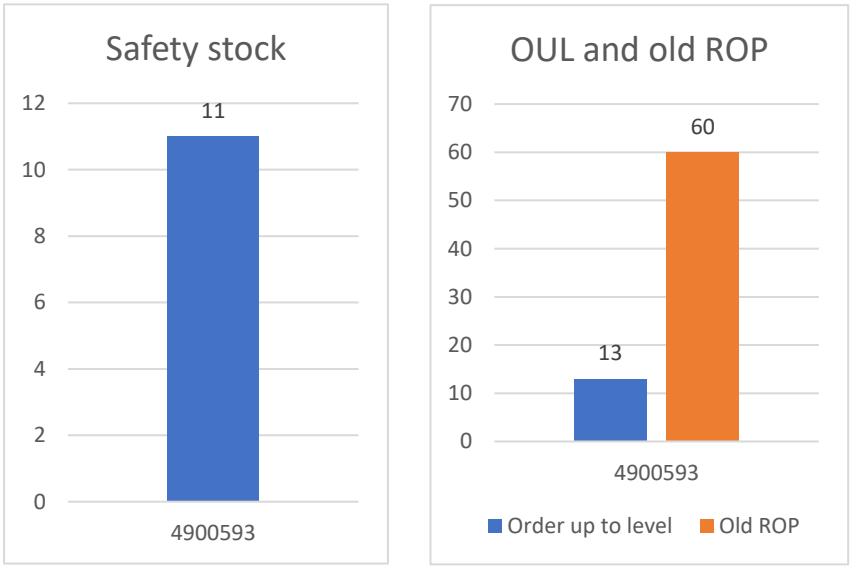


Figure 16: Safety stock, OUT, and Old ROP for case study 3

As we can see from Figure 18 it is shown that the OUT level is much lower than the old ROP and that is mainly because on average the part is not used a lot and it is also shown from Figure 19 we can see that the stock use was never up to 60 in fact in four and a half years the site only used 100 therefore it is really unreasonable to have the reorder point set at 60 especially for a part with such a short lead time of 35 days. So once again these calculated values of SS and OUT levels provide a better situation if they were implemented.

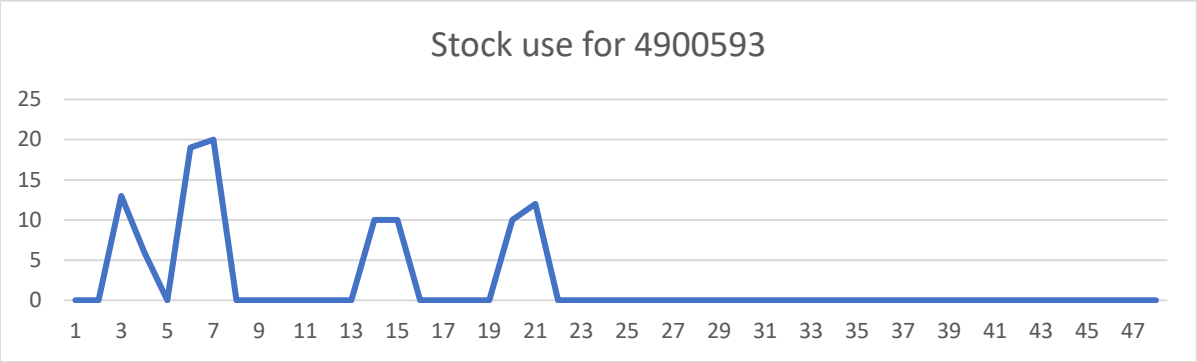


Figure 17: Stock use for case study 3

This case study concludes that the reordering policy created will help this SKU from saving costs and lowering the inventory cost while also keeping the service level availability at 95%.

Case study 4:

The material number of this case study is "4913319" with a description of SEAL MAL POSITIONEERPEN /NIEUW trapt GTE. The monthly average of stock use is 24,5 approximately. The price of this part is € 10,65 and over the whole period of the data given 1300 of this part was used. This gave a value of € 13.845. The lead time is 15 days, the SS, OUT level, and old ROP are given below:

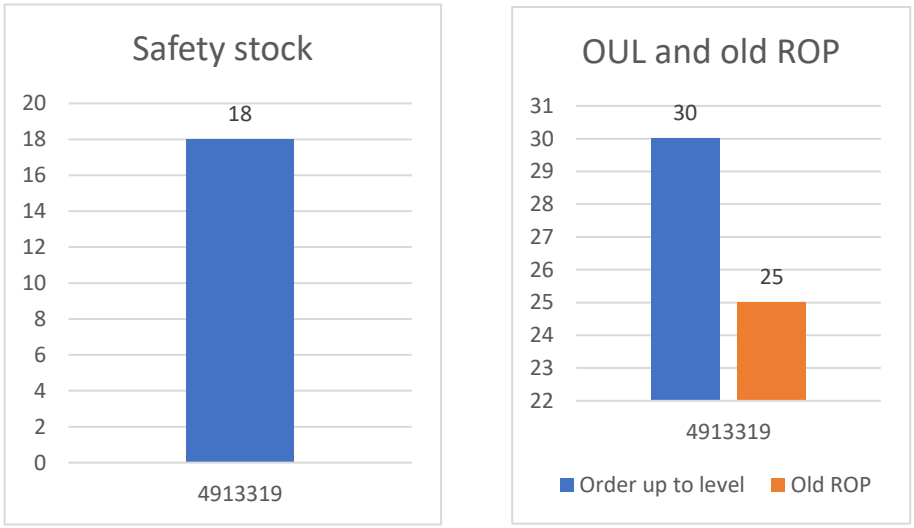


Figure 18: Safety stock, OUT, and Old ROP for case study 4

In Figure 20 we can see that the OUT that was calculated is a little more than the ROP that is set, and this OUT level will guarantee that the stock level will not be lower than 30.

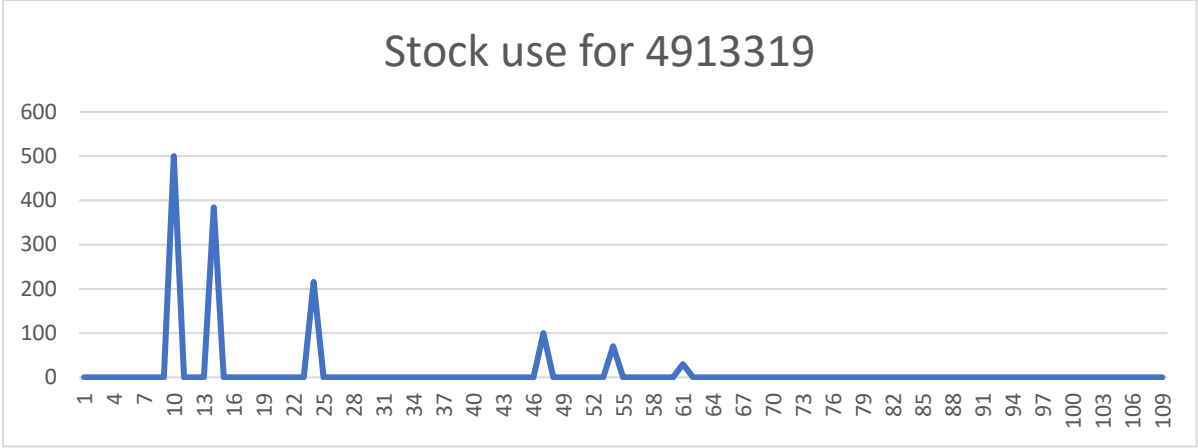


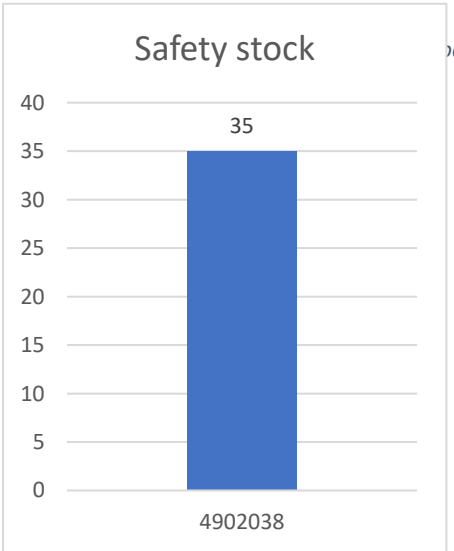
Figure 19: Stock use for case study 4

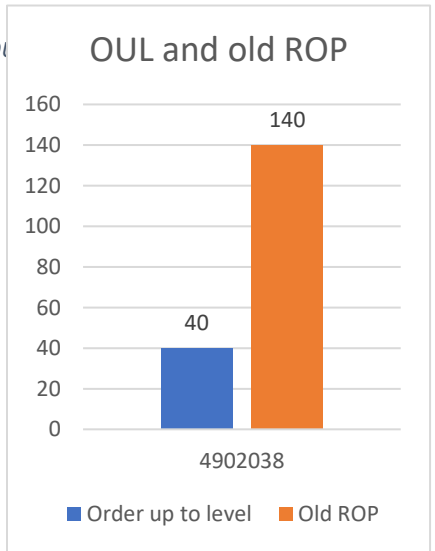
Even though the average for this part is 24,5 but we can see that when this part is used and excluding the months where the stock use is 0 we can see that the part is used in large quantities therefore we do need a safety stock that is relatively high which in this case the policy did not give and that the new policy is still not optimal which is a limitation for this policy and therefore we can say that there would be some parts were the policy will have to be changed for some SKUs.

This case study is a perfect example of one of the limitations that the policy has and which is that this policy sometimes fails to keep a service level of 95%, although this might be harm for the policy however this is only one SKU out of 5 and that means that only some SKUs wil have to get a change in the policy so that it is tailored to the demand trends.

Case study 5:

For material number "4902038" and the material description TRANSP. SILICON FRIC. LINING 3783900201. The monthly mean of this spare part is around 7,3 and the price is € 32,66 and it was used as a total of 387 parts in the last four and a half years. This is at a total of € 12,639,42. The lead time is 20 days, the SS, OUT, and the ROP are given in the figure below:





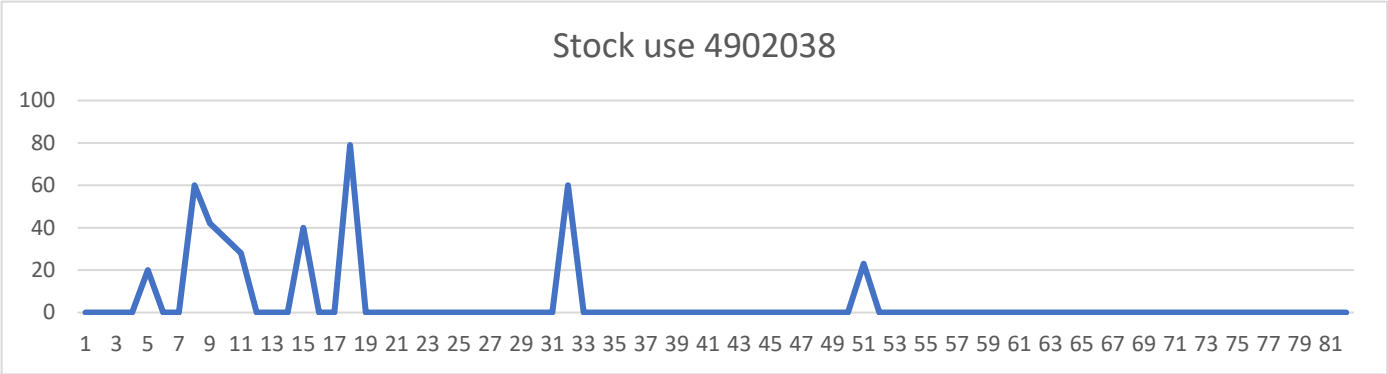


Figure 21: Stock use for case study 5

As we can see from Figure 22 it is clear that a reordering point of 140 is not optimal since the stock use over the historical data never even reached this far and therefore the new OUT level will be much better for the company and will prevent any stock outs.

The new reordering policy will help this SKU lower the average inventory cost and the amount of money spent when not needed while also maintaining a 95% service level availability.

5.2. Conclusion:

After looking at these five case studies we have concluded from this sample of five SKUs only one of the new values seemed to be unreasonable or lowers the efficiency of the site but however even this case did not have a better situation with the old policy, the 4 other SKUs in fact had the exact opposite as these values make the policy more efficient, saves costs, and limits the potential loss from having stockouts. Therefore, we can say that the calculated values of the SS and OUT levels are much better if they were implemented, instead of the old policy. The values for the rest of the SKUs are all given in appendix 4 and 5. The values for SS are all higher than the levels that were in the data because they were all set to 0 in the system of SAP. We can say that the new policy makes the company save some money and if we wanted to estimate we can say that because the company was spending money on parts which they do not need and this amount was around €200K over the last 4 and a half years, however with this improved policy we can confidently say that the policy will prevent this from happening in the future and it will also save some more money which was not computed in this research like downtime costs, stockout costs, and potential loss of revenue. Using this policy will guarantee having spare parts in stock when a part is needed 95% of the time due to our service level, also it will decrease the inventory in the technical warehouse which is the main core problem identified in the beginning of this paper.

Regarding the one case that failed to give a better policy than the old policy is unfortunate but it can also be solved by looking at the SKUs which fail to do so and change the policy so that it is tailored to the demand trends and which is not very hard as for this particular case raising the OUT and SS level will solve the problem entirely. But it is also important to know that the policy is very good and will save cost however it could be not the most optimal for a very few portion of the SKUs.

6. Conclusion:

6.1. Conclusion and recommendations:

This section will be summarizing the results of this research and how it was found and then finally answering the main research question of this thesis which is "*How can spare part management be improved to minimize the cost of materials?"*. The section will also contain the recommendations that are advised for the site which are based on the findings of the research.

The first step of finding the results of this question is to interview people in the company to grasp the current situation and how the company manages its spare parts, then try to discover the gaps and problems in this process and find out a way to solve these problems. Listed below are the gaps and problems that were identified with some recommendations that are advised to solve these gaps and problems.

- Process of collecting spare parts

The process of collecting spare parts in the meantime is an old process since forms are being filled out to indicate that a technical specialist for example has taken parts from the warehouse. Since this process was identified to be failing a lot a nice recommendation for the site is to consider investing more time and money for the technical warehouse to be able to introduce a barcoding system for all the spare parts so that it will be much easier to log any movement of the spare parts, and this recommendation is easy to be implemented since the SAP printer already exists in the warehouse. If this recommendation was implemented, then SAP will have a correct indication on what the actual stock is this way it will provide more accurate orders on when to order parts and exactly how many should be ordered. We must keep in mind that SAP is always efficient and gives optimal decisions but however that is only if the data that fed to SAP is correct and the human integration with SAP is done correctly.

- Storage capacity

For the storage capacity problem in the technical warehouse the site is already aware of this situation and management is already working on the solution where they will be bringing new revolving shelves to the technical warehouse soon and this is exactly the solution that is needed, therefore add recommendation can't be given and this problem is assumed to be fixed with this solution. An advice that can be said is to keep working on this problem and try to fix it as soon as possible as it will be very beneficial for the site.

Therefore to answer the research question we can say that the spare part management can be improved to save costs by firstly implementing the new SS and OUT levels into the OUT policy to make the process more cost efficient and also change the process of collecting the spare parts from the warehouse by having barcodes on the spare parts that can get scanned to directly enter the stock use into SAP this way it solves the data entry problem which will make SAP give the correct decision.

- Safety stock and OUT levels

After data gathering and data analyzation that was done using the information in section two and three the safety stock and OUT levels were calculated and tested in section 5. From this we can conclude that the recommendation that could be given for the site is to implement these safety stock and OUT levels in the OUT policy so that the company could save costs, limit potential losses due to spare parts

stockout, and use money as efficiently as possible by not ordering more than what's needed. Using the new reordering policy allows the company to improve on the KPIs of this research by reducing the inventory cost while also keeping a service level of 95% to reduce the probability of having a stock out.

6.2. Limitations:

The limitations that are found in this research start with the data as explained earlier the data that was given and that is available from the site has a data entry problem, this means that the actual stock is different than the stock in the data which was extracted from SAP. Therefore, this gives a limitation that makes the calculated safety stock and OUT levels not the most optimal. However, this does not mean that those recalculated values are not beneficial, but they would give a better result if the actual stock use was correct and therefore a solution to this has also been given in the recommendations to fix the data entry problem. The other limitation that is found is that the monthly demand was assumed to be the average of the past months although this method works however other methods could be better for example we could look at the mixed distributions and try to fit the demand data to these distributions in order to get better results of demand expectation which will be more reliable for the calculation of the SS and OUT levels, of these SKUs, this was not done unfortunately because it will take more time than what we have for this research and could be something to consider in further research. Another limitation is that in this research we ignored Economic order quantity and we provided an OUT policy for the SKUs and this could be a limitation to some SKUs which we will need in large quantities and if the supplier will provide a lower price for bulk buying, however for the scope of this research it is outside that scope and the information for making these conclusions are missing. Another limitation that is in this research paper if that when testing the OUT and SS levels only 4 out 5 samples succeeded to provide an optimal policy and one of them didn't therefore it is important to be careful when implementing the policy and try to alter the policy for a few SKU, however it is also important to note that the policy does work for most of the SKUs but just a review before implementing is recommended.

7. Standard operating process (SOP):

This section will give a brief guide for how the process should be going based on the results of this research and it will help the people from the company on following the recommendations that were given in the thesis.

7.1. Ordering parts:

The ordering of parts must be following the reordering policy that was found from this thesis meaning that for each SKU a certain amount of stock must be always stored and that is the safety stock levels and the reordering must happen only when the stock level of a certain SKU reaches below the OUT level and we must order up to reach that OUT level. This way the company does not order more or less than what is needed.

7.2. Data logging of stock use:

This step is crucial and will help make the policy more optimal as the logging of stock use will give the company the correct expectations of demand therefore it is important to follow the process correctly by always filling in the forms for the stock use and also it is important to work towards improving this process of taking parts from the warehouse so that it automatically checks out the part that has been taken and this can be done by introducing the barcodes and scanners to the technical warehouse.

7.3. Kaizen:

Kaizen is a Japanese term that corresponds to the business philosophy of continuous improvements.[11] This philosophy is what needs to be done for the reordering policy as improving it will get it to become the most optimal and since parts differ from time to time and the demand for certain parts could increase or decrease depending on many factors therefore, the policy should also be improved and changed respectively.

7.4. Policy testing:

The policy testing will happen through closely monitoring the spare parts stock use and analyzing the data to find if the stock use was close to the stock ordered or not and whether any changes should happen which also goes back to the previous section which is kaizen as it creates a loop of continuously improving the policy and the process of spare parts in general.

8. Further research:

The further research that could be done is firstly looking at the rest of the SKU in the company as this researched only focused on the SKUs in category A and B from the ABC classification, however, to reach an optimal reordering policy all the SKUs must be recognized and the parameters for all these SKUs must be adjusted. Another point that could be taken into consideration if this research was taken further is as mentioned in the limitations and try to fix the expectation of the demand by finding a distribution that fits the demand model using a mixed distribution which as mentioned in the limitations couldn't have been done due to the limited knowledge about these mixed distributions and the limited time we had for this research which made learning this topic something that couldn't be done in this research.

[11] Google. (n.d.). Google search. Retrieved August 16, 2022, from https://www.google.com/search?q=kaizen%2Bmeaning&rlz=1C1GCEA_enNL996NL996&oq=Kaizen%2Bmeaning&aqs=chrome.0.0i512l10.4860j1j7&sourceid=chrome&ie=UTF-8

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Appendices:

Appendix 1:

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Figure 22: Excel screen shot of the ABC classification table

Appendix 2:

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Figure 23: Calculation of finding the amount of money spend when not needed

Appendix 3:

Table 1: Table listing the monthly averages

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Appendix 4:

Table 2: List of the computed safety stock levels

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Appendix 5:

Table 3: List of the order up to levels and old ROPs

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