INCREASING THE MATERIAL AVAILABILITY TO DELIVER ON TIME

Bachelor thesis Industrial Engineering and Management

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DEMCON | production

UNIVERSITY OF TWENTE.

Preface

Dear reader,

I would like to present you my bachelor thesis, the final project of my bachelor Industrial Engineering and Management at the University of Twente. I conducted this research about material availability for DEMCON Production B.V. in Enschede in the period September 2019 until February 2020.

The goal of this research is to get a solution for the problem ‘the material is too late in stock’. I have learned a lot about doing this research, about inventory management, working in a company and asking for feedback.

I would like to thank my supervisor at DEMCON, Gino Heijnsdijk, for all the support and help. Also, my thanks go to the employees of DEMCON, who always have time for answering questions. I felt welcome at DP and I am pleased that I got this opportunity.

I would also like to thank my supervisor at the University of Twente, Matthieu van der Heijden. His feedback helped me to get the most out of my thesis and he was always available for questions.

I hope you enjoy reading my thesis.

Arisca Wonders

Management summary

The basis of this research is the action problem: delivery of products is too late. The core problem of the action problem is: material is too late in stock. The goal of this research is to get an answer on the research question:

What must DP do to have the needed material in stock at the moment the production is planned to start?

To get an answer on this question, the following sub questions are answered in this research:

1a. How can processes in an organization be mapped in a clear way?
1b. What does the current purchasing process look like?
2. What are the reasons that the required material is not in stock at the moment the production is planned to start?
3. What are solutions to get material on time?
4. How can the solutions be implemented at DP?

A literature study is done for answering question 1a. After comparing three different mapping techniques, the Business Process Management Notation (BPMN) is used to map the purchasing process and to get an answer on sub question 1b.

During the data analyse phase, it becomes clear that 57,3% of the sales orders of company X are too late and 57,1% of the sales orders of company Y are too late. The material for the orders of company X are 23,7% of the time too late and the material for the orders of company Y are 29,0% of the time too late. The data, however, is not always accurate. After analysing the map, the data from AFAS, the ERP system of DP and having interviews with six employees of DP, the following main problems within the scope of this research are found:

- There is no overview of the material planning
- Suppliers are unreliable

These problems can be divided into more sub problems. In consultation with DP, we choose to focus on the following sub problem: *The fluctuations of the demand and the delivery time of suppliers are not captured with a safety stock*.

For this problem, a tool for determining the safety stock is developed. It can be connected to the ERP system of DP. The tool is based on independent demand instead of the situation at DP, were dependent demand occurs. A simulation study with 20 items is done to find the differences. The percentage of days where 'stock outs =>1' is 26,7% lower for a dependent inventory than for an independent inventory. Also, the average value of the total stock is 9,7% higher for a dependent inventory instead of an independent inventory.

If the frozen period increases, the total value of the safety stock becomes lower. For a frozen period of 65 days, the frozen period has the most influence on the value of the safety stock. The value of the safety stock with a frozen period of 65 days is 59,0% of the value of the safety stock with a frozen period of 0 days. Also the standard deviation of the demand influences the safety stock. The value of the safety stock is 10,9% lower if the standard deviation of the demand per month is 0 instead of 20.

Class C (50,6% of the components are classified in class C) and class B (34,2% of the components ae classified in class B) have relatively much influence on the service level of the safety stock. If the

CSL of class C products increases from 0,900 to 0,999 and the CSL of the other classes is 0,900, the total value of the safety stock increases with 0,2%. For class B products, the total value of the safety stock increases with 8,4%. Recommendable is to have a high CSL for these both classes (0,990 – 0,999). 15,2% of the components are classified in class A. If the CSL increases form 0,900 to 0,999 and the CSL of the other classes is 0,900, the total value of the safety stock increase with 56,2%. For class A products, a trade-off between service and costs must be made.

Forecasting models for predicting the demand is taken out of scope during this research. If the expected demand is predicted well, the uncertainty of the demand decreases, which results in a lower safety stock (if other parameters are unchanged). Besides, the simulation showed difference between an independent demand and a dependent demand. Before implementing the tool, it is advisable to elaborate the tool with an assembly inventory model.

Table of contents

List of abbreviations

BOM – Bills Of Material

BPMN – Business Process Management Notation

DDMRP – Demand-Driven Material Requirement Planning

DP – DEMCON Production B.V.

EPC – Event-driven Process Chain

ERP – Enterprise Resource Planning

ISO – International Organization For Standardization

KPI – Key Performance Indicator

MRP – Material Requirement Planning

NPI – New Product Introduction

SMPS – Supplier Performance Measurement System

UML – Unified Modelling Language

1. Introduction and problem identification

1.1 Company: DEMCON Production

DEMCON Production BV is a part of DEMCON Holding Group, a high-end technology company. DEMCON was started as a spin-off of the University of Twente twenty-six years ago. At the moment, DEMCON is still growing and has more than 600 employees and six locations. DEMCON Holding Group exists of a lot of companies and corporations with companies. Customers of DEMCON take advantage of the fact that DEMCON can meet all their needs as a system supplier, from designing products until production.

DEMCON has five focus areas, namely:

- High-tech systems
  These systems could be 'a single production machine, but also complex modules in series'. Examples are 'an advanced qualification tool, a robust tool moulding machine, a highly accurate positioning module and an innovative mass flow sensor' [1].
- Industrial systems & vision
  The industrial systems are developed 'for the broad mechanical engineering market'. Examples are 'a vision system for process control, setting up manual or automated worksites, the installation of an assembly line and the construction of a special machine' [2].
- Medical systems
  Medical systems are designs for 'diagnosis, therapy, care and self-care'. Examples are 'an operating system for eye surgery, a hand scanner for rheumatoid arthritis, a ventilator or a hearing aid' [3].
- Focal optomechatronic systems
  These systems are developed 'for the semiconductor industry, space travel and other high-tech markets'. Examples of these systems are 'alignment and level sensors, lenses/optics for laser-based manufacturing and complete lithography systems'[4].
- Robotic systems
  Robotic systems have a lot of applications, such as 'medical robots for diagnostics and therapy, inspection robots and drones'[5].

At DEMCON Production (DP), the production of some of these products and systems take place. The products, made by DEMCON, are made-to-order and are made in small amounts. At the moment, DEMCON Advanced Mechatronics (DAM) is especially the developer of the products, which are produced at DP. DP wants to bring in more production orders from other companies in the near future.

[1] https://www.demcon.nl/en/hightech/
[2] https://www.demcon.nl/en/industrial/
[3] https://www.demcon.nl/en/medicaldevices/
[4] https://www.demcon.nl/en/optomechatronic/
[5] https://www.demcon.nl/en/robotic-systems/

1.2 Research motivation

DP is a production-oriented organization. The manager director of DP wants to deliver all the products on time instead to get satisfied customers. The organization has problems with delivering on time. This became clear during a conversation with the manager director of Company X, one of the clients of DP. Company X mentioned that only a small amount of the products of last year was delivered on time.

Company X is a part of the DEMCON Holding Group. In this case, this means that DEMCON Holding is the main shareholder of Company X. As a consequence, Company X cannot choose another producer of their products. Company X explained during an interview that if it is possible to switch to another supplier, Company X would do this. The negative consequences of the late delivery for Company X are less profit and less reliability to the customers. Another customer of DP, for example Company Y, is also confronted with late delivery of products.

1.3 Problem identification

The action problem is that the delivery of products is too late. To identify the core problem of the action problem, a problem cluster is made (Heerkens & Van Winden, 2012). The problem cluster is shown Figure 1.

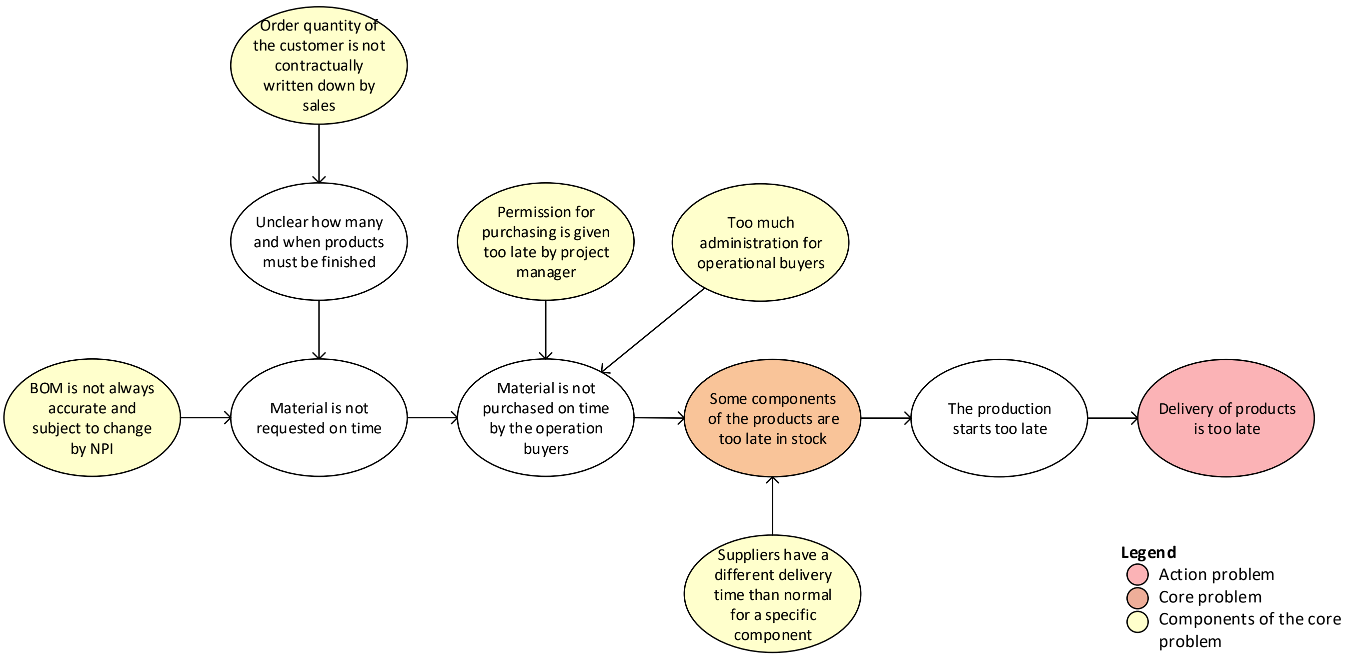

Figure 1 The problem cluster

In the problem cluster, the action problem is shown in red. The core problem is coloured in orange. The core problem is: ‘some components of the products are too late in stock’. Products at DP are ‘make to order’, which means that only after a sales order, material can be bought. The core problem is the basis of this research. Due to the core problem, the production starts too late.

At DP, there are more causes of late delivery of products. These problems are still not noticeable at this moment. The first barrier is the lack of materials, but surely more problems will appear when the first barrier is cleared up.

In the problem cluster, also problems are shown in yellow. These problems are components of the core problem. These problems cause the core problem, but it is not clear to which extent. That will be investigated during this research.

The components of the core problem are:

- Bill of Materials (BOM) is not always accurate and subject to change by New Product Introduction (NPI)
  Because of the fact that DP produces relative new products, the BOM is changed frequently. DP gets information about how to produce the products from NPI. NPI creates the supply chain and BOM. Changes in the BOM are not always discussed on time with the operational buyers.
- Order quantities of the customer are not contractually written down by Sales
  As a result, it is not clear how much and when the customer wants his products. Frequently, the products are composed of parts with a long delivery time. DP does not want to charge the long delivery time to their customers. The two discussed components of the core problem are related to material request. The material is requested by the project manager, by the forecast or by a sales order. The information which is needed for the material request, comes from NPI. If the material is requested too late or the information of the material is not accurate, the material is not requested on time.
- Permission for purchasing is given too late by the project manager
  The procedure is as follows - if material is requested, the operational buyers must get permission before they can purchase the material. If the operational buyers get the permission too late, material is ordered too late.
- Operational buyers must do too much administration
  The operational buyers must monitor the requested material, ask permission for purchasing, purchase the material by suppliers and keep track of the purchased goods. This is a lot of work and there is not enough capacity.
- Suppliers sometimes have a different delivery time compared with the regular delivery time
  Sometimes, the delivery time differs from a few weeks to half a year or a specific component is not produced anymore. A specific case comes from Company X. Company X placed an order on 2 July 2019 and on 22 Augustus 2019 they got a message from DP that the displays, which they use in their design, are only available from February 2020.

1.4 Research design

The goal of this research is to find out why material is too late in stock and to come up with some recommendations for solving this problem. The main research question is:

What must DP do to have the needed material in stock at the moment the production is planned to start?

In short, the research is as follows:

Step 1. Describing the current situation and the purchasing process
- a. Doing literature study
- b. Interviewing and observing

Step 2. Finding the causes of the core problem
- a. Analysing the current purchasing process
- b. Analysing data of AFAS in Excel
- c.. Interviewing

Step 3. Finding solutions for the core problem(s) in the literature
- a. Literature study
- b. Determining the effects of the solutions

Step 4. Giving implementation plan with recommendations.

1.4.1 Sub-questions

Before getting an answer on the main research question, the following sub questions must be answered:

1a. How can processes in an organization be mapped in a clear way?

To show how the current process operates, an effective mapping technique must be used. To get an answer on the first sub-question, a literature study will be performed. Different methods of mapping processes will be reviewed and one method will be chosen. The mapping technique will be valuable for making the purchasing process (see sub question 1b).

1b. What does the current purchasing process look like?

The results of sub-question 1a will be used for giving an answer on sub-question 1b. This implies that the mapping technique will be applied for making the purchasing process overview. Sub-question 1b will be answered by observing and by interviewing the employees of DP who are involved in the purchasing process.

2. What are the reasons that the required material is not in stock at the moment the production is planned to start?

This question will be answered after sub-questions 1a and 1b are answered. To get an answer on sub-question 2, the purchasing process map will be analysed, data will be analysed and interviews will be held. When sub-question 2 is answered, the phase in the purchasing process where the most problems occur, will be clear.

Data from AFAS will be analysed. AFAS is the current Enterprise Resource Planning (ERP) system of DEMCON. AFAS is rarely used for a production oriented organization, but because of the fact that DEMCON is a project-oriented organization, DP also has to use AFAS. As a result, AFAS does not contain detailed data about the stock.

The ICT department will put data from AFAS into an Excel sheet for the research. The following data will be retrieved from AFAS:

- Sales orders – the order placed by a customer of DP
- Work orders – orders to produce a specific product
- Purchase orders – an order at a supplier, placed by DP
- Picking slip – a list with goods to pick before the production
- Packaging slip – the slip with shipping information and the sign that the package can be send

The data will be obtained from the Company X production line and from the Company Y production line. The data, generated between 01-01-2019 and 15-10-2019 will be analysed. The data will give information about when the problems of the late delivery arise in the purchasing process. After analysing the data, interviews will be held to find the specific causes of the problem. The reason that interviews are held after analysing the data is that I am able to get into more detail on examples or moments in the whole purchasing process. The interviews will be held with employees of DP who are involved in the most problematic part(s) of the process.

3. What are solutions to get material on time?

After identification of the main cause(s) of the problem, possible solutions can be proposed. To found solutions, a literature study will be done. After finding solutions, the effect of one of more solutions will be determined.

A possible solution can be having more components in stock. For this specific solution, literature about inventory management will be searched. The influence of the different parameters on the value of the safety stock will be calculated and simulated in Excel (VBA) with the current available data in combination with results according to the literature. This will give an estimation about the effects of the solutions.

4. How can the solutions be implemented at DP?

The last sub-question is about the implementation possibilities of the solutions for DP. The answer of this question results in a implementation plan with recommendations for DP.

1.4.2 Research scope

During this research, I will look into the processes at DP and not look to processes of the suppliers or other external factors. Besides, the data from the cases of Company X and Company Y is used to analyse the purchasing process. These two lines have the most problems with delivering products on time, according to the employees of DP.

1.4.3 Deliverables

At the end of the bachelor thesis, a report with an implementation plan with recommendations for DP will be delivered. In addition, a presentation for DP will be given. The implementation plan with recommendations is based on interviews and on the data of the cases of Company X and Company Y. However, the results will also be useful for other production lines at DP. A tool in Excel for determining the stock is part of the implementation plan.

2. Current situation

In order to solve the core problem, the current purchasing process will be analysed. Firstly, three process mapping techniques are compared to give an answer on the first research question in section 2.1. Secondly, the production process is modelled in section 2.2. The last step of this chapter is to analyse the production process in 2.3. In this part, the results of analysing the BPMN map, the data and the interviews are discussed. At the end of this chapter, the causes of the core problem are presented.

2.1 Process mapping technique

The question which will be answered in this section is:

How can processes in an organization be mapped in a clear way?

The current purchasing process is complex and not established. The goal of mapping the purchasing process is to see who is responsible for which step in the purchasing process and to determine the duration of the steps in the process, using the data from AFAS in Excel (see 1.4 Research design). In addition, the model must be able to map complex processes and easy to understand. Specific steps of the purchasing process will be discussed during the interviews and checked if this is necessary. In agreement with DP, the following criteria are defined for the mapping technique:

- It is visible who is responsible for a specific step in the process
- It is possible to determine the duration of the steps in the process
- It is possible to map complex processes with a lot of decisions and options.
- It a general used technique/language and not difficult to learn.

Before the next step, a pre-selection is already made. If it is not possible to map complex processes with the mapping technique, the technique is not discussed. The reason for this is that the current purchasing process is complex. An example of a technique which is not useful for mapping complex processes is Value Stream Mapping (Toivonen & Siitonen, 2016). Value Stream Mapping is not taken into account during the analyse of the mapping techniques.

In the Appendix 1 - Theoretical framework process mapping technique, three different process modelling techniques are explained: Business Process Model and Notation (BPMN), Event-driven process chain (EPC) and Unified Modelling Language (UML). EPC and BPMN are commonly used for the purpose of mapping processes. UML is less frequent used for mapping processes (Booch, Rumbaugh, & Jacobson, 1999).

In Table 1 the mapping techniques are compared with the requirements of DP. According to the results in Table 1, BPMN scores the best. For the purpose of this research, BPMN is the most useful mapping technique. The answer on research question 1a is to use the BPMN method for mapping the purchasing process.

	BPMN	EPC	UML
It is visible who is responsible for a specific step in the process	Yes - with swim lanes	Not very visible – can be done with adding small figures to the boxes	No
It is possible to determine the duration of the steps in the process	Yes	Yes	Not the main purpose of UML
It a general used technique/language and not difficult to learn	Yes	Yes	The technique is more complex than other techniques

Table 1 Comparison between BPMN, EPC and UML

2.2 Purchasing process overview

In this section, the purchasing process in BPMN and important information about the model can be found. The model is constructed with the help of the employees of DP. The question which will be answered in this section is:

What does the current purchasing process look like?

To validate the model, more versions are discussed with the operational purchasers and other employees. Only the final version is showed in this report. The model can be found in Appendix 2 - Purchasing process overview and in Appendix 3 - Material planning.

2.3 Analysing the purchasing process

The goal of this section is to find the main causes of the core problem, the 'too late material arrival'. The purchasing process, which can be found in Appendix 2 - Purchasing process overview, is analysed and Appendix 3 - Material planning process. Firstly, potential problems, mentioned by making the BPMN map, are explained. Hereafter, data is analysed from AFAS to get more insight into potential problems. Interviews with six experts of DP are held at least. These employees at DP are two purchasers, two project buyers, one project manager and one supply chain engineer. During the interviews, the possible causes of the main problem, which are found during analysing the BPMN map and the data, are discussed. The influence of these causes on 'too late material arrival' is asked.

The question which will be answered in this section is:

What are the reasons that the required material is not in stock at the moment the production is planned to start?

2.3.1 Analysing BPMN map

When making the BPMN map and talking with the employees of DP about the current purchasing process, different problems were mentioned. These are surrounded in the BPMN map (which can be found in Appendix 2 - Purchasing process overview and Appendix 3 - Material planning process) and have a number. The possible problems are explained in Table 2.

Number on BPMN map	**Problem**	**Explanation**
1	Service uses material	If Service uses material, it is sometimes taken out of stock without recording this. As a result, there is not enough material available before production. This is not planned.
1	The theoretical stock is not the same as the real stock	Because of this problem, it is unclear how much material must be ordered. At the moment material is picked from stock before production, it is checked if the material is available in the real stock. This also means that material is not reserved for a specific work order. DP does not have a work-in-progress stock. The stock is recorded in an Excel file and not in the ERP system of DP, because this system does not work with a BOM and a material requirements planning.
1	The material planning is not clear (multiple outsources are forgotten)	Multiple outsources are components of the end product which need an extra sub assembly. Only the components are in the material list, not the material which is needed to make the components. As a result of missing an overview of the material planning, the material for the sub assembly is easily forgotten. Besides, the material planning is done for each line separately and there is no overview. One supplier can get more orders on one day of DP. Also, before the material is done, DP aims to have a forecast and commitment of the customer. This is not always the case.
2	Pre-arranged delivery time of material is the input for production planning	For making the production planning, the theoretical available material (theoretical stock is not the same as the real stock) is used as input. The production planning is a short term planning with specific work orders. If material is not available, the production line stops.
3	The quality check takes too long	The department quality must check some material before it can be used for production. For this step, time is reserved before ordering the material. Sometimes, the real period between incoming goods and a quality check is longer than expected. This gives delay.

Table 2 Problems in the current situation

Material is ordered based on a forecast or sales order. This process can be found in In Appendix 3 - Material planning For each line, the 'stock & picking list' or 'Hoppatool' is used. Both are Excel documents, made by DP. In the 'stock & picking list' the theoretical stock and the planned work orders are used to determine what material is needed. The 'stock & picking list' can be found in

Appendix 4 - Stock & picking list.

The ‘Hoppatool’ is the replacement of the ‘stock & picking list’. The ‘Hoppatool’ is specific developed for the processes of DP. Instead of searching to materials which are not on stock, the ‘Hoppatool’ gives alerts with actions for the buyers. An example of an alert list can be found in

Appendix 5 - Hoppatool. Using the 'Hoppatool' makes it easier to determine what must be done to get the material on time.

Each production line has its own 'Hoppatool' or 'stock & picking list' to keep track of the stock. This means that after the 'stock & picking list' or 'Hoppatool' is used, the results must be checked with results of other production lines to buy efficient at one supplier. Besides, multiple outsources, which are components of the end product which need an extra assembly at another company, must be checked manually. Otherwise, only the assembly as a whole is taken into account and not the parts which must be bought to make the assembly.

After checking the results and multiple outsources, the total amount of material needed must be determined. This included material for service and yield loss. Yield loss is material which is lost during the production. The required quantity of material is based on past experiences and assumptions.

DP has a safety stock for one line. This safety stock is used to capture fluctuations in demand and lead times, to cope with yield loss and material for service.

2.3.2 Data analyses

Data from 01-01-2019 until 15-10-2019 is analysed to get the problems clear. Only the moment of making the sales orders is before 2019, because of the fact that a sales order can be made in the future.

The throughput time of sales orders is calculated and that the total material delay is calculated. During this, I noticed that a lot of data was incomplete. Besides, the throughput time of sales orders and purchase orders combined cannot be calculated, because there is no connection between these two. The reasons for this is that material is not reserved for a specific work order.

Method calculating throughput time of sales orders

For calculating the throughput time of the different steps in the purchasing process, data from AFAS, the Enterprise Resource Planning system of DP, is used. In the BPMN map (see Appendix 2 - Purchasing process overview), it can be seen where in the process the data is generated. In Figure 2, an overview of the calculations of the throughput time is added.

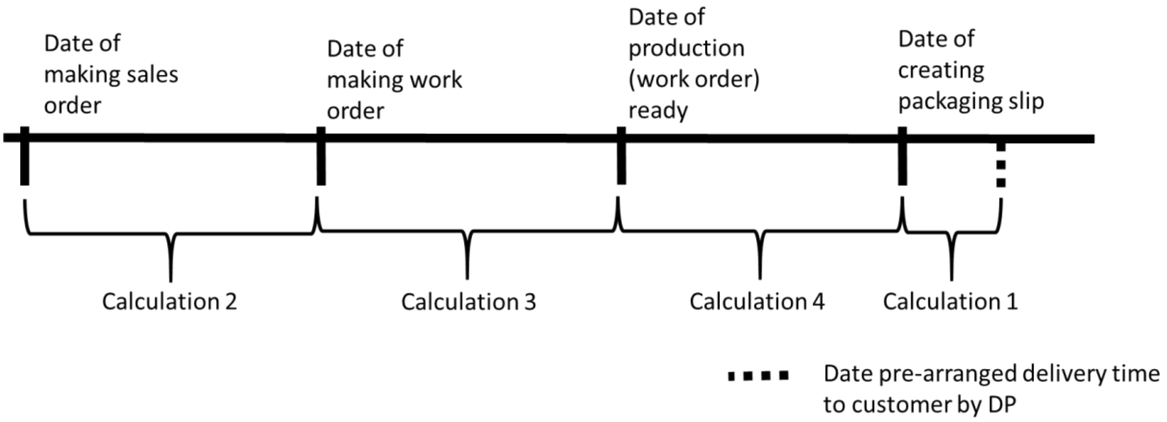

Figure 2 Calculations of the throughput time

As can be seen in the BPMN process map (see Appendix 2 - Purchasing process overview), the work orders are made when the delivery time of products is known or if the current stock is sufficient to make the products. The moment of making a work order is the same as getting the pre-arranged delivery time of the supplier. Included in the last timeslot, is the receipt of material.

The sales order number is used to connect the packaging slips and work orders. Sales orders are mostly sent with more packaging slips and the products of the sales orders are made within more work orders. When analysing the data, it was not possible to take all the packaging slips and work orders into account. The moment of making the last packaging slip is used for calculating the delivery time. The reason for this is that only if all the packaging slips are send, the order is complete. The pre-arranged delivery time of a sales order, is based on the entire sales order and not on an incomplete sales order.

The same applies to the work orders. Only when the last work order is done, which means that the production is ready, the order can be packaged and sent to the customer. As a consequence, the last date of making the work orders and the last date of production ready of each sales order are used for calculating the amount of days between making the work order and the production ready.

Results throughput time of sales orders

Company X

The sales orders of Company X are combined with the work orders, production orders and packaging slips. The data included 293 sales orders in total. Sales orders which did not have a pre-arranged delivery time or did not have work orders and/or production orders and/or packaging slips within the available data, were not used. It was remarkable that 9,2% of the sales orders did not have a pre-arranged delivery time.

Of the 266 sales orders with a pre-arranged delivery time, only 76 orders had all the information to calculate the throughput time. The throughput time can be found in Table 3: 32 where on time and 43 where not. This means that 57,3% of the sales orders is too late. The amount of days too late can be found in
Figure 3.

Calculation	Mean	Standard deviation
Calculation 1	10.84	5.60
Calculation 2	35.32	28.72
Calculation 3	63.22	47.63
Calculation 4	0.75	2.13
Total throughput time	100.43	52.10

Table 3 Table with throughput time sales order of Company X

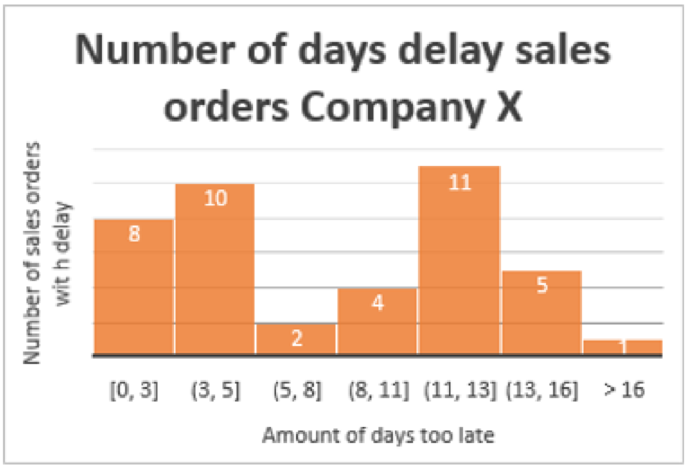

Figure 3 Number of days delay sales orders Company X

After calculating the throughput time, I tried to find a correlation between calculation 1 and the other calculations. There are no correlations found.

Company Y

The data included 37 sales orders of Company Y. Of these 37 orders, 9 orders (24,3%) did not have a pre-arranged delivery time. Of the 28 orders with a pre-arranged delivery time, 12 sales orders were on time. This means that 57,1% of the sales orders was delivered too late. The amount of days too late can be found in Figure 4.

Calculation	**Mean**	**Standard deviation**
Calculation 1	9.00	16.90
Calculation 2	88.45	126.79
Calculation 3	34.15	36.07
Calculation 4	0.27	0.90
Total throughput time	111.40	132.91

Table 4 Table with throughput time sales order of Company Y

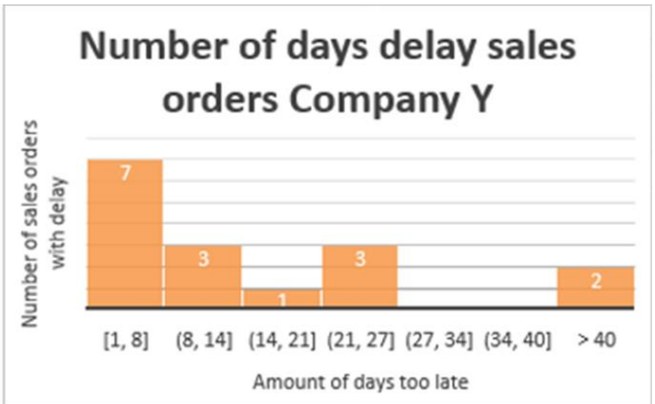

Figure 4 Number of days delay sales order Company Y

For only 13 sales orders, the packaging slips, work orders and pre-arranged delivery time is determined. 5 of these include false information, for example the packaging slip is made earlier than the work orders or the amount of days between sales orders and packaging slip is 0. Only 8 orders could be analysed to calculate the throughput time. The throughput time is shown in Table 4. No correlations could be calculated because the number of orders was too low.

Method determining material delay

The purchasing orders cannot be linked to the sales orders, because material (on stock and ordered) is not linked to a sales order or work order. The pre-arranged delivery time and the real delivery time of a purchase order can be found in AFAS. These two will be compared to find out if the material is on time or too late.

According to the material planners, a few days delay of a purchase order does not give problems. When making the production planning, extra time between the incoming goods and the start of the production is taken into account. Therefore, the comparison between material on time, material arrived with 1 or 7 days delay and material with more than 7 days delay is made.

Each production line has its own stock. For the cases Company Y and Company X, this means that Company Y has one Excel sheet with the stock and Company X has more Excel sheets with stocks, because Company X develops more products. Some of these Excel contain the same products. This makes is also very difficult to find out which material is used for which product.

When analysing the data, also a lot of incomplete information was found. Therefore, also the percentage of incomplete data was determined.

Material Company X

87,3% of the materials of Company X with a defined supplier have a pre-arranged delivery time. Of these 87,3%, 76,3% of the material was on time, 17,7% between 1 and 7 days too late and 6,0% was more than 7 days too late.

Material Company Y

For Company Y, 84,2% of the purchase order with a defined supplier had a pre-arranged delivery time. Of the part with a pre-arranged delivery time, 71,0% is on time, 19,3% is 1 – 7 days to late and 9,7% is more than a week too late.

Conclusions of analysing data

After analysing the data, it is not possible to draw conclusions about at which stage of the purchasing process problems specifically occur. It is however clear that the data in AFAS is not always filled in or it is not filled in well. Sales orders do not always have a pre-arranged delivery time. If sales orders do not have a pre-arranged delivery time, it becomes impossible to make a material planning and a production planning. In addition, the pre-arranged delivering time of the material is not always written down. As a consequence, it is not possible to check if material is on time and the reliability of the suppliers.

The reliability of suppliers is also an important factor. Only 76,3% of the material of Company X and only 71,0% of the material of Company Y was on time. This is low, especially because the production planning is based on the pre-arranged delivery time of the material. More safety time for possible delay can be calculated if the sales order is early known.

2.3.3 Interviews

After analysing the process and the data, the problems in Table 5 are found.

	Problem	**Explanation**
a	Service uses material	If service uses material, it is taken out of stock without proper registration. As a result, a lack of material can arise
b	The theoretical stock is not the same as the real stock	As a result, it is unclear how much material must be ordered. At the moment material is picked from stock before production, it is checked if the material is available in the real stock. This also means that material is not reserved for a specific work order. DP does not have a work-in-progress stock. The stock is recorded in an Excel file and not in the ERP system of DP.
c	The quality check takes too long	Quality must check some material before it can be used for production. For this step, time is reserved before ordering the material. Sometimes, the real period between incoming goods and a quality check is longer than expected. This gives delay.
d	There is no overview of the material planning and material reservations (multiple outsources are forgotten)	Multiple outsources are components of the end product which need an extra sub assembly. Only the components are in the material list, not the material which is needed to make the components. As a result of missing an overview of the material planning, the material for the sub assembly is easily forgotten. Besides, the material planning is done for each line separately and there is no overview. A supplier can get more orders of different production lines on the same day.
e	Suppliers are not always reliable	Suppliers do not make the pre-arranged delivery time and are too late. The pre-arranged delivery time is used for making the production and material planning. If the suppliers deliver too late, the material planning and production planning are not reliable. Besides, it is not checked at the moment if suppliers deliver on time before ordering.
f	Pre-arranged delivery time of a sales order is not always agreed with customer	This makes it difficult to make an accurate material planning in the current process.
g	Pre-arranged delivery time of a purchase order is not always agreed with supplier	This makes it difficult to make an accurate production planning in the current process. For making the production planning, the theoretical available material (theoretical stock is not the same as the real stock) is used as input. The production planning is a short term planning with specific work orders. If material is not available, the production line stops.

Table 5 List with possible causes of the core problem

These problems are discussed with two purchasers, two project buyers, one project manager and one supply chain engineer of DP. One of the subjects was how frequently these six problems occur and how they deal with the too late delivery of orders. Besides, their opinion and vision about the problems with the material delivery is asked.

Table 6 gives the proportion of each problem to each other problem, according to the six interviewers. The table shows the total value; this is the proportion of the six problems compared to each other. For example, if the interviewer gives the value of 5% to problem a and 10% to problem b, first the ratio between a and b is 5 / 10 = 0.5. Thereafter, the ratio between a and b of all the interviewees is added up and put in Table 6. It can be seen that the biggest problem is the too late delivery of suppliers, followed by the material for multiple outsources is difficult to plan and the material is not tested on time by Quality.

Relative to	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**Total**
a	1.00	0.87	0.56	0.55	0.29	2.57	4.28	*10.13*
b	1.15	1.00	0.65	0.63	0.34	2.95	4.91	*11.63*
c	1.77	1.55	1.00	0.98	0.52	4.56	7.59	*17.97*
d	1.81	1.58	1.02	1.00	0.53	4.66	7.75	*18.35*
e	3.42	2.98	1.93	1.89	1.00	8.80	14.64	*34.65*
f	0.39	0.34	0.22	0.21	0.11	1.00	1.66	*3.94*
g	0.23	0.20	0.13	0.13	0.07	0.60	1.00	*2.37*

Table 6 Proportions of the problems to each other

Besides these problems, the interviewees are asked to give a top 3 of the main causes of the too late material delivery. The table can be found in **Error! Reference source not found.** (see Appendix 6 - T ables interviews).

In **Error! Reference source not found.** (in Appendix 6 - Tables interviews) the answers are clustered i nto five themes: material planning, relationship suppliers, no safety stock, checking material by Quality and other. The causes which are mentioned the most by the experts during the interviews are planning related and supplier related. The third cause of the core problem, no safety stock, can also be seen as a solution for unreliable suppliers and with unreliable forecasts of the customers.

2.4 Causes of the core problem

For getting an answer on research question 2, 'What are the reasons that the required material is not in stock at the moment the production is planned to start?', first research question 1a and 1b are answered with making the current purchasing process in a BPMN map. Hereafter data is analysed and interviews with six employees are hold. In consultation with DP, the following criteria are mentioned for selecting the problems:

1. The problem must have a relative high impact as a cause for the too late material delivery.
2. The problem can be tackled within the logistic department of DP (production planner, purchasers, warehouse)

Based on the first criteria, the problems 'checking material by quality takes too long', 'no overview of the material planning and material reservations' and 'suppliers deliver too late' are the main problems. Also looking to the second criteria, 'there is no overview of the material planning and material reservations' and 'suppliers deliver too late' meet these criteria. In Table 6, it can also be seen that material planning and suppliers are called the most by the interviewees in the top 3 of main causes of the main problem.

In addition, the problem 'suppliers are not reliable' can be noticed looking to the data analyse. For Company X, 76,3% of the material in on time and for Company Y, only 71,0% of the material in on time. This gives problems within the material delivery, according to the interviewees. The other problem, ‘material planning is not good’ is a problem with indirect impact on the core problem.

The problem ‘the quality check takes too long’ is not involved in logistic department, but in the quality department. As a result, this problem is not included with the core problems.

The two core problems can be subdivided into several sub problems. This is done based on the results of the interviewees from Appendix 6 - Tables interviews. The sub problems are presented in Table 7. In chapter 3, literature for possible solutions for these problems will be searched. The solution for the problem ‘the fluctuations of the demand and the delivery time of suppliers are not captured with a safety stock’ is worked out with a tool for determining the safety stock.

Main problem	**Sub problem**
There is no overview of the material planning and material reservations	The input on which the material planning is based, is incorrect. The input of the planning is the BOM and the forecast/commitment with the customers.
	It is difficult to oversee the whole material planning for a longer period. A lot of Excel sheets are used and the material planning is complex.
Suppliers are not reliable	There are not always agreements with the suppliers about delivery time, quality etc.
	Suppliers are not monitored about their performances.
There is no overview of the material planning and suppliers are not reliable	The fluctuations of the demand and the delivery time of suppliers are not captured with a safety stock.

Table 7 Two main problems with sub problems

3. Solutions for the problems

The goal of this chapter is to find an answer on research question 3. '*What are solutions to get material on time?*'

The problems - as presented in Table 7 - are used as a basis for getting an answer on the research question. A literature study is done to generate solutions for the main problems. The literature study can be found in Appendix 7 - Solutions from the literature. The solutions all require more investigation study for the specific situation at DP. Because of the limited time, I decided in consultation with DP to focus on the safety stock and the tool to determine the safety stock for the current situation at DP for solving the sub problem: *The fluctuations of the demand and the delivery time of suppliers are not captured with a safety stock.* This is discussed in this chapter.

3.1 Safety stock

The goal of a safety stock is to have material available for production, independently from the fluctuations in supply and demand. A safety stock can help as a buffer to cope with the fluctuations of the delivery time of suppliers and of the demand (Jonsson & Mattsson, 2003; Korponai, Tóth, & Illés, 2017). There are a lot of different methods for different situations to determine the safety stock (Silver, Pyke, & Thomas, 2017). The best fitting methods for DP are discussed further in this section.

The safety stock for DP is originally based on dependent demand. The demand of each component is dependent on the demand of the end product. This is also called an assembly inventory (system). Because of the high complexity of these methods, an independent inventory will be used to determine the safety stock.

Hausman (1998) showed the effects of a correlation between a multi-item inventory. An independent order-up to policy is used in this research, in combination with a deterministic lead time. The higher the correlation between items, the higher the joint demand fulfilment probability (Hausman, Lee, & Zhang, 1998). The difference of the joint demand fulfilment probability (for the same correlation) between an 1-item inventory and an 10-item inventory is lower if the safety stock factor is higher. The effects using an independent demand instead of a dependent demand will be measured later in a simulation study.

3.1.1 System

A lot of different methods for calculating the safety stock are developed. For calculating the safety stock, the choice between a continuous stock or a periodic stock is made. A periodic stock is reviewed every review period, for example each week. On the contrary, a continuous stock is monitored continuously with a computer. The required safety stock for a continuously stock is smaller than the safety stock for a periodic stock (Silver et al., 2017).

At the moment, DP uses a computer to calculate the inventory level. The system, 'Hoppatool' can be considered as a continuous stock monitoring system and is especially developed for the purchasing process of DP. In the future, the formulas for calculating the safety stock, can be connected with the 'Hoppatool'. A continuous review system requires less safety stock than a periodic review. Therefore, I decided to use the continuous stock model.

The two systems available for continuous review are an ‘order-point, order quantity’ (s,Q) system and a ‘order-point, order-up-to-level’ (s,S) system. The first system calculates the order quantity, which must be ordered if the safety stock is equal or lower than ‘s’. The second system, a (s,S) system, calculates the minimum order point (s) and the maximum order up to level (S). The order quantity is flexible and is the difference between S and s. The system does not allow to have a higher safety stock than ‘S’, instead of the (s,Q) system, which does not have a maximum safety stock. Because of the fact that in our situation S = s + Q, a (s,Q) system is used for determining the safety stock for all classes (Silver et al., 2017).

3.1.2 Safety factor for product class classifications

Product classes are useful for managing the inventory. A common used classification is the ABC classification. This classification is based on the 20/80 rule, which means that most of the time, 20% of the items generates 80% of the annual usage. The class A items are the most important and gets the most attention of the management, followed by class B products. Class C products are not relatively important and get less attention of the management (Silver et al., 2017).

Also, other classification methods can be used. An example is the XYZ inventory, where the variability of the demand is used to classify the products. The items with very little variation are classified in class X and the items with the highest variation are classified in class Z (Dhoka & Choudary, 2013). Other examples are the HML classification, which is based on the unit price (high, medium and low) and the FSN analysis, based on the consumption pattern (fast, slow, on moving items) (Pandya[1] & Thakkar, 2016). Two classification methods can also be combined in one matrix.

For DP, a classification will be made between the unit price and the lead time. The reason is that the value of the safety stock is important for DP and the value of the safety stock is highly dependent of the unit price and the lead time.

Besides the classifications, the safety factor must be determined for each class. For calculating the safety factor of the safety stock, the cycle service level or the fill rate can be used. The cycle service level (CSL) shows the percentage of replenishment cycles which are done without a stock out. The fill rate is the percentage of products or orders (depending on the choice) which are directly satisfied form inventory. Because of the fact that the variability in demand and lead time are long, the cycle service level is used for the calculating the safety stock at DP (Chopra & Meindl, 2013).

3.1.3. Influences on the safety stock

The safety stock is dependent on the lead time. This is the time between ordering the product and getting the product in stock, the standard deviation of the lead time, the demand and the standard deviation of the demand. This means that unreliable suppliers and a fluctuated demand have an influence on the safety stock. The safety stock becomes higher if the demand is less certain and suppliers are less reliable stock (Korponai et al., 2017). Causes of the core problem at DP are also unreliable suppliers and no agreements with the customer about the demand. This means that the safety stock becomes relative high.

To improve the control of the fluctuated demand, a long-term planning can be created. The planning, called a Sales & Operations Planning (S&OP) monitors the demand and supply (Alfaro Santa Cruz, Valverde Torres, & Ibanez, 2019). It is also possible to freeze the MPS to get to stabilise the demand. In a frozen period, the planning cannot be changed (Tang & Grubbström, 2002).

The standard deviation of the lead time and the length of the lead time can be improved by focusing on the relationship with the supplier. In Appendix 7 - Solutions from the literature, more information about improving the relationship with suppliers can be found.

3.1.4. Formulas for calculating safety stock

In this part, the formulas for calculating the safety stock are discussed. Only the formulas for the specific situation at DP are discussed.

In general, the following formula is used for calculating the safety stock:

$$\text{Safety stock} = k\sigma_L \quad (1)$$

Where:
k – Safety factor
σ_L – Standard deviation of demand during lead time

The safety stock can also be determined in combination with a frozen period. In a frozen period, the planning cannot be changed. For calculating the safety stock in combination with a frozen period, σ_L in formula 1 is replaced by σ_{L-FP}.

After defining the safety stock, the reorder point, s, is calculated with the following formula:

$$s = D_L + \text{Safety stock} \quad (2)$$

s – Reorder point

For calculating D_L, the following formula is used:

$$D_L = D \cdot L \quad (3)$$

Where:
D – Forecast or expected average demand
L – Average lead time for a replenishment
D_L– Forecast (or expected) demand over a replenishment lead time, in units (Silver et al., 2017)

With the use of a frozen period, instead of L, $E[(L - FP)^+]$ is used (personal communication, M. C. Van der Heijden, 14 January, 2020). This formula give an estimation of the demand during the lead time minus the frozen period. The derivation of this formula can be found in Appendix 8 - Derivation of the safety stock with a frozen period. $E[(L - FP)^+]$ can be calculated with the following formula:

$$E[(L - FP)^+] = s_L G\left(\frac{FP - L}{s_L}\right) \quad (4)$$

With $G(z) = \phi(z) - z * [1 - \Phi(z)]$ where $\phi(z)$ denotes the standard normal density function and $\Phi(z)$ denotes the standard Normal distribution function and where:

FP – Frozen period
s_L – The standard deviation of the lead time

For calculating σ_{L-FP}, the following formula is used:

$$\sigma_{L-FP} = \sqrt{E[(L-FP)^+] \cdot {\sigma_D}^2 + D^2 \cdot {s_{L-FP}}^2} \tag{5}$$

Where:
σ_D – The standard deviation of the demand
s_{L-FP} – The standard deviation of the lead time minus the frozen period
σ_{L-FP} – The standard deviation of the demand during the lead time minus the frozen period (Silver et al., 2017)

The standard deviation of the demand must be in the same time period as the lead time. If for example, the standard deviation is given in days but we want to know the standard deviation in weeks, the standard deviation in weeks is the standard deviation in days multiplied with the square root of 7. If 'x' items of the same component are used for one product, the average demand and the standard deviation of the demand are multiplied with 'x'.

Before formula 6 can be used, the standard deviation of the lead time minus the frozen period is determined with the following formula (personal communication, M. C. Van der Heijden, 14 January, 2020):

$$s_{L-FP} \approx \sqrt{E[\{(L-FP)^+\}^2] - (E[(L-FP)^+])^2} \tag{6}$$

Where $E[\{(L-FP)^+\}^2]$ can be determined with the following formula (personal communication, M. C. Van der Heijden, 14 January, 2020):

$$E[\{(L-FP)^+\}^2] = s_L^2\{(z^2+1)[1-\Phi(z)] - z\phi(z)\} \tag{7}$$

For defining Q, the economic order quantity (EOQ) gives an indication, based on a few criteria. In the tool, it is possible to use the EOQ. The EOQ is determined with the following formula:

$$EOQ = \sqrt{\frac{2AD}{vr}} \tag{8}$$

Where:
EOQ - The economic order quantity in units
A - The fixed cost per replenishment in €

D – Demand in unit / unit time
v - Variable costs of one item in €
r - Carrying charge in € / € / unit (Silver et al., 2017)

To indicate the average level of the total stock, the following formula can be used:

$$E(OH) = \frac{Q}{2} + \text{Safety stock} \tag{9}$$

Where:
E(OH) – the average level of the total stock

3.2 Properties of the tool

In this chapter, the method for calculating the safety stock is explained. The value of the safety stock is dependent of unrealisable suppliers and a fluctuated demand.

The tool for calculating safety stock will have the following properties:

- A continuous stock review will be used;
- The safety stock will be based on a (s,Q) inventory;
- The cycle service level is used to determine the safety factor;
- The classification between product classes is made on basis of lead time and the price per product;
- The demand is given as independent demand instead of dependent demand.

In the next chapter, the tool with the model for determining the safety stock is made and analysed. The model is analysed with the data of one product as input.

4. Model development

In this chapter, the development of the tool for determining the safety stock is explained and analysed. The tool is based on the information, given in chapter 3. The assumptions for analysing the tool are explained, the classification between the product classes is done and the impact of the cycle service level, frozen period and the standard deviation of the demand on the total value of the safety stock are analysed. The difference between a dependent and an independent demand for a simplification of the situation at DP are also simulated.

4.1 Assumptions for the development of the tool

The model is based on the data of Product X. This product is built up of 92 different components. Of these 92 components, information of 79 components was available. The following assumptions are made:

- The demand and the lead time follow a normal distribution;
- All the available data is correct (including the price per product);
- The lead time is the moment between the signal that components are needed and the arrival of the components;
- The components are only used for Product X and does not occur in other products.

Also, the tool is developed with keeping in mind the following points:

- The inventory is dependent, but because of the complexity of dependent inventory models, the model is based on an independent inventory;
- The calculation of the safety stock with a frozen period is an approximation and not exact, because of the use of the normal distribution for the demand and the lead time.

4.2 Using the tool

The formulas, mentioned in 3.1.4. Formulas for calculating safety stock, are coupled in a tool in Excel. Q must be filled in manually instead of using automatic the EOQ. The reason for this is that it could be easier sometimes to buy one box with 25 products instead of buying 27 products, which is advisable by the EOQ. Q can be filled in manually, after EOQ is given.

The data, used for calculating D_L and σ_L comes from AFAS. It is possible to connect this tool to AFAS for the data. The average lead time and standard deviation of the lead time may change, for example because it takes less time to determine the quantity of a specific product or suppliers become more reliable. This can be calculated automatically if the tool is connected to the 'Hoppatool' or AFAS, the ERP system of DP. It is recommended to define a time slot of the data for determine the average lead time and standard deviation of the lead time. For example, only the data of last year can be used.

With the tool, the parameters can be filled in and the total value of the safety stock is given. This can be discussed with the customers of DP.

4.3 Results and discussion of the safety tool

The input for the tool is based on the data of Product X in the period 01-01-2019 until 15-10-2019. The average of the demand and the standard variation of the demand are calculated. In this case, an average of 37 system per month was sold. It is remarkable that the forecast was 24 systems per month.

More difficult is to determine the standard deviation. According to the data of the sold systems, the standard deviation is 21,5 systems per month. However, the data of the sold systems it not the same as the demand. In November, 73 systems were sold and in February, May, July and Augustus, no systems were sold. A possible explanation is that this is because of the material shortages instead of the demand of the customer. In this case, the standard deviation is not reliable. Still, the standard deviation is used as a starting point for the analyses. Later in the analysis phase, the influence of the standard deviation on the total stock is shown.

The results of the analysis are given in the total value of the safety stock. The order quantity is not taken into account. Information about the holding costs and the order costs is not available. For the demand, only the demand of the customer is taken into account. Field loss and material for service is not taken into account, because there is not data available.

4.3.1 Classification of the product classes

The product classes are dependent from the unit price and the average lead time. The distribution is based on the total amount of items in each class. The following classification is made:

		Price product		
		High > 20 €	Medium 1 - 20 €	Low < 1 €
Average lead time	High > 100 days	A	A	B
	Medium 20 – 100 days	A	B	C
	Low < 20 days	B	C	C

Table 8 Classification of the product classes

The amount of products in class A, where the purchaser should focus on the most, cannot be too high. The limits of the classes are determined to look to the total amount of products in each class. We want the most products in class C, followed by class B and at least, followed by class A. The classification of Product X is as follows:

Class A: 12 products
Class B: 27 products
Class C: 40 products

50,6% of the total inventory exists of class C products. This means that the inventory safety level is determined for 50,6% of class C products. For class B products, this is 34,2% and for class A products, this is 15,2%. Class C products have the most influence on the service level of the safety stock.

4.3.2 Safety levels

The influence of increasing the cycle service level for each product class on the total value of the safety stock is measured. The values are compared to the maximum value of the safety stock (if the CSL for the analysed class is 0.999 and the CSL of the other product classes is 0.90). For example, if the maximum value would be 50, the other values are calculated by (value / 500 * 100).

For calculating the influence, the CSL of the other product classes is kept on 0.90.

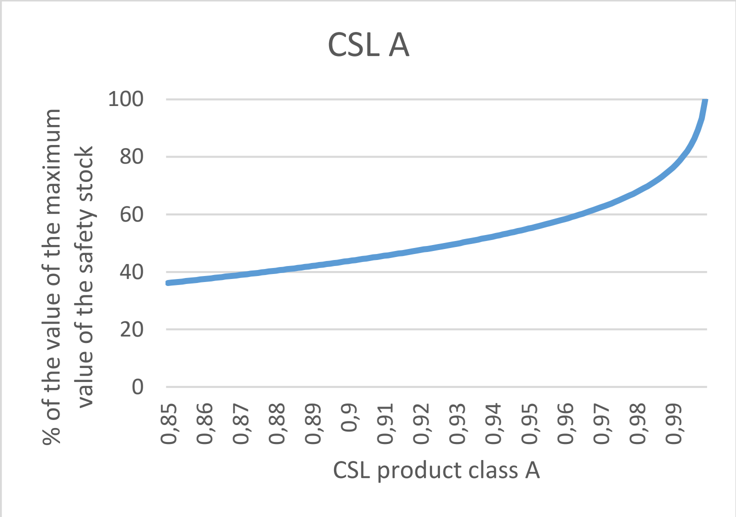

Figure 5: Influence of the CSL of class A on the value of the safety stock.

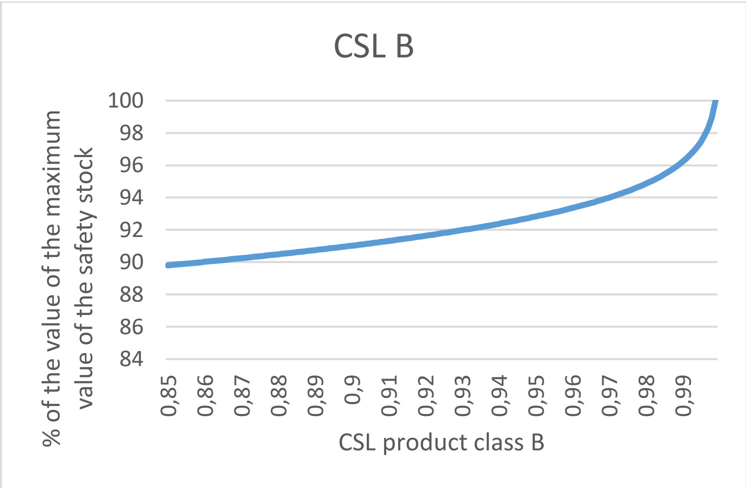

Figure 6: Influence of the CSL of class B on the value of the safety stock

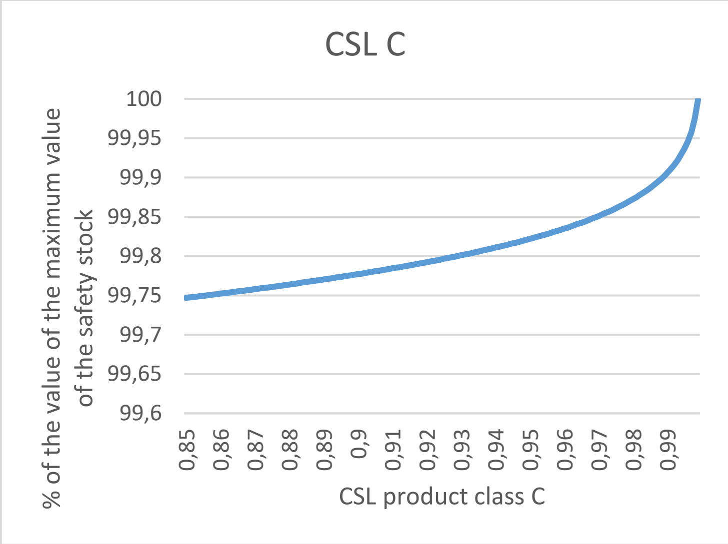

Figure 7 : Influence of the CSL of class C on the value of the safety stock

The total value of the safety stock increases significantly if the last few percent of the cycle service level increases (see: Figure 5, Figure 6 and Figure 7). For the class A products, the value of the safety stock with a CSL of 0,900 is 43,8% of the value of the safety stock with a CSL of 0,999. For class B products, the safety stock with a CSL for 0,900 is 91,6% of the maximum value of the safety stock and for class C products, this is 99,8%. Increasing the CSL of class A products has the most influence on the total value of the safety stock. It is recommended to keep the CSL of class C and class B products high (between 0,990 and 0,999). The CSL of class C and class B products have high influence on the total service level and relatively low influence on the value of the safety stock. For class A products, a trade-off between costs and cycle service level must be made.

4.3.3 Frozen period

The input for finding out the influence of the frozen period on the total value of the safety stock is the same as in the above situations, namely an average demand of 37 per month and a standard deviation of 21,5 per month. The input for the frozen period is based on 1 day to 100 days.

For determining the effect of the frozen period, the following cycle service levels for the classes are taken:

Class A: 0.95
Class B: 0.97
Class C: 0.99

The maximum value of the safety stock is based on the maximum value of the safety stock if the frozen period = 0 days. Looking at the results in Figure 8, it is clear that the longer the frozen period, the lower the value of the safety stock. The first derivation, which shows the slope of the value of the safety stock in Figure 9, is the lowest as the frozen period is 65 days. Before and after this period, the difference between the value of the safety stock decreases less if the frozen period is extended with 1 day. If the frozen period is 65 days, the maximum value of the safety stock is 59,0% of the value of the maximum safety stock. If the frozen period 100 days, the maximum value of the safety stock is 35,3% of the value of the maximum safety stock.

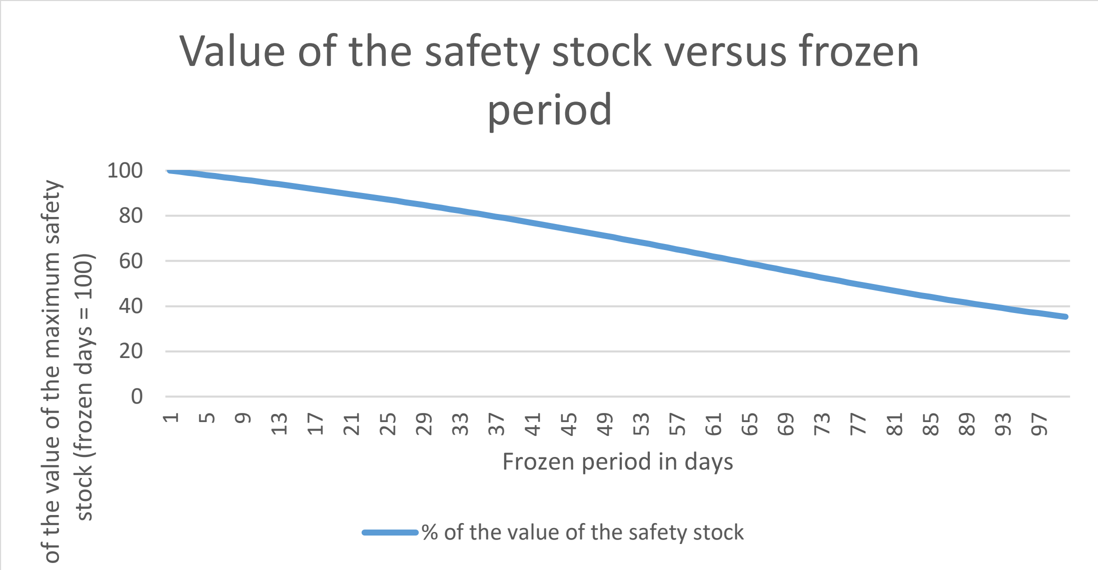

Figure 8 The value of the safety stock versus the frozen period in days. For the maximum value of the safety stock, frozen period = 0 is taken.

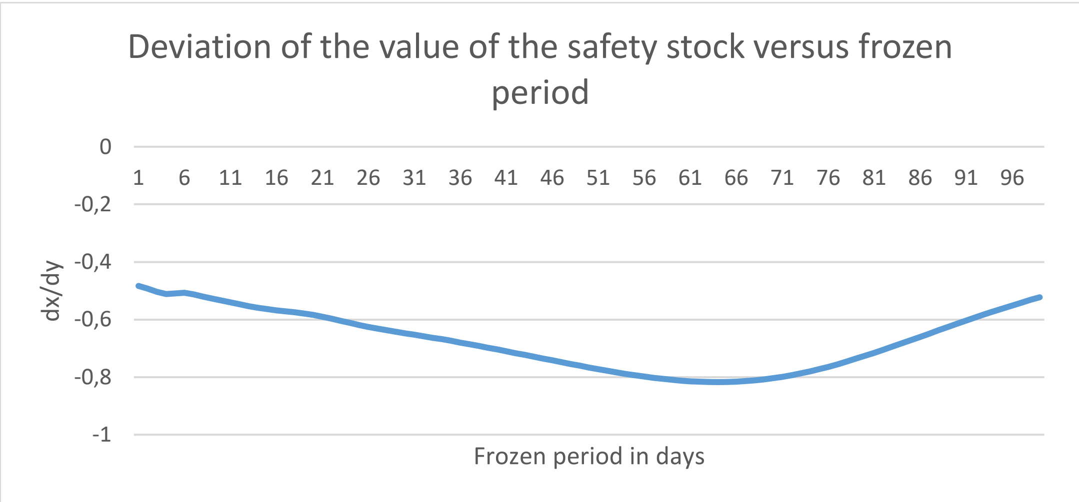

Figure 9 The deviation of the value of the safety stock versus the frozen period (Figure 8)

A longer frozen period makes it easier to predict how much of a specific item is needed. The use of a long frozen period ensures less safety stock. However, a long frozen period means less flexible option for the customer of DP. This implies that the length of the frozen period must be discussed with the customer.

4.3.4 Standard deviation of the demand

In the starting situation, the standard deviation of the demand of end products per month is not reliable, because it is not known. The standard deviation of the demand influences the safety stock directly. The influence of the standard deviation of the demand on the safety stock is analysed and can be found in Figure 10. For the maximum value of the safety stock, the value of frozen period = 20 is used. For this analyse, the following input is used:

Demand per month: 37 units
Frozen period: 0

CSL Class A products: 0.95
CSL Class B products: 0.97
CSL Class C products: 0.99

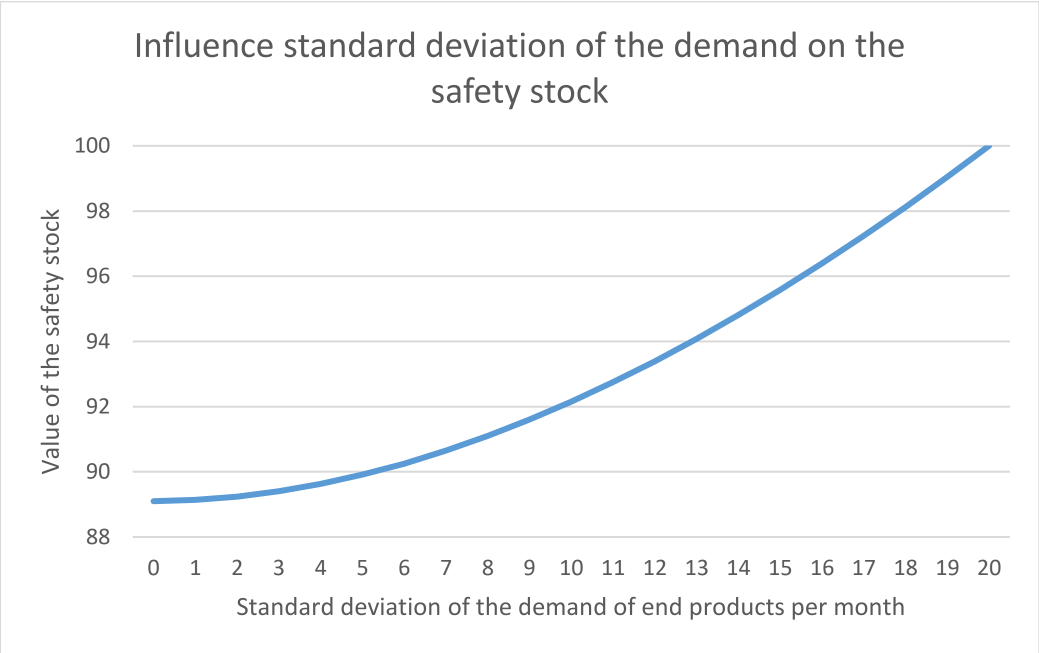

Figure 10 Influence of the standard deviation of the demand of end products per month on the safety stock value

The difference of the maximum value of the safety stock between a standard deviation of 20 end products per month and a standard deviation of 0 end products per month is 10,9 % lower. The slope of Figure 10 becomes higher if the standard deviation of the demand of end products per month becomes higher.

4.3.5 Dependent demand compared with independent demand

As already mentioned in chapter 3, the safety stock is determined on the basis of an independent inventory instead of a dependent inventory. The differences between these two situations is simulated with a model in Excel. This model contains 10 products of class C, 7 products of class B and 3 products of class C. The reorder point is determined for a CSL of 0.95 for the class A products, 0.97 for the class B products and 0.99 for class C products. The simulation will give an indication of the difference in the output of an independent and dependent inventory.

Two situations are simulated. In the first situation, the demand is dependent and calculated for each day according to the normal distribution. This contains that if the demand is two, every items has a demand of two (or a multiple of two in the case the end product contains more than one of a specific item). In the second situation, the demand is independent. This means that for each item, the demand is calculated separately according to the normal distribution. If the demand for an item is 2, the demand of another item can be different.

The input of this model is the same as the other model, the average demand is 37 per month and the standard deviation is 21,5 per month.

The two models are a simplification of the real situation. The following point must be taken into account:

- There can only be ordered once between the current day and the day + the average lead time
- There are no weekends or holidays taken into account
- The first situation, for calculating the average days of stock out = 0 is simulated 40 times. Each simulation contains 300 days and the last 200 days are used for analysing.
- The second situation, for calculating the average value of the total stock is simulated for 1200 days and the last 1000 days are used for analysing.
- Q is calculated with the EOQ formula with following input, the holding costs are 0.2 and the fixed ordering costs are 85. If Q was smaller than the average demand during the lead time of the component, the value of Q was the same as the average demand multiplied with 3. This was mostly the case by class A products.

As an output, the percentage of the days that not all products are available (stock outs >= 1) compared to all days and the average value of the total value of the safety stock are calculated. The results can be found in Table 9. It is noticeable that the percentage of days 'stock outs >= 1' of an dependent inventory is 26,7% lower than in the situation of an independent inventory. However, the average value of the total stock for a dependent inventory is 9,7%. higher than the average value of the total stock for an independent inventory. The dependent inventory shows also a 53,0% higher standard deviation of the total value of the safety stock compared with an independent inventory.

	Percentage average days stockout >= 1	Average value of the total stock	Standard deviation of the value of the total stock per day
Dependent demand	8.8%	€37.460	€9.668
Independent demand	12.0%	€34.147	€6.321

Table 9 Output of the simulation for a dependent and an independent inventory

The differences in both situations were smaller than expected, compared to the results of the study of Hausman (1998). There are however a lot of differences in the type of study. We use a statistic lead time, instead of a deterministic lead time. Besides, another model (periodic order-up-to system) is used for determining the safety stock. Hausman (1998) showed that the higher the safety stock fractile, the lower the differences between a correlation of 0 and a correlation of 0.9. The safety factor, used in our model, is based on the cycle service level, which results in a relativity high safety stock. This can also explain the relatively small differences.

When implementing the tool, it is important to keep in mind that the average value of the stock is higher and the standard deviation of the value of the total stock are both higher than in the case of independent inventory. This is further discussed in 5. Implementation plan.

5. Implementation plan

In this section the last research question *'How can the solutions be implemented at DP?'* will be answered. Hereby, the results of the conclusions of chapter 4 will be taken into account. The focus of the implementation plan is on the tool for calculating the safety stock. The implementation plan contains 7 steps, which should be followed step-by-step.

1. **Put reliable data into the information system.**
   In the current situation, the input of the information system is not always accurate. This makes it not possible to make a material planning or to correctly determine the safety stocks. Especially the quality of the data of the BOM, the pre-arranged delivery time of goods to receive and the pre-arranged delivery time of products must be improved. Options to increase the data quality are to use no free text fields and to check and correct the data on a regular basis by an employee.
2. **Measure the field loss, the material used for service and if necessary for the component, the rejected material**
   In order to determine the average demand and the standard deviation of the demand adequately, we need:
   - The field loss;
   - The material used for service
   - The rejected material.

   During the analyse phase, this is not taken into account. DP must generate reliable data about the field loss, the material used for service can the rejected material. The field loss, material used for service and the rejected material can be monitored in an Excel file and can later be included with the total demand.
3. **Elaborate the tool with an assembly model for calculating the safety stock for the components of each product.**
   The tool at the moment is based on an independent demand. The situation at DP is however a dependent demand. If the tool is implemented without an assembly model, it is more difficult to determine the cycle service level and to determine the effect. The simulation research showed a higher average value of the safety stock and a lower days of stock-outs for 20 items. For more items, we expect that the differences are higher.
4. **Connect the tool to the 'Hoppatool'**
   The data of the ERP system is needed for calculating the safety stock. Thus, before the tool can be used, the tool must be connected to the ERP system. The average lead time and the standard deviation must be calculated automatically. The output of the tool must be connected to the 'Hoppatool', which gives attentions if material must be bough. After connecting the tool to the ERP system, each item of each BOM must be classified. After this, the cycle service level for each class must be determined before the tool can be used.
5. **Make appointments with the customers of DP about the service level, the frozen period and the (maximum) standard deviation of the demand.**
   DP wants that the customer guarantees the safety stock. This implies that the customer bears the risk of the safety stock. Therefore, decisions, about the frozen period, the cycle service levels, the demand and the standard deviation of the demand must be discussed with the customer.

6. **Monitor the demand**
   The quality of the output of the model increases if the quality of the input is better. Therefore, the average demand and the standard deviation of the demand must be monitored. By doing so, it is easier to check if customers keep appointments and to change the appointments if necessary.
7. **Check the input and output of the tool regularly for continuous improvement**
   If the input changes, for example, the lead time of the components becomes lower, it influences the amount required of the safety stock. The required output should continuously be checked with the input for predicting which factors influence the safety stock. For doing this, doing research to a monitoring system is recommend.

6. Conclusions and further outlook

In this chapter, first the conclusions of this research are given. After this, the further outlook regarding this research can be found.

6.1 Conclusions

The focus of this research was the following sub problem:

The fluctuation of the demand and the delivery time of suppliers are not captured with a safety stock.

A tool is made to calculate the safety stock. The tool is based on a (s,Q)-inventory with a cycle service level as safety factor. A classification is made between products classes and the demand is given as independent demand instead of dependent demand. After the model development phase and analysing the results, the following conclusions can be made:

- The standard deviation of the demand per month influences the value of the safety stock. The value of the safety stock is 10,9% lower if the standard deviation of the demand per month is 0 instead of 20;
- The higher the frozen period, the lower the total value of the safety stock. If the frozen period is 65 days, the value of the safety stock is 59,0% of the value of the safety stock for a frozen period of 0 days;
- Class A products have the highest influence on the total value of the safety stock. For CSL of class A = 0,900 (and CSL for other classes = 0,900), the total value of the safety stock is 43,8% of the total value of the safety stock for CSL = 0,999. For class B products, this percentage is 91,6% and for class C products, this percentage is 99,8%;
- The CSL of class C products have the most influence on service level of the safety stock compared with the other product classes. 50,6% components are class C products. For class B products, this percentage is 34,2% and for class A products this percentage is 15,2%;
- In combination with the total value of the safety stock, we recommend to have the CSL of class C and class B products around the 0,995 – 0,999;
- The percentage of days ‘stock outs => 1’is 26,7% lower for a dependent demand than for an independent demand. However, the average value of the total stock is 9,7% higher and the standard deviation of the average value of the total stock is 53,0% higher for a dependent inventory compared to an independent inventory.

Before the tool can be used, the tool should be extended with an assembly model. Besides, the data into the ERP system of DP must be reliable. If the input is not correct, the output can never be good. Also, the field loss, material used for service and the rejected material must be monitored. These parts must be included with the demand and the standard deviation of the demand for each item. Hereby the input must be correct before the output can be correct.

One solution for the core problem is worked out during this thesis. Advisable is to have a safety stock, which captured the fluctuations in demand and supply. It is advisable to elaborate the tool with an assembly model before implementing the tool.

6.2 Further outlook

The purpose of this research is completed, but remarks for improvements can be made. More research related to the model for determining the safety stock can be done. Besides, the sub problems requires more investigation before they all have a solutions.

6.2.1 Assembly inventory management

Dependent inventory management, also known as assembly inventory management, is different from independent inventory management. The simulations showed difference between the two situations with 20 components. It is expected to have more difference with 79 components. Advisable is to investigate in an assembly inventory model for determining the safety stock. This model must also be tested to check the outcome.

6.2.2 Forecast

In the current tool, the assumption that the demand is a normal distribution is made. No forecast models are used to expect the demand.

The products, produced at DP, are new at the market. The grow of these products can be predicted with different type of models. With the use of these models, DP can better predict the demand of products in the future. This makes it easier for predicting the amount of material which is needed in the future and can result in a lower total value of the safety stock. The uncertainty in the demand becomes namely lower.

As a input for the tool, only the demand of the customer is used. For the optimal value of the safety stock, also the material used for service, the field loss and the rejected material must be added to the demand. These three types of demand must also be taken into account during the investigation to a forecast model.

6.2.3. Other sub problems

During the research to the causes of the core problem, more sub problems were found. In this thesis, I focussed only on the safety stock. It can be worthwhile to investigate in the other sub problems. More information on these problems (the literature research) can be found in Appendix 7 - Solutions from the literature.

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Appendix

Appendix 1 - Theoretical framework process mapping technique

The three process modelling techniques are analysed in the following part. The three methods are event-driven process chain (EPC), business process modelling and notation (BPMN) and Unified Modelling Language (UML) diagrams.

Event-driven process chain (EPC)

Event-driven process chain, also called EPC, is a technique for process modelling. The documentation of process modelling is conceived in the early 90's by Augus-Wilhelm Scheer (Amjad, Azam, Anwar, & Butt, 2018). EPC is designed as a device for documenting business models (van der Aalst, 1999). EPC contains the following elements:

- *Functions*
  A 'function' refers to an activity, such as a task or process step. A 'function' must be executed (van der Aalst, 1999).
- *Events*
  'Events' give the pre-condition(s) and the post-condition(s) in the process chain (Weske, 2007). 'Events' and 'functions' are linked with each other. The post-condition(s) of one 'function' can be the pre-condition(s) for the next 'function' (van der Aalst, 1999).
- *Logical connectors*
  The 'logical connectors' are used to connect 'functions' and 'events' with each other. The different types of 'logical connectors' are 'and', 'exclusive or' and 'or' (van der Aalst, 1999)

Figure 11 Elements of EPC ((van der Aalst, 1999)

In Figure 11, the main elements of EPC are described. The first 'logical connector' is the 'exclusive or' connector, the second is the 'and' connector and the third is the 'or' connector. A process, described with EPC, begins and ends with an 'event'. Between these two 'events', 'events' and 'functions' alternate and 'logical connectors' can occur. It is also possible to add data with possible KPI's in the EPC (Tscheschner). Doing this, EPC can be used to analyse processes.

EPC is a semi-formal modelling language and is used by many industries. EPC helps getting the quality document, according to the international standard ISO 900x. The language of EPC is not difficult and understandable for everyone. This makes EPC accessible for everyone (Amjad et al., 2018).

Different EPC variants exists in the literature. The reason is that some specific complex events cannot be mapped in the original version of EPC (Amjad et al., 2018). In the paper of Riehle et al., these variants are called EPC dialects. In total, Riehle et al. found 14 variations of the EPC (Riehle et al., 2016). Variant are used to increase the possibilities of process mapping with EPC.

BPMN process maps (Business Process Model and Notation)

Business Process Model and Notation, also called BPMN, is a notation of processes, based on a flowchart technique. The first version of BPMN is invested in 2004. BPMN is developed with the purpose of having a notation which is understandable by all business users. It contains a set of graphical components, which can be classified in four groups (White, 2004):

- *Flow objects*
  'Flow objects' are the main components of BPMN. Three different 'flow objects' exists, namely event, activity and gateway. The first one, event, is something that 'happens'. Mostly, the event has an input (the cause) or an output (the impact). Three types of event occur, namely 'start', 'intermediate' and 'end'. These are described as circles.
  The next object, activity, is a rectangle with round corners. The two different types are Task and Sub-process. The last flow object is the gateway; described as a diamond shape. It is used for control.
- *Connecting objects*
  The 'connecting objects' connect the 'flow objects'. There are three types of connecters, namely the 'sequence flow', a 'message flow' and an 'association'. The first one shows the order and is a solid line, the second one, 'message flow', shows the flow of messages and is a dashed line. The last flow, 'association', is a dotted line and associate 'artefacts' with 'flow objects'.
- *Swimlanes*
  'Swimlanes' are used to clarify the responsibilities. There are two types, namely 'pool', which represents a participant in a process, and 'lane', which represents a sub-partition within a 'pool'.
- *Artefacts*
  BPMN knows three types of 'artefacts', namely 'data objects', 'group' and 'annotation'. 'Data objects' shows the data, which can be an input or an output of an activity. The connection with other elements is done with 'associations'. The second 'artefact', 'group', has as main purpose documentation and analysis, for example with KPI's. It does not have an effect on the flow. The last artefact, 'annotation', is used for adding text for the comprehensibility of the BPMN (White 2004).

An example of a part of the process is showed in Figure 12. Here, three different 'pools' are shown, namely administration, management and web server. Beside this, the activities are shown, as well as the 'sequence flow connecter'. The BPMN also contains 'data objects', in this example the purchase info and the approval request email. Besides, the 'group' can be found and the 'annotation', giving information about when the activities start, can be found in the BPMN.

BPMN version 2.0 is an ISO standardised notation. This means the notation is the standard international norm for modelling business processes (Krishna, Poizat, & Salaün, 2019). Hereby different gateways are added to the first notation of BPMN. This can be found in Figure 12.

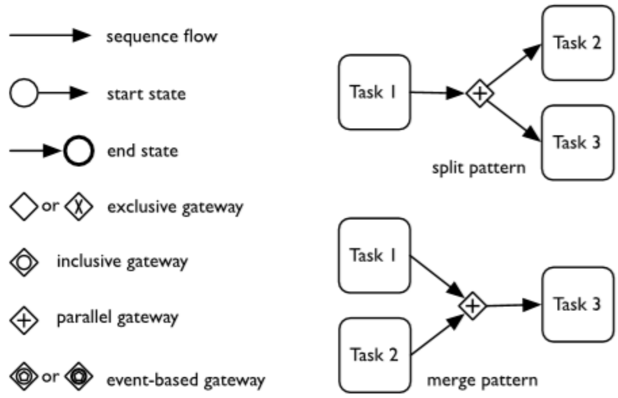
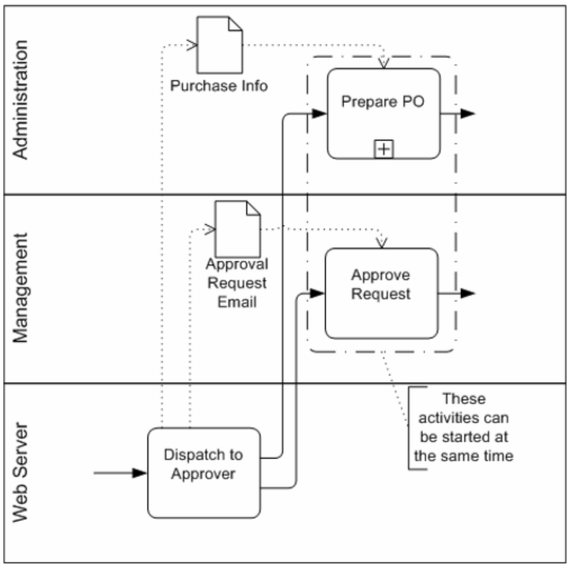


Figure 12 A part of the notation of BPMN (Krishna et al., 2019)



Business Process Management (BPM) used the notation of BPMN. If the processes are reordered with BPMN and KPI's are determined, different techniques can be used to optimize the process. A useful example of these techniques is Lean. The BPM model is used to determine the steps of the process and after that to eliminate the waste and to balance the workflow. This is done with different tools, for example Value Stream Mapping. (Skalle, Ramachandran, Schuster, Szaloky, & Antoun, 2009). Value Stream Mapping focuses on process improvement and eliminates value-added and non-value-added activities (Shou, Wang, Wu, Wang, & Chong, 2017).

UML (Unified Modelling Language) diagrams

Unified Modelling Language (UML) 'visualize, specify, construct and document' the artefacts of a system (Booch et al., 1999; Fleacă, Fleacă, & Maiduc, 2016). UML can be seen as language with own rules. UML is mainly used for programmers and fits the gap between thinking and coding. In the first place, UML is modelling software, however, the workflow helps also visualize processes (Booch et al., 1999).

UML exists of three different elements, namely:

- *Things*
  The 'things' are the basic blocks of UML. UML has four different 'things', namely 'structural things', 'behavioural things', 'grouping thing's and 'annotation things'. The 'structural things' are the nouns of a model and the behavioural things are the verbs of a model. 'Grouping things' are used for the organizational purposes, such as grouping. The 'annotation things' explain some part of the UML model. A lot of different variant exists, especially the 'structural things' and the 'behavioural things' groups a lot of different components.
- *Relationships*
  UML knows four types of 'relationships', namely 'dependency', 'association', 'generalization' and 'realization'. If the independent 'thing' affects a dependent 'thing', the

‘dependency’ relationship is used. For a structural relationship between one and his parts, the ‘association’ is used. When an object is an element of another object, the ‘generalization’ relationship is used. The last relationship, ‘realization’, is a relationship between classifiers.

- *Diagrams*

  ‘Diagrams’ are the representation of a set of elements. UML knows nine different types of ‘diagrams’. Because of the high number of different types, the different types are not explained (Booch et al., 1999).

  The specific rules of UML according to the sequences, are more complex than other business modelling techniques. As a result of this, the rules are not described. UML is mostly used for understanding systems which are going to be developed. Sometimes, UML is also used for understanding the processes, but this not the main purpose of UML. However, the purpose of UML is to be understandable for everyone (Booch et al., 1999). In Figure 13, a part of a model made with UML can be seen. It shows the state of machines. As seen in the figure, it is a complex language and mostly used for modelling software.

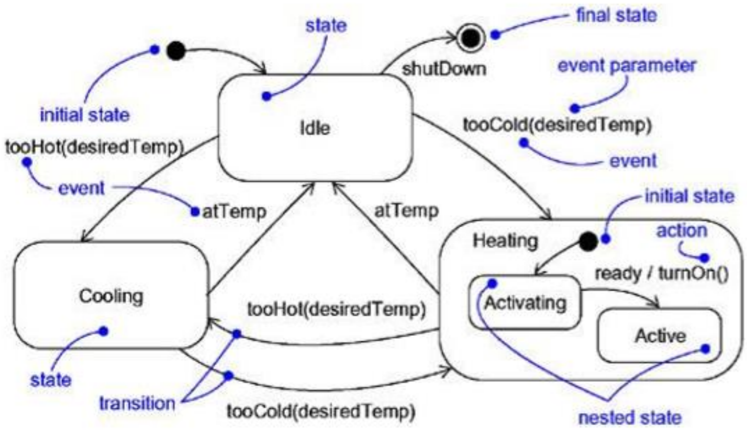


Figure 13 model made in UML

Appendix 2 - Purchasing process overview

Confidential information

Appendix 3 - Material planning process

Confidential information

Appendix 4 - Stock & picking list

Confidential information

Appendix 5 - Hoppatool

Confidential information

Appendix 6 - Tables interviews

Confidential information

Appendix 7 - Solutions from the literature

The two problems which will form the basis of this section are 'there is no overview of the material planning' and 'the suppliers are not reliable'. These two problems can be dived into different subsections. For each subsection, solutions from the literature are found.

There are not always agreements with the suppliers about delivery time, quality etc.

Suppliers are important for creating value for organizations. Most of the time, companies assume, after making the 'make vs buy' decision, that competitive forces of the market are enough to get the best transaction. Nonetheless, using the competitive forces of the market does not work anymore if products and services become more and more complex (Vitasek & Manrodt, 2012).

The Kraljic matrix is a commonly used tool to manage different types of suppliers. The matrix combines two dimensions, namely 'profit impact' and 'supply risk'. These both can be divided into 'low' and 'high'. As a results, this gives four quadrants. Of each quadrant, Kraljic has developed 'main tasks' for interact with the supplier. Most of the material which gives problems to DP, have a high supply risk for DP and a low profit impact for the supplier. This scenario can be found in the 'bottleneck quadrant'. For ensuring enough supply, a high safety stock is recommended, according to the Krajlic matrix (Caniëls & Gelderman, 2005). This will be discussed later in this section.

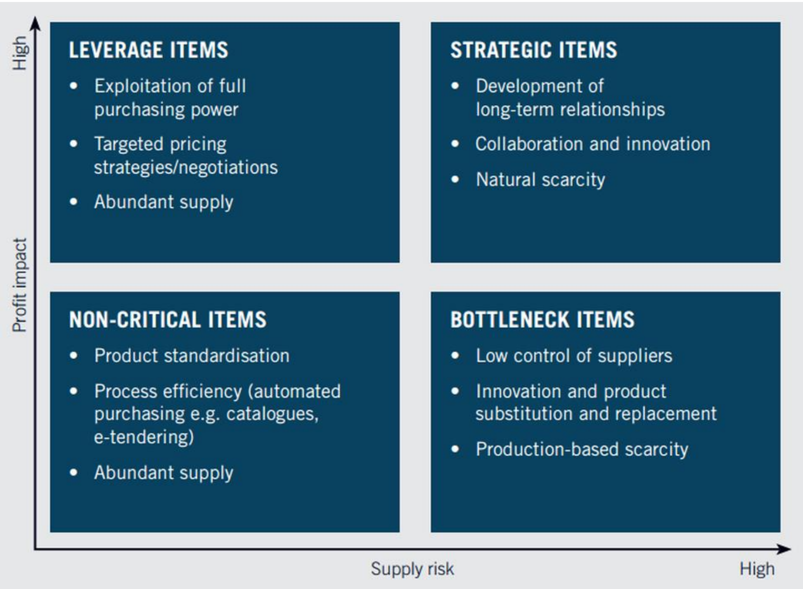


Figure 14 The Kraljic matrix. Source: Peter Kraljic, HBR

At the moment, DP is used to place an order, get an invoice and purchase the orders, for all types of components. The relationship with the suppliers is transaction-based. Most components have an approved provider, which means that the supplier is selected on specific criteria, for example quality. This model is called an 'approved provider model'. Contracts can be used between the suppliers and the organization in an 'approved provider model' (Vitasek, 2016). This is not always the case by the suppliers of DP.

Besides the 'approved provider model', which is a transaction-based model, more models exists. The models can be divided into transactional models, relational models and investment models. For simple components, the transaction-based model is the most efficient. However, this model is not useful for complex, variable components. For the suppliers of these components, a relational business model is recommended. Relational models are more focussed on adding value to both the suppliers and organizations. This can be seen as a 'win-win' situation (Vitasek & Manrodt, 2012). Three different types within the relational models exists, namely 'preferred providers', 'performance-based/managed service model' and 'vested sourcing business model'.

For DP at this moment, the switch between 'approved provider model' and 'preferred providers' has to be made first for the complex components. At the moment, it is not possible to monitor the performance of the suppliers, so a 'performance-based/managed service model' or 'vested sourcing business model' cannot be applied yet. Measuring the performance of suppliers will be discussed in the next part of this section.

To set up a basis for a relationship with suppliers, the first step is to get to know your supplier. How works the supplier? And how is the business where the supplier is in? (Liker & Choi, 2004). After that, it is recommended to come up with long-term and renewable contracts between the organization and the suppliers to improve the relationship (Liker & Choi, 2004; Vitasek & Manrodt, 2012). Before making the contract, a study to the exact needs of DP and the suppliers must be done.

The suppliers are not monitored about their performances

To choose the right supplier, it is important to monitor the suppliers (Liker & Choi, 2004; Maestrini, 2018). A system to monitor the suppliers is called supplier performance measurement system (SMPS). If a SMPS is implemented and the results are evaluated with suppliers, it also have a positive influence on the supplier performance (Gordon, 2005; Maestrini, 2018).

When implementing SMPS, the organization must know which key performance measurements (KPI's) they want to measure. Besides the traditional KPI's, such as delivery reliability, price and quality, other KPI's can be interesting. Examples of other important KPI's are 'continuous improvement' and 'channel relationship' (Simpson, Siguaw, & White, 2002). The organization must discuss which KPI's they want to measure.

At DP, the production planning is based on when the components are available. As a result, the reliability of suppliers is important. Measuring the reliability can already done with the current data in Excel. However, the basis is to make agreements with the suppliers about the delivery time and put the data correct into AFAS. After that, the reliability must be monitored. A study for the exact needs of making a SPMS for DP must be done before such system can be implemented. This can be done in follow-up investigation.

A lot of Excel sheets are used and the material planning is complex.

Material planning is about the moment and the quantity of an order (Maestrini, 2018). There are different methods for material planning, namely re-order point systems, run-out time planning, material requirement planning, Kanban and order based planning (Jonsson & Mattsson, 2002).

The products made at DP have a low volume, high complexity with an extensive Bills of Materials (BOM), long delivery lead-time, relative short assembly time, are produced in small batches and make to order. Make to order means that products are produced based on the demand. It is a pull system. In the paper of Jonsson and Wänström (2003), different material planning methods are compared which other in a specific environment. Re-order point systems and run-out time are material planning methods designed for independent demand. This is also not the case at DP. Kanban is the useful for repetitive mass production. As a consequence, Kanban is also not useful for the complex material planning at DP (Jonsson & Mattsson, 2003).

At the moment, Kanban is used at DP for commonly used materials. Kanban makes use of cards, which show the material flow and minimize the stock levels. Kanban is based on a pull system. If the stock is behind a specific level, new material is ordered. The method can also be used in the whole production process.

The two material planning techniques which can be interesting for DP are material requirement planning (MRP) and order based planning. The input for a MRP system is a the BOM, a master production schedule (MPS) and the inventory records (Slack, Chambers, & Johnston, 2010). A MPS is an overview with the sales orders and helps to determine if an sales order can be accepted and when the delivery date can be set. As an output, the MRP gives an overview about how many must be ordered and when these components must be ordered. A MRP system is based on calculations (Slack et al., 2010). The demand of the customers can be dynamic.

Besides the traditional MRP, Demand-Driven MRP (DDMRP) is developed since 2011 by Carol Ptak and Chad Smith. The traditional MRP did not function well enough in an environment with more complex networks, a lot of different products, long lead times and an uncertain demand (Shofa & Widyarto, 2017). A traditional MRP system is a push system (Slack et al., 2010). The demand is based on calculations of the order history. In addition, DDMRP is a pull system. This means that, as the name already says, the DDMRP is based on the demand (Pekarcíková, Trebuna, Kliment, & Trojan, 2019). This is the same as the Kanban system. Although Kanban is not useful for complex products (Jonsson & Mattsson, 2002), DDMRP can be used for complex products. In a DDMRP is the safety stock continuously calculated. This safety stock is called a ‘buffer’ and is dynamic (Pekarcíková et al., 2019).

Another method which is used a lot in environments like the environment of DP, is order based planning (Jonsson & Mattsson, 2003). The forecast and the BOM are used to make the order based material planning. With the order fill rate, the lead times of the materials, the forecasts of the customers and the forecast errors are used to determine the needed material. The order fill rate is the percentage of orders which can immediately be picked form stock (Aykin, 2003). The difference between MRP and order based planning is that no MPS is used. The material is purchased directly from the forecast.

Taken into account that the product at DP are made to order, which is a pull system, and that the environment at DP is complex and changeable, DDMRP or Order-based planning should fit. A lot of suppliers of these systems exists. The exact requirements of a material planning system must be researched in a following-up investigation.

The input on which the material planning is based, is not always correct.

Each material planning method uses input. The most important input are the stock level, the forecast of the customers and the BOM (Jonsson & Mattsson, 2002; Pekarcíková et al., 2019; Slack et al., 2010). If the input is incorrect, the output will also be incorrect. Before implementing a material planning method, the input must be determined and correct. On the short-term, a planning method is not useful, because of the fact that the input is not correct. If the input data is improved, a planning tool can be useful for DP. There are serval option to improve the data quality. Possibilities to improve the data quality are to validate the data automatically, use no free text field and correct and check data. An deeper study about how the data can be improved must be done.

The fluctuations of the demand and the delivery time of suppliers are not captured with a safety stock.

A safety stock can help as a buffer to cope with the fluctuations of the delivery time of suppliers and of the demand (Jonsson & Mattsson, 2003; Korponai et al., 2017). DP aims to have a forecast and commitment of the customer. There are a lot of different methods for different situations to determine the safety stock (Silver et al., 2017). Different methods are discussed in 3.1 Safety stock.

Unreliable suppliers and a fluctuated demand have an influence on the safety. The safety stock becomes higher if the demand is less certain and suppliers are less reliable stock (Korponai et al., 2017). The fluctuated demand can be controlled, by creating a long-term planning. The planning, called a Sales & Operations Planning (S&OP) monitors the demand and supply (Alfaro Santa Cruz, Valverde Torres, & Ibanez, 2019). It is also possible to freeze the MPS to get to stabilise the demand. In a frozen period, the planning cannot be changed

Possible solutions

The solutions according to the literature study can be found in Table 10. For determining the material planning tool, improving the relationship between DP and suppliers, choosing the KPI's and making the suppliers performance tool and determining the high of the safety stock, extra research must be done.

Main problem	Sub problem	Solution
Material planning is not good	The input on which the material planning is based, is incorrect. The input of the planning is the BOM and the forecast/commitment with the customers.	Check all the input before a sales order is accepted.
	It is difficult to oversee the whole material planning for a longer period. A lot of Excel sheets are used and the material planning is complex.	Make use of one material planning tool for all the lines, such as DDMRP or Order-based planning.
Suppliers are not reliable	There are not always agreements with the suppliers about delivery time, quality etc.	Improve the relationship from a transaction-based model to a relationship-based model
	Suppliers are not monitored about their performances.	Choose the KPI's, collect the data and make a suppliers performance tool
There is no overview of the material planning and suppliers are not reliable	The fluctuations of the demand and the delivery time of suppliers are not captured with a safety stock.	Determine the level of the safety stock

Table 10 Solutions of the problem, based on the literature

In consultation with DP, it is decided to work out the level of the safety stock for different parts of the material in section 3.2. The rest of the solutions is for investigation studies.

Appendix 8 - Derivation of the safety stock with a frozen period

The derivation of the formula for the safety stock with a frozen period can be found below (personal communication, M. C. Van der Heijden, 14 January, 2020).

Mean:

$$E[(L-FP)^+] = \int_{FP}^{\infty} (x-FP) f(x)\, dx = \int_{FP}^{\infty} (x-FP) \frac{1}{s_L\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-L}{s_L}\right)^2} dx$$

Integral substitution $y = (x-L)/s_L \Leftrightarrow x = L + s_L y$ and $dx = s_L dy$

$$E[(L-FP)^+] = \int_{(FP-L)/s_L}^{\infty} (L + s_L y - FP) \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy$$

Now define $z = (FP-L)/s_L$

Then

$E[(L-FP)^+] = s_L G(z) = s_L G\left(\frac{FP-L}{s_L}\right)$ with $G(z) = \phi(z) - z * [1 - \Phi(z)]$ where $\phi(z)$ denotes the standard normal density function and $\Phi(z)$ denotes the standard Normal distribution function.

Variance:

We use that $Var[\{(L-FP)^+\}^2] = E[\{(L-FP)^+\}^2]$- $\{E[(L-FP)^+]^2\}$

Second moment:

$$E[\{(L-FP)^+\}^2] = \int_{FP}^{\infty} (x-FP)^2 f(x)\, dx = \int_{FP}^{\infty} (x-FP)^2 \frac{1}{s_L\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-L}{s_L}\right)^2} dx$$

Integral substitution $y = (x-L)/s_L \Leftrightarrow x = L + s_L y$ and $dx = s_L dy$

$$E[\{(L-FP)^+\}^2] = \int_{(FP-L)/s_L}^{\infty} (L + s_L y - FP)^2 \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy$$

Now define $z = (FP-L)/s_L$

$$E[\{(L-FP)^+\}^2] = s_L^2 \int_{z}^{\infty} (y-z)^2 \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy$$

Simplification

$$\int_{z}^{\infty} (y-z)^2 \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy = \int_{z}^{\infty} y^2 \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy - 2z \int_{z}^{\infty} y \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy + z^2[1-\Phi(z)]$$

Similar to slide 15 of Session 5 DSP&IM: $-2z\int_{z}^{\infty} y \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy = 2z|\phi(y)|_{y=z}^{y\rightarrow\infty} = -2z\phi(z)$

$\int_{z}^{\infty} y^2 \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2} dy$:Derivative of $y\phi(y)$ is $\phi(y) - y^2\phi(y)$

- So the primitive of $y^2\phi(y)$ is $\Phi(y) - y\phi(y)$

and thus

$$\int_z^\infty y^2 \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}y^2}\, dy = |\Phi(y) - y\phi(y)|_{y=z}^{y\to\infty} = [1-0] - [\Phi(z) - z\phi(z)] = 1 - \Phi(z) + z\phi(z)$$

Combine the three components:

$$E[\{(L-FP)^+\}^2] = s_L^2\{1 - \Phi(z) + z\phi(z) - 2z\phi(z) + z^2[1-\Phi(z)]\}$$
$$= s_L^2\{(z^2+1)[1-\Phi(z)] - z\phi(z)\}$$