Bachelor assignment
Woven PP supply chain optimization

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UNIVERSITY OF TWENTE.

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Woven PP supply chain optimization

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Preface

Dear reader,

I would like to present my bachelor thesis for the Industrial Engineering & Management programme to you. This bachelor assignment was carried out at Company X and is about optimizing the supply chain of polypropylene related wovens.

I would like to thank Company X for the assignment they provided to me. It was a very educational period to carry out an assignment for a company that plays an important role for the products they supply to their customers. I would particularly like to thank my supervisor of Company X, who took most of the supervisor role within Company X for this bachelor assignment. I could always contact her with questions and she showed a lot of interest in my report, the tool and my progress.

From the university, I received help from Petra Hoffmann for my thesis. Through online meetings and her feedback, I have been able to continue to improve my report. This feedback and later also the feedback from Engin Topan helped me to eventually deliver this final version.

This entire thesis took place during the COVID-19 pandemic. This has ensured that the execution of the thesis has looked different compared to other years. The presence at Company X was limited, so most of the report was made at home. This was not always easy and that is why I would like to thank my friends and family. With their support, it was possible for me to overcome difficult points during this period.

I'm pleased with the end result of this report and I hope you enjoy reading this thesis.

Ruben de Boer

Hengelo, November 2020

Management summary

Problem definition

This research took place at Company X. Company X currently sources most of it yarns in Europe while the main (and most competitive) market for yarns is in Asia. Company X is currently testing with Asian yarns from their own Asian subsidiary but they are also interested in investigating options for purchasing yarns and / or woven material materials on the Asian market.

The current supplier for polypropylene (PP) related materials of Company X will soon cease their supplying operations, so Company X is looking for one or maybe even more new suppliers for these materials. The search for new suppliers for PP related materials ultimately fell on two potential suppliers, one in Europe and one in Asia. A number of points are important in choosing the best supplier:

- High quality products and materials
- High delivery reliability
- Low costs

With these points in mind, the following action problem has been created for this research:

The combination of purchasing and inventory cost of polypropylene related materials at Company X should decrease with 10% while the delivery reliability and the quality of the products will not decrease.

Research goal & design

The research goal is to find a way to solve the action problem and to find an answer to the main research question: *How should the supply chain for the polypropylene related wovens look like?*

Questions that must be answered to achieve this research goal include:

- Should Company X purchase only yarns, only wovens or a mix of both from the supplier(s)?
- Should Company X make use of the European supplier, the Asian supplier or a mix of both?
- How should the ideal safety stock and reorder level be determined?

Scientific literature in combination with files and conversations/interviews provided by Company X were used to solve the research questions and to develop an Excel tool. This tool is essential for this research because it is intended to provide suggestions about desired stock levels, reorder levels and order quantities in the future.

Results

With the tool it was possible to calculate the following values:

- Safety stocks
- Reorder levels
- Order quantities

These values are provided to indicate how high the stock levels of Company X must still be to purchase from a particular supplier and what the order quantity should be in that situation. The tool is made dynamic which means that when the input values change or are supplemented, the tool can give new output values for the safety stocks, reorder levels and order quantities based on the new input values. This ensures that the data in the tool is easy to adjust and that the tool can be used over a longer period of time. As an end result, the tool could make calculations about the purchasing and the inventory cost to see if the action problem could be solved.

Conclusion

The following statements can be concluded following this research:

- The holding costs of wovens are a lot higher than the holding costs of yarns so **purchase mainly yarns**. The flexibility of the production process remains high with this decision and Company X has enough production capacity to convert the yarns into wovens. Exceptions when it's advantageous to purchase wovens are when the demand for the coming period is known and when the weaving looms of Company X can no longer cope with the demand.
- There are a couple of PP related materials and a lot of different scenarios that have to be looked at before choosing a supplier. The **Asian supplier is by far the better option when costs are looked at**. Due to time constraints, the Asian supplier can't always be used. The **European supplier is better for the flexibility** of Company X towards their customers.
- It's ideal to make use of **dynamic values for safety stocks and reorder levels.** This way, the safety stock and reorder level can change due to uncertainties in costs, demand and lead time. The tool can take these uncertainties in account and provide dynamic values for the safety stocks and reorder levels.

Recommendations

This report also provides recommendations for Company X for the future. A general recommendation for Company X is to use the tool that is developed during this research. The tool itself provides recommendations on safety stocks, reorder levels and order quantities. Further recommendations are as follows:

- Purchase preferably from the Asian supplier
- Purchase mainly yarns
- Take a good look at the input parameters of the tool and replace them if more representative values are known

The Asian supplier is the cheaper supplier so if the time constraints aren't an issue for an order, it's recommend to purchase from the Asian supplier. It is also recommended to purchase mainly yarns from the suppliers. Due to lower holding costs of yarns, this is the cheaper option compared to purchasing wovens. A final recommendation for Company X is to look closely at the input parameters of the tool. The tool can give more accurate output values if the input parameters are replaced by more representative values if they are known.

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1. Introduction and problem identification

1.1 About Company X

The products that Company X provides are woven, nonwoven and knitted products. This research will be conducted for the production location based in the Netherlands. The type of products produced here are mainly woven products, nonwoven products. Through weaving looms, Company X converts yarns into woven fabric roll-goods. These are sold to the customers or they are converted in-house into tailor-made end products through a confection step.

1.2 Problem description & action problem

At the moment, Company X sources most of its yarns in Europe. The main and most competitive market for yarns, however, is in Asia. The woven supply market is just like the yarn market, highly competitive in Asia. The current supplier for polypropylene (PP) related materials of Company X will cease their supplying operations, so Company X is looking for one or maybe even more new suppliers for these materials. This is therefore a good time to also look at possible supplier alternatives in Asia. Company X is already testing with Asian yarns that they got from their own Asian subsidiary but are also interested in investigating the options for buying yarns and/or woven materials on the Asian market. The search done by Company X for suppliers for PP related materials ultimately fell on two potential suppliers, one in Europe and one in Asia. The supplier from Asia is a subsidiary of Company X and the supplier from Europe is an independent company.

Before choosing the best supplier, a number of points must be carefully taken into consideration. The quality of the materials and products should at least meet Company X's criteria. If a company simply cannot meet all of these criteria, this supplier option will be dropped. For these two options, this has been checked and both suppliers meet the quality requirements. Company X itself also has delivery reliability towards their customers, which is something that is essential to the company. Company X strives for 100% delivery reliability towards their customers. If the supplier cannot deliver the materials and products to Company X on time, Company X runs the risk of losing their own delivery reliability. Therefore, when choosing a new supplier, it should be taken into account that the delivery reliability of Company X can be at least as high as in the current situation.

Regarding the costs, a company wants the costs for the purchasing process to be as low as possible while meeting the requirements of material quality and delivery reliability. The costs for the purchasing process don't only consist of purchasing costs but also inventory costs are included. When choosing the supplier, not only the purchase price must be considered, but also the long-term costs. With the inclusion of long-term costs, the principle of Total Cost of Ownership (TCO) is used. Total Cost of Ownership is an analysis that places a single value on the complete life-cycle of a capital purchase (Vaqari, 2020). The two supplier options can be compared with each other with TCO and the option with the lowest TCO has the best value for Company X.

When choosing a supplier with a longer lead time, it is likely necessary to keep larger stock quantities at the company to be able to satisfy the demand of the customers compared to having suppliers with shorter lead times (Rumyantsev & Netessine, 2007). The stock quantities that are kept in the company cost money, so it's preferable to keep the stock quantities low while also being able to meet the customer demand.

With these points in mind, the following action problem has been created for this research:

The combination of purchasing and inventory cost of polypropylene related materials at Company X should decrease with 10% while the delivery reliability and the quality of the products will not decrease.

The 10% was chosen to have a goal to work towards in this research. Later on in this research, it will become clear whether this decrease of 10% is really feasible.

1.3 Problem cluster

To find the core problem(s), the action problem had to be looked at more deeply. This has been done by creating a problem cluster that can be seen in figure 1. At the top of the cluster is the action problem shown. Looking from top to bottom in this problem cluster, a split can be seen between purchasing costs and stock related costs.

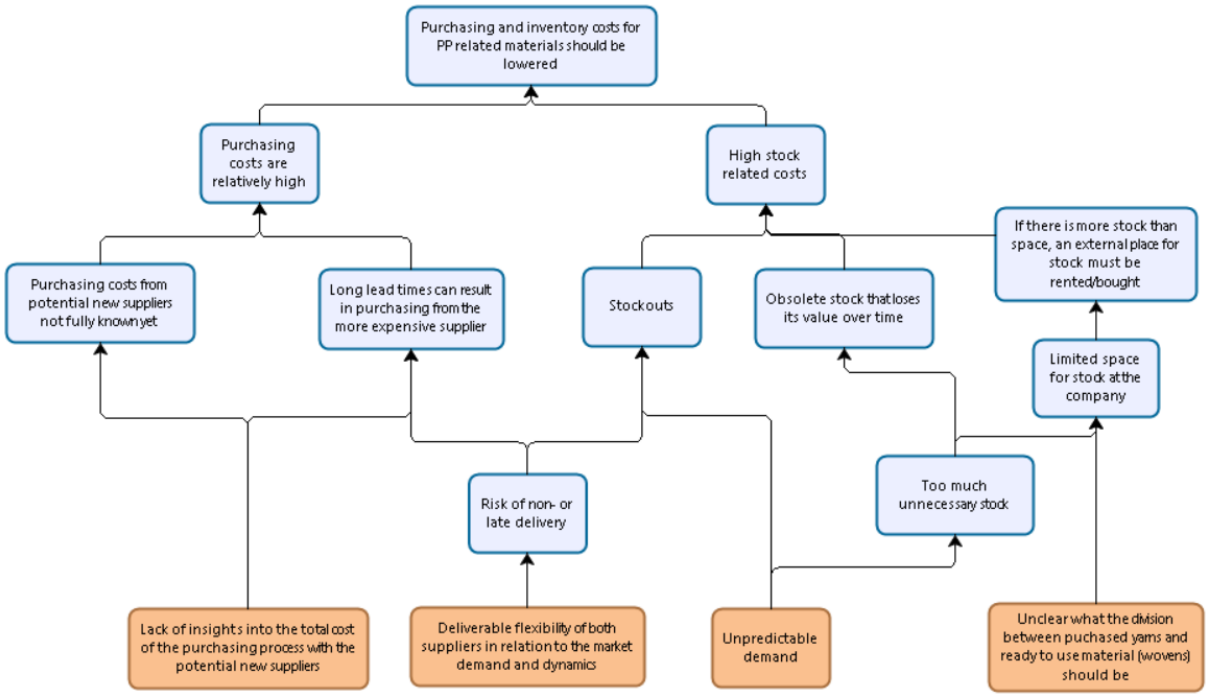

Figure 1: Problem cluster

1.3.1 Purchasing cost

For the purchasing part, the purchasing costs of the potential new suppliers can be a problem. As can be seen at the bottom left of the problem cluster, there is a lack of insights into the total cost of the purchasing process with the potential new suppliers at the moment. If these insights become clear later on in the research, it can help with the decision which supplier is the better option in terms of cost. For both suppliers, there may also arise a problem with the regards to the risk of non- or late deliveries. When new suppliers are chosen, it is not immediately clear whether the suppliers are flexible enough to deliver orders on time. A major influence on the flexibility can be the lead times of the suppliers. With suppliers who are far located from the production location, in this case the distance between China and the Netherlands, it is difficult to say if they can deliver the materials on time with the potentially long lead times. The risk of non- or late deliveries can be decreased by having suppliers with a high delivery flexibility. A high delivery flexibility means that suppliers can consistently deliver products before promised due dates (Ng & Zhang, 2016). If the flexibility of suppliers is high, the

chances of non- and late deliveries will be small. It is therefore important to look at the flexibility of the supplier in relation to the market supply and dynamics, especially for the supplier in Asia because of their potentially long lead times. A very flexible supplier with a long lead time, however, might still cause problems. If products are needed quickly at Company X, it may still be that a flexible supplier cannot deliver on time because the lead time is greater than the time interval that Company X needs to have the products. The lead times can influence the choice of supplier in such a way that the more expensive supplier may have to be chosen because the cheaper supplier isn't able to deliver the products on time.

1.3.2 Stock costs

For the stock costs part, the main problems are the unpredictable demand and the division between purchased yarns and wovens. In the market in which Company X operates, it is difficult to predict when certain materials are needed. For a product that is highly in demand during a period this year, does not mean that this product is highly in demand during the same period next year for example. The reason that the demand is so unpredictable is because the demand is largely influenced by projects. If, for example, a road or highway has to be constructed somewhere, Company X will receive a larger order. At the beginning of the year it is difficult to predict when such projects will occur during the year. With an unpredictable demand, a company can run into two risky situations:

1. Running out of stock for a material. Without this material, production can't continue for products containing this material. This will result in that your company can not deliver everything to the customers anymore, so the company will lose money and customers can go to competitors instead of your company the next time that the customer needs to order products and materials. These stockouts can also be a result of non- or late deliveries.
2. Too much stock. Company X can also buy too many materials which will result in large stock quantities. If a part of the stock is stored for a long period of time at the company, this part of stock can become obsolete and lose its value while it is still present in your company. The materials and products continue to improve that Company X obtains from their suppliers and convert themselves over time. So if materials or products have been in the company for a longer amount of time, there is a chance that a better alternative is already present at the company, so that results in the older materials and products becoming obsolete. Materials and products can also become obsolete because the quality decreases of the materials and products when they are stored for a longer period of time.

With a limited space for stocks at Company X, a choice has to be made which quantities should be put into stock for every material and product. Too much stock of one material results in lack of space for other materials to be stored. If the stock quantities become larger than the space that Company X has for it, an external storage location should be looked at, which also costs money. So having too little stock and having too much stock are both scenarios that should be avoided and therefore it is necessary to search for a middle ground solution.

For the choice of purchasing yarns and/or wovens, it is useful to first know how the converting and confection steps work. The yarns can be used in two different ways during the weaving process, namely the warp and the weft. The warp is the yarn that is used vertically on the loom. The warp is stretching on the loom during the weaving process so these yarns are typically stronger compared to the weft. The weft is the yarn that runs horizontally on the loom and gets woven in front of and behind the warp (*What Is the Difference Between Weft and Warp?*, 2014). By using different combinations of yarns as warp and weft, several different products can be produced on the looms.

For the purchase of these yarns, an advantage of this is that it is easy to adapt to the requests of the customers. The length of the finished products can still be determined after the customer has made an order. A disadvantage of storing yarn is that it usually stays longer in your company. After an order has been placed, the yarn must still be processed at Company X and this process takes time. For purchasing wovens, the advantages and disadvantages are reversed compared to storing yarns. The wovens or the ready to use materials, as the name already implies, can be used immediately when an order comes in, which means that these materials could reduce the waiting time of the customers of Company X. These materials can be sold directly to the customers or be converted into a tailor-made end product through a confection step. There is, however, a problem when a customer wants a certain length and/or width and the wovens that are available at Company X do not have these sizes. Then it is still necessary to convert yarns into an end product with the right sizes or parts of larger wovens have to be used. When using parts of larger wovens, Company X will probably end up with smaller leftover parts that are no longer usable for production and thus become waste. For this research, the costs of the waste are not considered because it is very hard to estimate when something becomes waste and what kind of costs are associated with this. The difference between stock related costs of yarns and wovens is that the stock costs of the wovens are much higher compared to the yarns. The choice of purchasing yarns, wovens or both can ensure that the limited space for stock can be used optimally and that the stock costs can be reduced.

1.4 Core problems

With the problem cluster, four core problems were determined. These four core problems are indicated in the orange blocks.

- The lack of insights into the total cost of the purchasing process with the potential new suppliers
- The (lack of) deliverable flexibility of both suppliers in relation to the market demand and dynamics
- The unpredictable demand
- The division between purchased yarns and ready to use materials (wovens)

For the lack of insights into the total cost of the purchasing process with the potential new suppliers, this research can help. To look at the different options of suppliers and all the costs involved during the purchasing process, it is possible to come with a clear overview. With this clear overview, Company X can hopefully be helped with finding the right supplier(s) and the best order quantities for the best price.

The decision about what the division between purchased yarns and ready to use materials should be, is also something that should be answered with this research. This means how large the percentage of purchased yarns should be in relation to the percentage of purchased wovens. By looking at the advantages and disadvantages of both yarns and ready to use materials, an answer should be found for this problem. Things that could be looked at are, for example, the size of the material stored, the duration that a material is present within the company and the costs associated with this.

The deliverable flexibility of both suppliers in relation to the market demand and dynamics and the unpredictable demand are both problems that cannot be solved with this research. These two points have a lot of influence on the purchasing and inventory costs, so they should be definitely taken into account during the research.

The identification of the core problems has given some direction for the research to ultimately provide a proper solution to the action problem. These problems can be dealt with by creating and solving research questions. The research questions will be discussed in the next paragraphs.

1.5 Research questions

The four research questions were partly determined together with Company X. These four research questions have been formulated to solve the action problem and to find an answer to the main research question: *How should the supply chain for the polypropylene related wovens look like?*

The research questions are explained below as to why they are of importance to this research.

1. *Should Company X purchase only yarns, only wovens or a mix of both?*

It is useful to have the answer to this question first before looking at the potential new suppliers. If it is known what the best decision is for this research question, it is possible to look more specifically at what the suppliers have to offer.

2. *What is this deliverable flexibility from the Asian supplier with regards to the dynamics of market demand?*

It is very important to get good insights about this when conducting the research. If Company X receives an order from a customer, they must of course know whether the Asian supplier has the response time to deliver the materials to Company X. The answer to the question would show whether the Asian market is a viable option for Company X to get their materials from. The reason why this question only considers the Asian supplier is because Company X has worked with European suppliers in the past and the current situation and therefore already has more insights into the deliverable flexibility of European suppliers. The deliverable flexibility of Asian suppliers is not completely known to them.

3. *Is the European supplier, the Asian supplier or a mix of both suppliers the best solution for Company X?*

The answer of the second research question is important for this research question because an answer has been given if the Asian market is a viable option for Company X. If the Asian market is a viable option, a comparison must be made with the European supplier to see whether obtaining the materials from the Asian market is also the best option or if the European supplier is the best option. There are a couple of PP related materials and a lot of different scenarios that have to be looked at before making this decision. The order quantities, the urgency for the materials and the quality of the materials are all important factors in the decision between Europe and Asia.

4. *How should the ideal safety stock and reorder level be determined with unpredictable demand and potentially long lead times?*

Due to the fluctuations in demand it is essential to have a safety stock. In case of uncertainties, it often happens that safety stocks become very high and there are costs involved in maintaining a safety stock at a certain level like holding costs. To place an order on time at the suppliers, having a reorder level is a good indicator of when an order must be placed. That is why an answer is sought for this question in this research. The aim is to establish a safety stock and a reorder level for all products that keep costs low and the delivery reliability towards the customers high.

1.6 Deliverables

The deliverables at the end of this report should be the following:

- A report with the different purchasing options and a description of the best overall scenario
- An advice of buying yarns, wovens or a mix of both
- An advice of obtaining materials in Europe, Asia or a mix of both
- An accurate decision tool that can show Company X in an easy way which decisions are the most suitable for specific situations regarding suppliers and stock quantities.

1.7 Research design

This research started as an exploratory study in order to find multiple research questions. These research questions were obtained through conversations with my supervisors from Company X and self-made observations around the problem statement. After more research questions were obtained, the type of research changed from an exploratory study to a formal study (Cooper & Schindler, 2018). The research population of this research will be the potential new suppliers and the materials and products that are selected by Company X. The strategy is to first read and analyse scientific literature on topics that may be of interest for this research, such as sourcing strategies, safety stocks, reorder levels and economic order quantities to name a few. The literature in combination with files and conversations/interviews provided by Company X is hopefully enough to solve the research questions. By solving the research questions, there will be enough data available to create a tool for Company X and solve the action problem. The tool is essential for this assignment because all calculations can be made with this tool. The tool is intended to provide suggestions about desired stock levels and order quantities based on real data from Company X itself. The aim is that the tool can be used over a longer period of time and not only for this assignment. By collecting information and data from many different sources, an attempt has been made to make sure that the information and data are reliable and valid. If several sources provide similar information, it is usually more likely that the information is reliable and valid.

The data gathering methods will be both quantitative and qualitative. This is because both secondary data that contains numbers and conversations/interviews with the employees are used. Examples of quantitative data are the previous sales of a product, the holding cost of materials and the purchase price of materials. Data and information that can be found with qualitative research are the desired cycle service levels, information about the current situation and information about the potential new suppliers. The data and information that is collected during this research will be stored in files together to process and analyse the data and information afterwards. The data will be analysed by putting data that are closely related to each other near each other in the file. For some data, it is even possible to create graphs so that it is easier to visualize what can be improved and what the current flaws are. This is all done to make it easier to find connections within the data and draw conclusions later on with this information. The conversations/interviews are held with employees of Company X, taking into account the rules of privacy and the code of conduct of Company X.

The research question about purchasing yarns and/or wovens will be mainly answered with the conversations/interviews with the employees and the available data. Purchasing yarns and wovens have both their advantages and disadvantages and the conversations/interviews with the employees can make these advantages and disadvantages clear. The information obtained from these conversations and the data on the costs of storing and purchasing yarns and wovens can give an answer to this research question. An interesting question could be why they only buy yarns in the current situation and why they are now also looking at the option of purchasing wovens.

The answer to the research question about the deliverable flexibility of both suppliers will be mainly based on data that is already available of these suppliers. Company X is already testing with yarn from these suppliers, so some data is already available about the delivery times and flexibility. A conclusion can be drawn from this data for this research question. If the Asian supplier is a viable option, a comparison can be made between the Asian and European supplier to answer the research question related to the choice of the supplier. This question involves a lot of work with calculations that are made with the data that is available. The costs of both suppliers, the stock levels that need to be maintained to purchase from these suppliers, the lead times and the flexibility are all points that must be compared with each other.

For the last research question about determining the ideal safety stock and reorder level with unpredictable demand and potentially long lead times, a lot of work has to be done with both calculations and scientific literature. The scientific literature is very important for this research question because a safety stock and reorder level can be determined in many ways. In the case of Company X, unpredictable demand and potentially long lead times are two major factors that influence the safety stock and reorder level and are therefore included in this question. The scientific literature helps to find appropriate formulas and concepts that can later be used to answer this research question and be the starting point of the tool. With the tool, calculations can then be made to ultimately get numbers that can be used as safety stock and reorder level for the various materials and products.

A limitation for this research design may be the overflow of data. There are many different ways to solve the action problem of Company X and therefore care must be taken that theories that do not match each other are not used together. When appropriate theories have been found, it must be checked whether the required data is available in practice. It often happens that a theory looks good on paper, but in the real situation the necessary data is simply not available. This may be because this data does not exist in the real situation or that Company X doesn't keep track of the specific data that is required for a certain theory. Appropriate assumptions must then be made or other theories must be sought.

1.8 Systematic literature review

With the help of systematic literature review (SLR), one of the research questions is answered. In appendix A, it is indicated how the SLR was carried out and what results have been obtained. A number of steps have been carried out for the SLR:

1. *The definition of the research question.* The research question to which the answer is provided with SLR is about the safety stock and the reorder level and how they should be determined with unpredictable demand and potentially long lead times. Scientific literature plays a large part for this research question and it is therefore a logical choice to find an answer for this question using SLR.
2. *Defining the exclusion criteria.* In order to determine what kind of literature studies are interesting, a number of criteria must be determined and defined in advance of the searching process. Exclusion criteria are factors that make a study ineligible to be included. For this review, four criteria have been determined why a study should be excluded from the review. The main reason for these criteria is that the main subjects of the studies should be about the subjects of the research question. The precise explanation for these criteria can be found in appendix A.

3. *Choice of databases.* The databases that were chosen for this SLR are Scopus, Web of Science and Business Source Elite. Three different databases have been chosen to guarantee the reliability and validity of the literature studies as much as possible.
4. *Search terms.* In all three databases a number of search strings were entered to find literature studies. In each search string was “Safety stock” the main subject and the second subject was something that was associated with the research question. All these search terms can be found again in appendix A.
5. *Selection made for review.* After all literature studies have been found with the search strings, a selection is made that is suitable for review. All duplicates were removed and further use was made of the exclusion criteria established in step 2. After reading the remaining studies completely, a final selection for review was made.
6. *The conceptual matrix.* A matrix was made that shows which concepts are discussed in each of the studies. The key findings are stated in the concept matrix with content in appendix A.
7. *Integration of the theory.* The findings of the remaining literature studies will be elaborated in “3.2 Findings systematic literature review” later on in this report.

2. Current situation

2.1 Suppliers

In the current situation, Company X has one supplier for the yarns that are being looked at during this research. There are short lines with this supplier to keep the flexibility of Company X high towards their customers. This means that there is a lot of contact with the supplier and the supplier is relatively close to the production location, which means that it is possible to respond quickly to unexpected events. This supplier is located in Europe and will soon cease their supplying operations. As a result, Company X is forced to look for another supplier for these yarns. Having one supplier for a certain yarn type can be seen as a risk and that is why for this research there will be looked at two suppliers. Quality is very important to Company X, so the materials of the suppliers must meet all the criteria that Company X has determined.

For the wovens discussed in this research, these are not purchased from the current supplier. These wovens are produced by the location itself and the potential new Asian supplier. This will provide an additional option to purchase wovens immediately instead of purchasing yarns. Both yarns and wovens can be purchased from the Asian supplier and only yarns could be purchased from the potential new European supplier.

2.2 Materials

The value of Company X is delivered to the customers through woven, nonwoven and knitted products. The knitted and nonwoven products are not produced at this production location, these products are produced at other locations. This production location is focused on weaving mainly PET and PP materials. Within this report a selection of the PP yarns will be discussed that are being used at the production location. This research is therefore only focused on this production location and not the other Company X's production locations around the world. This production location has no extrusion department therefore its needed to seek it elsewhere. Company X needs the yarns from the suppliers to produce their products. Because the finished products are used for large projects, such as road construction, the materials must meet certain requirements. Examples of these requirements are the strengths, the extensibility and the water permeability of the yarns. The wovens acquire a number of these properties after the weaving process.

2.3 Production

Company X has several weaving looms in a large production hall. The weaving looms require two bobbins of yarn to convert the yarns into wovens. Two bobbins of yarn are required because one bobbin is used as warp (the vertical direction) and the other bobbin is used as weft (the horizontal direction). In order to continue producing the wovens, both bobbins of yarn need to be present at the weaving loom. If one of the two bobbins is missing, production must be stopped. Figure 2 shows what a woven consists of. The white yarns illustrates the warp yarns and the black yarns illustrates the weft yarns. The weaving loom ensures during the converting that the weft yarns are always intertwined alternately over and under the warp yarns. By continuing to do this, a woven will eventually form from the yarns.

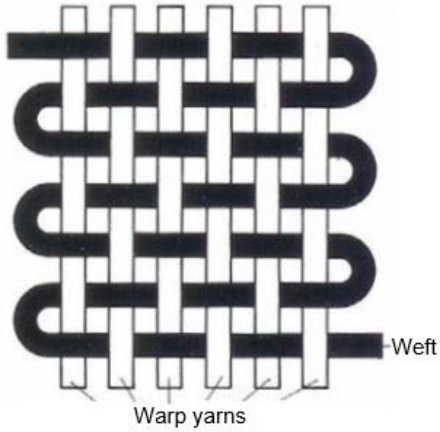

Figure 2: Warp and weft in a woven

So through the weaving looms, Company X converts the yarns into woven fabric roll-goods. These are sold as such or they are converted in-house into tailor-made end products through a confection step, then sold. Figure 3 shows which steps the polymer goes through until it finally reaches the customer. Only the weaving and confection steps are done at this production location. The yarn spinning is done by the suppliers before it is shipped to Company X.

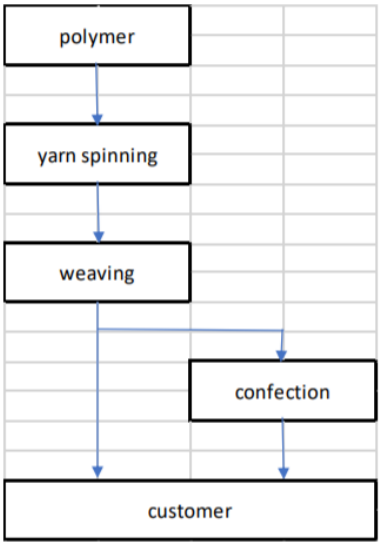

Figure 3: From polymer to customer

Company X uses a combination of two different production planning strategies for their production, namely Make-To-Order (MTO) and Make-To-Stock (MTS). MTO means that Company X only starts to produce products when a confirmed customer order is received for these products. Products that are typically produced to order are high valued and/or customized products with irregular demand because stocking can be expensive or even impossible for these products. (Beemsterboer et al., 2016). The other strategy, MTS, is a strategy in which products are produced based on demand forecasts. Low valued, standardized products with regular demand will often be made to stock, allowing demand to be satisfied instantly.

2.4 Stock

The purchased materials and the finished products are on rolls in stock at Company X. When an order comes in, the required rolls of yarn can be brought from the stock to the weaving looms to start the production if the production of that specific woven wasn't already in progress. The produced woven rolls are after production returned to stock ready for transport to the customer.

The inventory policy applied by Company X most closely resembles an order-up-to policy. This policy is also often notated as (s,S). The s stands for the minimum stock amount and the S stands for the maximum stock amount. Orders are placed as soon as the inventory drops to or below the minimum stock amount s (Willemain, 2019). The ordered amount can vary but the ordered amount combined with the current stock level should never exceed the maximum stock amount S.

Company X keeps track of the yarns and wovens for how many days a particular item is already in stock. If a certain item has been in stock for more than one year, a percentage is deducted from the total purchase price of that item as depreciation expenses. After two years, a percentage is taken off again and after this the items are at their lowest value. For yarns and wovens, Company X works with other percentages, whereby a larger percentage is depreciated for wovens than for yarns. This is because produced wovens lose their value faster than yarns that are still needed for production.

For some materials and products it is not often that something is in stock for a very long time. These are the products that are sold fairly consistently every year. However, there are also products that had reasonable sales one year and virtually nothing the year after. Certain quantities of yarn are purchased for these products, but they are sometimes in stock for more than one year. This is because it is difficult to predict what the market demands in the upcoming year in the sector in which Company X will supply its products. In the worst case, some items remain in stock for such a long time that they are declared obsolete.

3. Literature

3.1 List of concepts

In this part of the thesis, a number of key concepts regarding the research are explained with the help of literature. This is done to provide a better understanding of the concepts that will be used within the tool and to show why certain concepts are important to look at during this research. The concepts are the following:

- Safety stock
- Cycle service level
- Reorder level
- Probability distributions
- Economic order quantity
- Sourcing strategies

3.1.1 Safety stock

Safety stock is stock held in case demand exceeds expectation, it is held to counter uncertainty (Chopra & Meindl, 2016). If demand was perfectly predictable, safety stock wouldn't be necessary. Unfortunately, demand is not perfectly predictable so companies have to hold safety stock to satisfy unexpected high demand. Within each company that works with inventory, it is an important consideration how much exactly should be kept as safety stock. Safety stocks that are too low will result in demand that can't be satisfied. As a result, the company loses sales along with the margin that the products would have yielded if they were sold. In order to prevent this, there are companies that ensure to work with really high safety stocks in order to cope with the biggest peaks in demand. However, having very high safety stocks and stock quantities in general also has its disadvantages. A company must have storage space for the products and materials so if there are higher stock quantities, more storage space is needed. Not all companies have the storage space for this and they have to look for an external place for storing their goods which costs money. Products can also lose their value if they have been in stock for a longer period of time. This may be due to season demand which means that after a certain season products can only be sold at lower prices because the demand after the season is a lot lower than during the season. Another reason may be that the products become obsolete or may lose their quality over time. Therefore, a company has to look at the trade-off between the costs of having too much stock and the costs of losing sales because of not having enough stock.

The amount of safety stock that is required for certain situations can be calculated with several formulas. Two big factors that can impact the safety stock a lot are demand variability and lead time variability. If a company wants to take these two factors in consideration for the calculation of the safety stock and these two factors are independent of each other, is the following formula advised (King, 2011):

$$Safety\ stock = Z * \sqrt{L * \sigma_D^2 + D^2 * S_L^2} \quad (1)$$

Z = Z-score (more explanation in part about cycle service level)
L = Average lead time
σ_D = Standard deviation of the demand
D = Average demand
S_L = Standard deviation of the lead time

The lead time is the amount of time that is between the placement of an order and the delivery of the goods at the company in this case. This lead time can deviate and that is why the standard deviation of the lead time is included in this formula. This takes the lead time variability into account. The reason that this is necessary is to cope with delays in delivery. If the lead time variability is not taken into account, there is a greater chance of stockouts.

3.1.2 Cycle service level

The definition of a cycle service level (CSL) is the fraction of replenishment cycles that end with all the customer demand being met (Chopra & Meindl, 2016). A replenishment cycle is the time interval between two replenishment deliveries. The CSL is always a value between 0 and 1 or 0% and 100% and shows the fraction of times of not having a stockout during a replenishment cycle. The closer a value is to 1 or 100%, the more replenishment cycles there have been without any stockouts. These stockouts can be prevented by maintaining a higher level of safety stock. So the cycle service level and the safety stock are closely related to each other.

In the formula that is stated in the paragraph about the safety stock, a Z-score is used. This Z-score is determined when a CSL is chosen or calculated. When demand during lead time is normally distributed, the Z-score can be determined by returning the inverse standard normal function of the CSL. Table 1 and figure 4 show the associated Z-scores for a number of cycle service levels:

Table 1: CSL with corresponding Z-scores

Cycle service level	Z-score
0,50	0,00
0,60	0,25
0,70	0,52
0,80	0,84
0,85	1,04
0,90	1,28
0,95	1,64
0,96	1,75
0,97	1,88
0,98	2,05
0,99	2,33
0,991	2,37
0,992	2,41
0,993	2,46
0,994	2,51
0,995	2,58
0,996	2,65
0,997	2,75
0,998	2,88
0,999	3,09
0,9999	3,72

Figure 4: Z-scores

For a cycle service level of 0,50 is the Z-score 0. This means that a company has a stockout in half of their replenishment cycles because no safety stocks are used. In the graph, it can be seen that the relationship between the CSL and Z-scores is disproportionate. The higher the CSL becomes, the steeper the graph becomes. A cycle service level of 1 or 100% is usually not a feasible option. This takes into account extremely large deviations in demand that often do not occur in real life. As a result, extremely large safety stocks should be used which will simply cost too much money for companies. Typically goals of CSL fall between 90% and 98% for companies (King, 2011).

3.1.3 Reorder level

The reorder level (or reorder point) is the stock level at which a company would place a new order. The reorder level can be calculated with the following formula (Chopra & Meindl, 2016):

*Reorder level = D * L + ss* (2)

D = Average demand
L = Average lead time
ss = Safety stock

The purpose of the reorder level is to identify when a certain product or material quantity has dropped to a level that new products or materials must be ordered because otherwise the desired cycle service level will not be achieved. This reorder level takes into account that the demand can be met during the time between the placement of the order and the receiving of the goods from the suppliers. In figure 5 is an example shown from an inventory model with a safety stock and a reorder point.

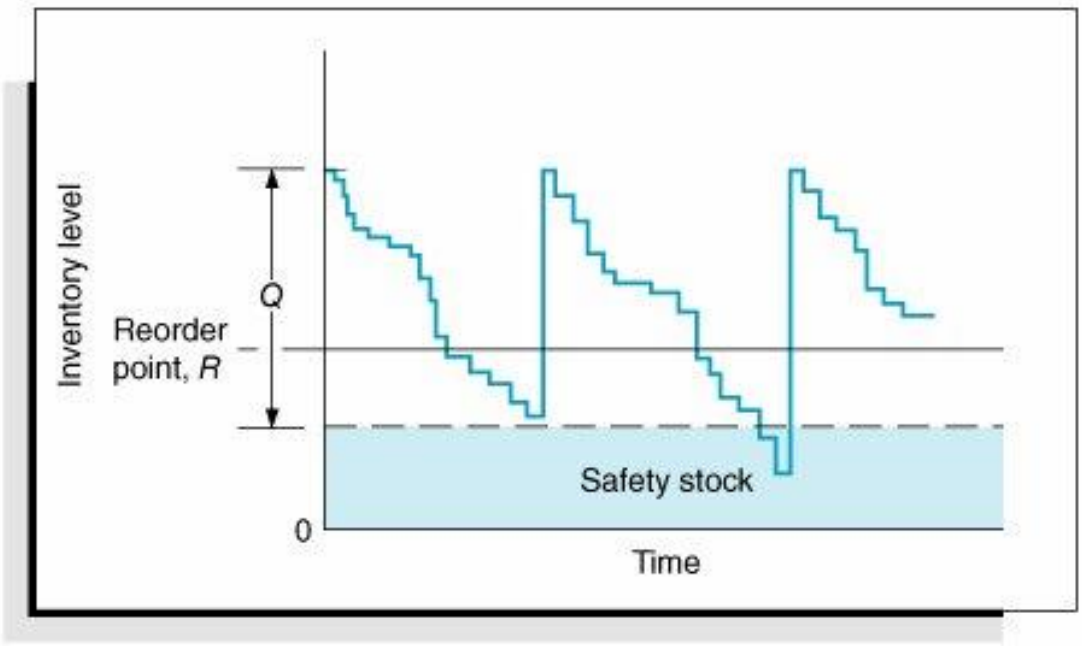

Figure 5: Inventory model with safety stock (Taylor, 2006)

That the blue line doesn't slope down perfectly in this figure indicates that the demand is not constant. When the demand is not constant, there is often uncertain demand involved. Therefore, a safety stock is used in practice. The safety stock is illustrated in this figure by the blue area underneath the black dotted line. At the moment that the blue line hits the reorder point line, an order is placed with the suppliers. This order is delivered when the blue line rises vertically and the time between these two

moments is the lead time of the suppliers. The time between a delivery and the placement of the next new order is something that often differs with uncertain demand. A new order is only placed when the inventory level is equal to the reorder point. It doesn't matter how long it takes to get to this level.

3.1.4 Probability distributions

Probability distributions are often used to calculate safety stocks and reorder levels. A probability distribution is a function that describes the likelihood of obtaining a possible value that a random variable can assume (Frost, 2018). In the case of safety stock and reorder level calculation, a probability distribution is used for the variability in demand and lead time. There are a lot of different probability distributions but the first one that will be discussed is perhaps the most common probability function, the normal distribution. When variables show a symmetric, mound shaped density function, it is known as a normal distribution (Meijer, 2017). The centre point of the symmetry is the mean μ, also known as the expected value or average. The further away a value is from the mean, the less likely it is that this value will occur. If many values are far from the mean, it means that the standard deviation σ is high. Figure 6 shows the distribution of values at a normal distribution with the same mean but with different standard deviations. A higher standard deviation results in a flatter and wider curve compared to a low standard deviation, which can be seen from the difference in shape of the green and red curves.

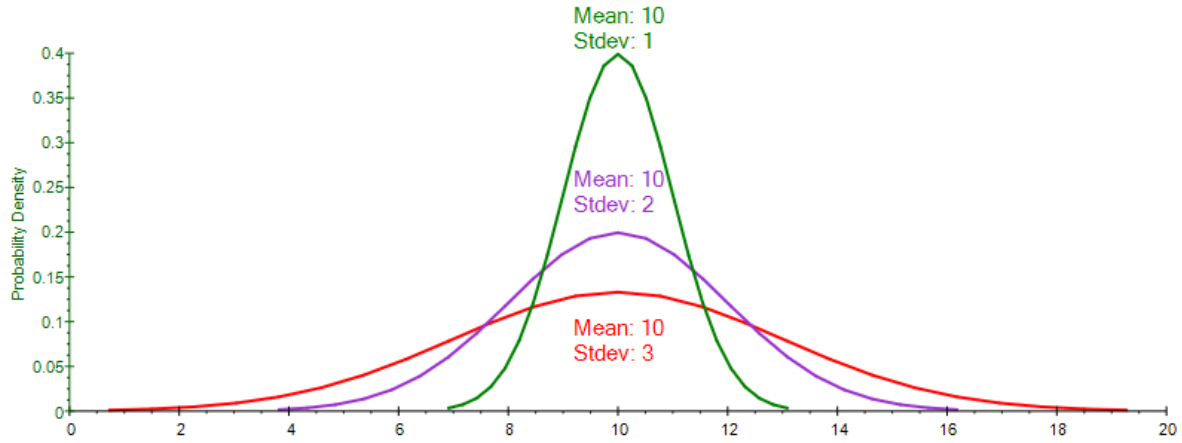

Figure 6: Normal distribution with same mean, different standard deviations ***(Mun, 2015)***

The normal distribution is mainly used when the mean, the median and the modus are nearly the same of the available values. This means that the average value, the middle value when all the values are sorted from low to high and the value that appears the most are nearly the same. If this is not the case, it is most convenient to look at other probability distributions.

The other probability distribution that will be discussed in this part is the gamma distribution. When looking at both the shape of a function of the normal distribution and the gamma distribution, a difference can quickly be seen. A function of the gamma distribution is skewed to the right compared to a function of a normal distribution. The reason for this is because the mean, the median and the modus are not nearly the same. The median is a smaller value than the mean, so the highest point of the function is on the left. When the highest point is on the left side of a function, it is called a right-skewed distribution.

The gamma distribution is specified by two parameters, the shape α and scale θ (Kim, 2019). There are also other parameters that can be used for the gamma distribution, like shape k and rate β, but in this report the parameters shape α and scale θ will be used. The shape parameter α determines the skewness of the function. If the value of shape α increases and the value of scale θ stays the same, the gamma distribution will become less skewed. Figure 7 gives some examples of changes in the shape of the functions with different values α.

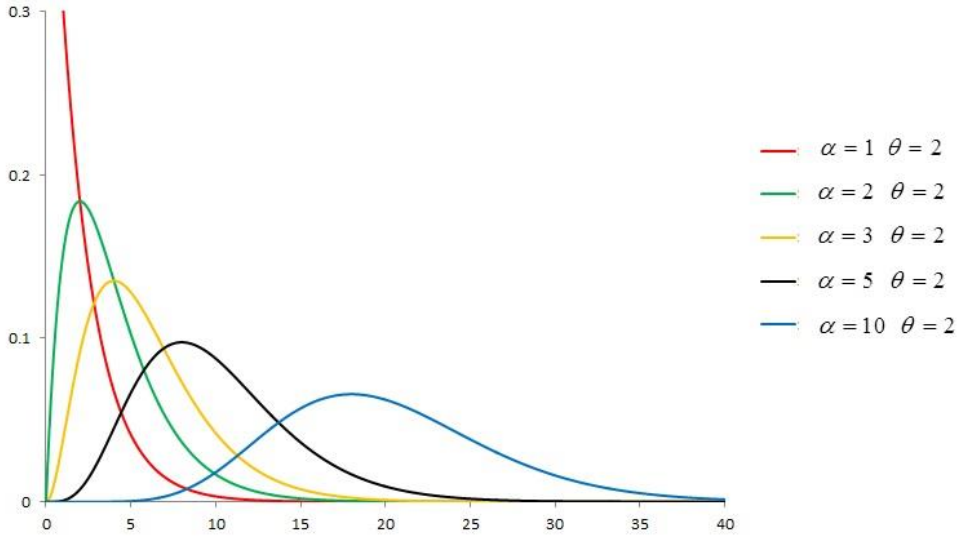

Figure 7: Role of shape parameter α in a gamma distribution (Ma, 2016)

The highest point of the function also shifts more and more to the right, when the shape parameter α increases and thereby the skewness decreases. A couple of other changes happen to the function when the scale parameter θ changes and α stays the same. The skewness stays the same but the spread of the values becomes bigger when the scale θ increases. If the red and yellow curves are compared in figure 8, it can be seen that the probability of predicting a value is a lot easier with the yellow curve where the scale value θ = 1.

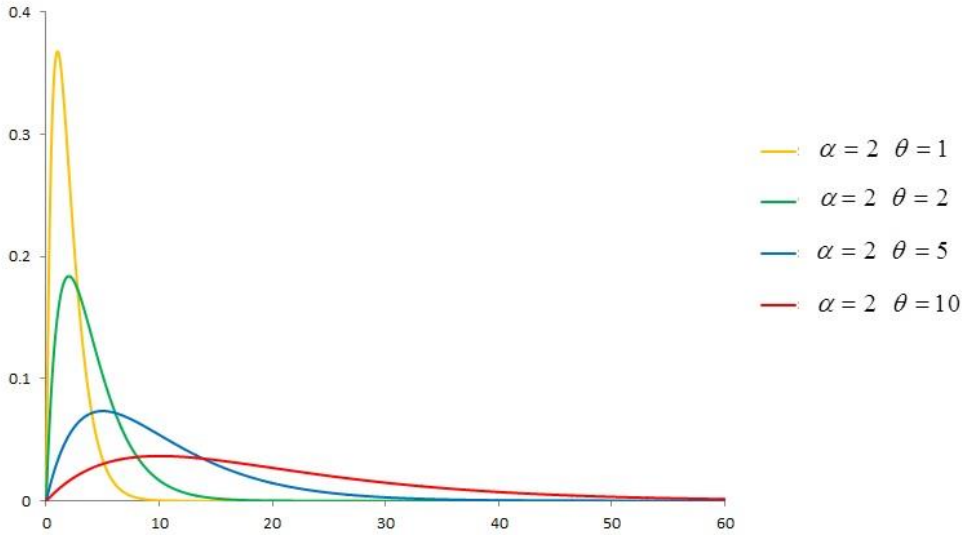

Figure 8: Role of scale parameter θ in a gamma distribution (Ma, 2016)

Finding which probability distribution best suits the available data is an important aspect. This is the best way to make predictions about future values. In the case of safety stocks, predictions can be made about future demand and this can give information about how high the safety stock should be to meet this demand. For the reorder levels/points, a probability distribution can give more insights in the variability in lead times of the supplier options. Why in this section was chosen for an explanation of the normal and gamma distribution will become clear later on in this report.

3.1.5 Economic order quantity

The economic order quantity (EOQ) is the optimal lot size for a certain product (Chopra & Meindl, 2016). The goal of the EOQ is to have an optimal order quantity where the combination of purchasing and stock costs are minimized. The following formula is often used to calculate the economic order quantity (Holmbom & Segerstedt, 2014):

$$EOQ = \sqrt{\frac{2 * D * S}{h * C}} \tag{3}$$

D = Annual demand
S = Order cost
h = Holding cost per year as fraction of the unit cost
C = Unit cost for product or material

The order costs are the fixed costs that are incurred per order. Examples of fixed costs in this case are costs to prepare an order, costs to put away goods once they have been received and costs to process the supplier invoice related to an order (Bragg, 2018). The ordering cost often decreases when larger lot sizes are used because the number of orders reduces. The unit cost is the price of a single product or material. As the name already implies, can this be the price for a single unit but it can also be about the kilogram price of a certain product of material. If the price in kilograms is used, the other variables in this formula must also be taken in kilograms. The holding cost per year as a fraction of the unit cost is a number between 0 and 1. This involves the depreciation costs of goods when they have been in stock within the company for a year. For example, if a product has a value of €10,- when it enters the company and after a year the value of the same product is only €7,-, the holding cost per year as a fraction of the unit cost is (10-7) / 10 = 0.3. The total holding cost increases when larger lot sizes are used. This is because a larger number of products arrive at the company where every product has its holding costs.

Figure 9 shows the holding costs, ordering costs and the total cost and what happens with these costs if the lot sizes or order quantity increases. The total costs are at their lowest when the holding and ordering cost are equal to each other. The order quantity that belongs to this point is the EOQ.

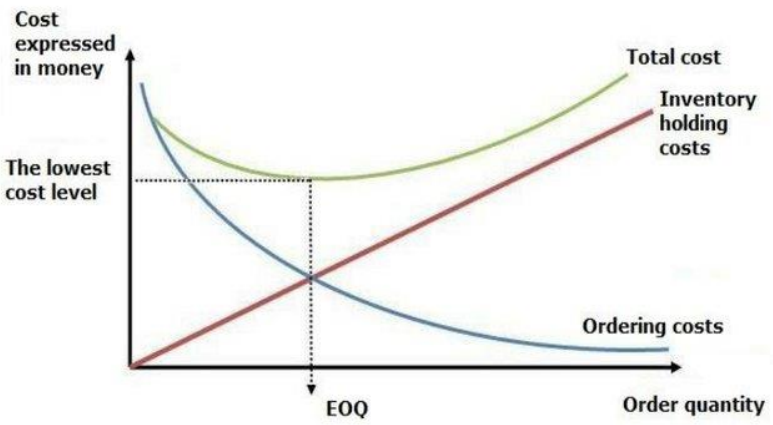

Figure 9: Concept of economic order quantity (Boroń & Bartyla, 2014)

3.1.6 Sourcing strategies

When it comes to purchasing, there are a number of different ways how a company can do this. Some sourcing strategies a company can consider are:

- Insourcing
- Outsourcing
- Dual sourcing

3.1.6.1 Insourcing & outsourcing

Two of the sourcing strategies that may be of interest to Company X are insourcing and outsourcing. When a company decides to insource something, it means that the company performs the activities within the company itself. Outsourcing results in the supply chain function being performed by a third party (Chopra & Meindl, 2016). For many companies it is important to choose which strategy suits them best. A couple of reasons to choose for insourcing could be to keep the price and costs low, to avoid dependency on only one source and risk reduction in general. Some reasons to choose for outsourcing could be that a company lacks the production capacity, if a company lacks the managerial or technical expertise in creating certain products/services and the availability of a supplier of extremely good quality near-by (Johnson et al., 2011).

3.1.6.2 Dual sourcing

Another sourcing strategy that may be of interest to Company X is to make use of multiple suppliers. Dual (or multi) sourcing is a commonly used supply management strategy where a buyer purchases from two (or more) suppliers to mitigate the risk in supply due to disruption (Gupta & Ivanov, 2020). With dual sourcing companies can get goods from a preferred supplier and when disruptions take place, the companies can still get goods from a backup supplier. Disruptions that can take place so that the backup supplier is chosen are the following:

- The preferred supplier can't deliver the materials and products on time due to long lead times
- The preferred supplier doesn't have the ordered quantities at stock and isn't able to produce them on time
- The ordered quantities are so large that the preferred supplier does not have the capacity to produce them
- Political unrest in the country of the preferred supplier

The biggest advantage of dual sourcing is absorbing the risks in the supply chain, but there are more advantages. Dual sourcing can also help a company grow, because having more than one supplier for certain materials or products can help ensure a company is able to keep up with increasing customer demand (Rouse, 2017). To keep up with increasing customer demand, it's important for a company to have a supplier that can deal with this increasing demand. If the current supplier can't accommodate this increase in demand, the backup supplier can be used. Placing orders simultaneously among several suppliers can also reduce the total system cost. This reduction is because of lower prices, improved quality, uncertainty reduction in lead times and therefore savings in holding costs and shortage costs when employing more suppliers (Sajadieh & Eshghi, 2009).

Having two (or multiple) suppliers does not always have advantages compared to having a single supplier for particular materials. Studies show that dual sourcing performs better than sole or single sourcing except for the cases where the ordering cost is high, the lead time variability is low or the

customer service level is low (Chiang & Benton, 1994). When the order costs are high, it is really expensive to place orders at two or more suppliers. That's why it is better to choose for single sourcing in this situation. For a low lead time variability, there is a smaller chance of uncertainty in the deliveries of a supplier. If there is a small chance of uncertainties with a supplier, it is not always the best solution to choose for dual sourcing. For materials that have a low customer service level, it is usually not necessary to have an extra supplier. The impact of uncertainties of the supplier is smaller in this case compared to materials that have a high customer service level. Another disadvantage of dual sourcing is related to the quality of the materials. If materials come from different suppliers, there is a chance that not all materials have the same quality. This makes it difficult to deliver a set quality level to customers. This can also cause problems in the production and further processing of the materials. By placing strict requirements on the quality of the materials, it can be ensured that both suppliers used for dual sourcing deliver the same quality materials.

3.2 Findings systematic literature review

The aim of the systematic literature review is to find an answer to the following research question: *How should the ideal safety stock and reorder level be determined with unpredictable demand and potentially long lead times?* The difference between the SLR and the rest of the literature is that the literature of the SLR is specifically related to the research question about determining the ideal safety stock and reorder level. The findings of the SLR are explained per topic below.

3.2.1 Inventory and order policies

Many modifications to the classical inventory theory have been proposed over the years. The classical inventory model considers the ideal case that the value (or utility) of items in inventory will remain constant with deteriorating or perishable inventory models (Heung-Suk, 1999). This means that the classical inventory theory assumes that when items are in stock, they retain their value instead of the values of the items decreasing over time. A number of reasons that changes were necessary for the classical inventory theory are, for example, the costs that are constantly changing and the different kinds of uncertainties (Braglia et al., 2013). A couple of standard inventory and ordering theories are the reorder point policy (r,Q) and the order-up-to-level policy (S,T) (Babai & Dallery, 2006). With the reorder point policy, an order is placed for Q items when the inventory level has reached point r. The other policy, the order-up-to-level policy, works with a certain time period T. Every time a time period of T has expired, it is checked how much is still in stock and an order is placed so that the total stock level is replenished to level S. A drawback of these methods is that the values r, Q, S and T are calculated once and then remain the same. This causes that these methods are not dynamic. A method that is dynamic is called the dynamic reorder point policy (r_k,Q). The difference with the normal reorder point policy is that here the reorder point can change due to uncertainties in costs, demand and lead time. This is something that fits in well with the situation of Company X, which is why the tool would also look at dynamic reorder levels. The reorder level must change when the lead time with the suppliers and the demand changes.

3.2.2 Cycle lengths

A change in lead time has a major impact on the time when a new order should be placed. For example, if lead time increases, it becomes more important to work with varying cycle lengths instead of just using an EOQ-determined cycle length (Kouvelis & Li, 2012). An EOQ-determined cycle length is a time period that is predetermined and will always be the same. As mentioned earlier, something more dynamic is more appropriate for the situation of Company X. With the dynamic reorder point policy, the cycle length can constantly vary to cope with the different kinds of uncertainties.

3.2.3 Safety inventory

These uncertainties are also addressed by incorporating a certain safety into the ordering process. This safety tries to prevent shortages from happening. The probability of the occurrence of a shortage decreases proportionally with the increase of the safety stock, however, the complete safety can only be guaranteed by a stock with an infinite level (Korponai et al., 2015). The reason for this is that it is never possible to predict exactly what will happen in the future. Maybe next year, a certain product has its sales multiplied by a thousand compared with the previous year and to be able to absorb that kind of demand, the safety inventory should be so high that it simply costs the company too much money to keep this level of inventory. The chance that this will happen next year is so small that it should not be taken into consideration. It is better to look at past sales and to make expectations and estimates from this data about what could happen in the future for this product. The best ways to deal with shortages is to reduce uncertainties with better forecasting or to increase the safety inventory. With the past sales, better forecasts can often be made and patterns can be found over the years. If a certain pattern is repetitive in the demand, it can be explained as seasonal demand. If a certain product is sold a lot in the same month every year, sales can be expected to be high again in that month next year. With this data, inventory and order quantities can be changed accordingly. From a cost perspective, it is often difficult to decide whether or not to take seasonal demand into account. A fixed EOQ based on average demand throughout the whole year is almost as cost efficient as considering seasonal demand (Mattsson, 2010). Unless it is really clear when the low and high seasonal months are, then it is worth looking at seasonal demand. For Company X, the tool can be used to check whether it is worth looking at seasonal demand.

3.2.4 Shortages

To return to the topic of shortages, having shortages can cause customer satisfaction to drop. Under today's competitive conditions, customer satisfaction is one of the key points for companies. There are two possible scenarios when a customer places an order and the ordered quantity cannot be delivered at that moment by the company.

1. The first scenario is that the customer waits until the required quantity is back in stock again. This is usually the best scenario for the company because money is still received for the sold products.
2. The other scenario is that the customer does not wait for the replenishment of the stock and that the customer orders the products elsewhere. This leads to a loss of profit for the company and customers may stay away in the future.

Generally, it is observed that customers refuse to wait and will more likely choose for the second option (Keskin et al., 2015). This is something that should be prevented for Company X because the amount of future sales can be affected when there are too many shortages.

3.2.5 Order placement at suppliers

An important aspect to avoid shortages, is to place the desired orders on time at the suppliers. The average lead time and the variability of the lead time are crucial for determining when to place an order. When the lead time is lower, lower safety inventory and reorder levels can be maintained. So for ordering in Asia, higher values for the safety inventory and reorder level should be maintained compared to ordering in Europe. If the lead time and the variability of the lead time can be reduced, the stock quantities can also be reduced. Normally, if something should be decreased or a better forecast should be made for something, it is important that the variability is as low as possible. In case of the lead time, however, isn't this the case. Reducing the lead time has a greater impact than reducing the lead time variability on the safety stock (Chopra et al., 2004). So if the average lead time can be lowered it is also possible to lower the safety inventory and reorder level more efficiently. On the contrary, the safety inventory increases as the transport distance increases with each service level. Longer distance to the supplier, however, doesn't mean that the optimal order quantity should increase as well (Digiesi et al., 2013b). It may seem logical to order more if the lead time is higher, but the order quantity can simply remain the same. There is a chance that orders should be placed more often by Company X and that orders will be placed while the previous order hasn't even arrived yet, but that is fine as long as the order costs are low.

3.2.6 Fixed order cost & total logistics costs

There are various costs associated with the purchasing process. There has to be paid for the means of transport, the transport costs per m^2, kg or unit and fixed order costs that are always the same to name a few of the costs. The costs for the means of transport and the transport costs per unit speak for themselves, so the focus here is more on the fixed order cost. These fixed order costs are costs that are always present when an order is placed, regardless of the size of the order. It's proved that these fixed order costs strongly influence solutions in terms of the order quantity while a negligible influence on transportation means selection was observed (Digiesi et al., 2013a). These fixed order costs therefore play a very large part in the order sizes and also how often orders should be placed per year. If these costs are very low, it may be the cheapest solution to often order small quantities instead of ordering large quantities only a couple of times a year. To find the ideal distribution between the order frequency and the order size, the total logistics costs (TLC) must be considered. The total logistics costs consist of transportation cost, purchasing cost, order cost and inventory/holding cost. With the optimal order size, all these costs combined are at the lowest point for Company X. The order size has no further influence on the level of safety inventory and the reorder level.

3.2.7 Demand during lead time

Something that does affect the required level of safety inventory is the statistical distribution of demand during lead time (DDLT) (Vernimmen et al., 2008). The demand during lead time can typically be divided into three components: the order intensity, the order size and the lead time. It is often assumed that DDLT is normally distributed due to practical reasons. However, this assumption is not always valid in the real situation. There are situations where it is better to work with a gamma distribution. The gamma distribution has a couple of characteristics that makes it better suited for certain situations. One of the characteristics is that the gamma distribution only works with values that are higher than zero. When it comes to demand and lead time, this is good to use because these values are always higher than zero. Another characteristic of the gamma distribution is that it can take a

number of different shapes depending on its modulus. This is in contrast to the normal distribution, which is always symmetrical. By looking at the previous sales, it can be determined which distribution best suits the situation of Company X.

3.2.8 Correlation lead time & demand

The last interesting point that emerged from this SLR is the correlation between lead time and demand. A key assumption in a lot of calculations for safety stock and reorder level is that lead time and demand are not correlated. This means that the lead time does not change when the demand increases or decreases. In most cases this is indeed the case, but there are also exceptions. An increase in market demand that is not forecasted may tax supplier inventory and production capacity to a level that causes delivery delays. In this case, lead time and demand are positively correlated (Wang et al., 2010). When a company places an order and the supplier no longer has this quantity in stock, the lead time can increase because the remaining units still have to be produced. This can be a real problem for Company X and therefore a solution must be devised for this in the tool.

3.3 Conclusions literature

This section briefly explains what has become clear from the literature. This information can be further used in the tool and for drawing conclusions at the end. For the part of the safety stock, a formula has been chosen that can be used in the tool ($Safety\ stock = Z * \sqrt{L * \sigma_D^2 + D^2 * S_L^2}$). The safety stock is there to prevent shortages in the future. Shortages can cause customer satisfaction to drop and can lead to a loss of profit in the future. The best way to deal with shortages is to reduce uncertainties with better forecasting or to increase the safety stock. The safety stock can also be increased to accommodate seasonal demand, but in this case for Company X it is not necessary because it is difficult to say what of some products really are the best or the worst months.

For the reorder level are demand and lead time the two most important factors. With a higher demand and a longer lead, orders must be placed earlier. It would be ideal for Company X to have a reorder level that is dynamic instead of a fixed value. A policy that fits well with this is the dynamic reorder point policy (r_k,Q). The reorder level could change due to uncertainties in costs, demand and lead time. The formula for the reorder level is the following: *Reorder level = D * L + ss.* The level of both the safety stock and reorder level also depends on the CSL that Company X ultimately decides to use. The higher the CSL, the higher the safety stock and reorder level. A CSL of 1 or 100% is impossible to achieve because there would need to be an infinite safety stock.

A number of sourcing strategies were discussed already in the literature part. For the situation of Company X, I would recommend to make use of dual sourcing. This makes it easier to absorb risks while at the same time choosing flexibility and lower costs. The logistics part has costs involved around it and there are fixed order costs that play a very large role in the order sizes and also how often orders should be placed per year. For these order sizes, the optimal order size is the one with the lowest total costs. The frequency of ordering these optimal order sizes doesn't need to be the same all the time. Just like the reorder level, it's better to have something that is dynamic instead of a fixed frequency. There is also a chance that orders will be placed while the previous order hasn't even arrived yet, but that is fine as long as the order costs are low.

The last interesting conclusions of the literature can be drawn from the part about the probability distributions. The characteristics and the differences between the normal distribution and the gamma distribution were explained. When working with a probability distribution that does not fit well with the data, there is a high chance that the values are higher or lower than the correct values. For this case of Company X, it is necessary to determine the suitable probability distribution for the demand, the lead time and the demand during lead time. In the parameters section of the tool, it is indicated which probability distributions best suited this data.

4. Tool

4.1 Application

The application that will be used for the tool is Excel. The reason why Excel was chosen for this assignment is because it is an application that most people can work with. Company X's assignment states that they are looking for a model or tool that can make accurate decisions while it remains simple to work with. Even more complex formulas can be put in Excel in a well-organized way. Adding new materials and products to this tool can be done in an easy way for Company X and this makes sure that the tool is not easily outdated. If other data changes over time, for example the material costs of a particular product, this can also be easily changed and the results will immediately be calculated with the use of the new values. The purpose of the tool is to advise Company X about the safety inventory levels, reorder levels and order quantities of the various yarns and wovens.

4.2 Parameters

For the tool to work, a number of parameters are required. The parameters that are needed to perform the calculations are the input parameters. The data that comes from these calculations are the output values. In the upcoming sections, it will be explained which input parameters are used in the tool and why these parameters are so important for this tool and research. There will also be an explanation about the output values of the tool.

4.2.1 Input parameters

For the tool to work, there are a number of input parameters needed. The required input parameters are listed below with the reason why they are essential for the tool to work. After that, these input parameters are discussed in more detail to describe what they exactly mean.

- *Sales of the wovens.* With the sales in the past, better predictions can be made for the future.
- *Material consumption of the yarns.* Just like the sales, they are needed for better predictions for the future.
- *Costs suppliers.* These costs are necessary in order to determine which supplier is the cheapest.
- *Lead time suppliers.* This must be taken into account for determining safety stocks and reorder levels.
- *Shipping containers.* The size and price of the containers play a restriction role with regards to the order quantities.
- *Holding cost.* Together with the purchasing cost determine the order quantities.
- *Cycle service level.* An important factor in determining the height of the safety stock and reorder level.

4.2.1.1 Sales & material consumption

A large part of the input parameters are directly related to the wovens and the yarns. The sales of the wovens from January 2011 to March 2020 have been stored on a monthly basis for each individual woven in the Excel file. For the yarns, the annual material consumption from 2015 to 2019 is given. That these time periods are used for the sales and material consumption is simply due to the presence of data. The sales of 10 years ago in a specific month are easier to trace back than the material consumption of the same period for Company X. The sales are available for 111 months in the tool and this is enough data to make relevant statements about the average sales and the standard deviation.

These figures are the real figures of this period and are therefore not assumptions or estimates. Later in the file, the material consumption is also available on a monthly basis, but this data is calculated based on the monthly sales of the wovens. For example, if yarn X is only consumed in woven or fabric Y, the monthly consumption of yarn X is determined with the monthly sales of woven or fabric Y. So if in January 2015 the sales of fabric Y is 10% of the annual sales, then it is assumed that 10% of the annual material consumption of 2015 for yarn X has taken place in January. It has been agreed with Company X that this is the best way to make estimates about the monthly material consumption. The reason behind this is that the monthly material consumption and the monthly sales are closely related. If the sales of a month were high, the material consumption of this month were also high because more material has to be consumed to meet the demand of that month.

For 2020, it is indicated in the tool what is expected for this year in sales and material consumption, in other words the budget sales and budget consumption. These values are included in the tool to be able to compare the expectations of this year with the values of the previous years. When future monthly sales and yearly material consumptions are known, they can easily be added to the already existing data. The tool is designed in such a way that it will immediately calculate the new output data when new data is added to the designed spots in the tool.

4.2.1.2 Costs suppliers

For the suppliers from Europe and Asia, two separate tabs have been made in the file. These two tabs list the costs that are known to Company X from the two potential suppliers. These costs are the material costs, production costs and transportation costs. These costs together are the total costs or unit cost of 1 kilo or 1 m^2 for a certain material of product. The material costs can possibly change in the near future because Company X is currently in a negotiation phase about the prices of the materials with the suppliers. What the prices are at the moment are the prices that are in the tool. This was done in order to still be able to make a comparison between the two suppliers in terms of costs. The total cost or unit cost of the wovens is determined by first looking at the ratios of the yarns used as warp and weft that are used in 1 m^2 of a certain woven. After having received these ratios of Company X, by multiplying these ratios with the unit cost of the yarns, the unit cost of the wovens could be determined.

For the Asian supplier, for each cost, there is an additional column with the currency of the supplier's country. In a table that is also on the Asian supplier tab, the conversation rate of that currency to euros is given as it is now and this rate can easily be changed within the file if it changes over time. These columns and the table have been added so that Company X can also put the data in the tool when they receive costs in the currency of the supplier's country.

4.2.1.3 Lead time suppliers

The tabs of the two suppliers also include information that is important for placing orders. For the lead times, it was decided to have two options for both suppliers: the supplier has the necessary materials/products in stock or the supplier has to produce these materials/products before the supplier is able to ship it to Company X. To find out whether the supplier has the required quantity in stock, contact must first be made with the supplier. The reason why two options were chosen for both suppliers was that a conversation with the Purchasing Manager of Company X made clear that there was a big difference with lead times when the desired products and materials were or were not in stock at the supplier. It could also have been chosen not to make a distinction here, but then the standard deviation of the lead time would be a very large value. A very large value for the standard

deviation would ensure that the safety stocks and reorder levels would be many times higher. For these options an average lead time and a standard deviation have been assumed based on the conversation with the Purchasing Manager. It was looked at how long it normally takes before an order arrives at Company X and for that an average has been taken as lead time where it is logical that the lead times are higher when the supplier does not have the ordered materials/products in stock. For the standard deviation, something similar has been done and there is no difference between the two options with the same supplier. This also came up in the conversation with the Purchasing Manager. There is, however, a difference between the standard deviations between Europe and Asia. The deviation used for the Asian supplier is a higher number compared to the European supplier. The reason for this is that the materials and products take longer to travel from Asia to the Netherlands so there is a greater chance that there will be a deviation in the lead times. An example of this is that because the freight transport has to travel a longer distance, there is a bigger chance of incurring delays on the route, like bad weather conditions. The materials are sent to the Netherlands by ship and the weather conditions can have a major impact on the speed of the ships. The lead times and the standard deviations follow the normal distribution and the assumptions are stated in tables 2 and 3.

Table 2: Assumptions lead time and standard deviation supplier Europe

Materials are in stock at supplier Europe	**Yes**	**No**
Average lead time (days)	25	46
Standard deviation lead time (days)	4	4

Table 3: Assumptions lead time and standard deviation supplier Asia

Materials are in stock at supplier Asia	**Yes**	**No**
Average lead time (days)	63	91
Standard deviation lead time (days)	7	7

4.2.1.4 Shipping containers

When an order is placed, the ordered quantities are placed in containers which are then shipped to the Netherlands. These containers have a fixed cost and a maximum number of rolls that fit within these containers. By looking at the maximum number of rolls in a container, it is also possible to look at the maximum m^2 and kg that can be put in a container. This information is also stated on the first tab “Fabric qualities” of the tool so that it can be taken into account when determining the order quantities. It is also useful to determine the fixed order costs for determining the order quantities. These are the fixed costs that Company X must always incur with an order, regardless of whether 10 rolls are purchased or 1000 rolls. With the help of a conversation with the Financial Controller of Company X, an assumption is made for the value for the fixed order costs. If later a better value becomes known, can this value easily be replaced in the tool by Company X.

4.2.1.5 Holding costs

The costs that Company X incurs for purchasing materials and products are not just the unit costs. Company X also incurs costs related to the storage of the purchased materials and products, the holding costs. Company X itself works with depreciation costs that can be used as holding costs. These costs are made when an item is in stock for a year and then a certain percentage from the unit cost is used as holding cost. If an item is in stock for two years, a percentage will again be charged as holding cost and this percentage is taken over the original unit cost. After these two years, no further

depreciation is applied to the items. For all yarns are the holding cost per year as a fraction of the unit cost the same for both years. The same applies to the wovens, all the wovens have the same percentages as holding cost per year as fraction of the unit cost. The wovens have higher percentages that are being used as holding cost because the wovens lose their value faster when they are stored at the company compared to the yarns. Company X is currently working with the specific percentages that are being used in the tool.

4.2.1.6 Cycle service level

The last input parameter in the tool is the cycle service level (CSL). The tool is designed to calculate with CSLs of 95%, 96%, 97%, 98% and 99%. 95% was chosen as the minimum because Company X is a company where a high service level is essential, so a cycle service level lower than 95% is not interesting for them. For each individual product, it is possible to choose the preferred CSL that Company X wants to use between 95% and 99%. Unfortunately, the tool does not simply calculate everything with a CSL of 95% if 0.95 or 95% is entered in the designated place in the tool. Entering 0.95 comes with results that would be lower than the desired 95%. This is due to the probability distribution that the tool uses. The tool assumes that it must calculate with values that follow the normal distribution, but the values of the sales of the products follow more something that looks like a gamma distribution. The characteristics of both the normal distribution and the gamma distribution have already been explained in the literature section. To make the tool more accurate with the CSL, a method named service level adjustment has been used (Mirzaee, 2017). This method calculates manually what value is really needed as CSL to handle, for example, 95% of the monthly sales. As an example, figure 10 is given where the orange bars are the values and the dark blue line is the distribution.

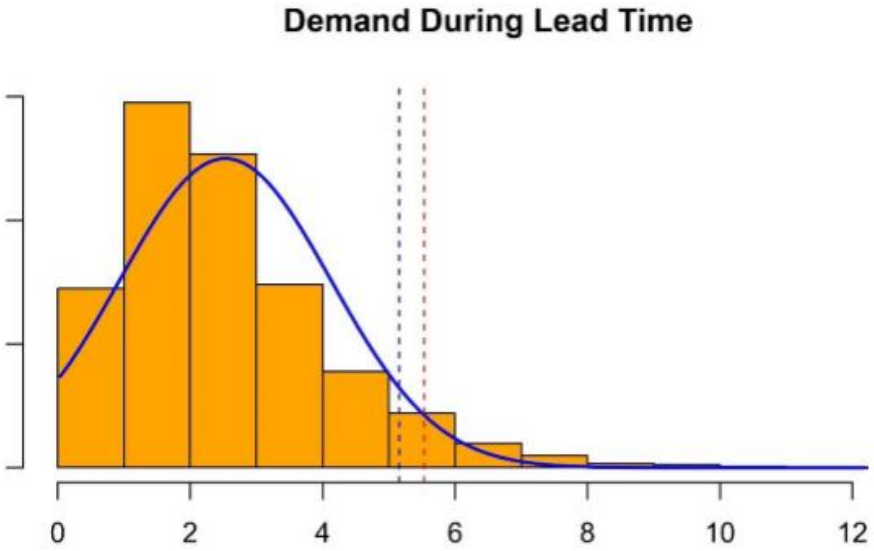

Figure 10: Service level adjustment (Mirzaee, 2017)

The dotted blue line in this example would indicate where for example the sales level would be with a service level of 95% based on a normal distribution. However, if one really looks at where 95% of the data is located, it turns out that the place of the dotted red line should be looked at. For each product, I looked at the 95%, 96%, 97%, 98% and 99% and which monthly sales value corresponded with these percentages. After this, it has been manually calculated what value should be entered in the designed place in the tool in order to achieve the preferred CSL percentages. A table with these values can be found in appendix B. A disadvantage of this method is that a lot has to be calculated manually, so if,

for example, Company X wants to look at a CSL of 94%, the value must first be calculated. A value below 95% is, however, not interesting for Company X so that is why this method was chosen. A value below 95% is not interesting for Company X because Company X strives for a CSL of 100%. The table with the corresponding values for each individual product and the five CSL percentages are also available in the tool so by looking at the table, the correct value can be entered at the designed spaces.

4.2.2 Output values

After the input parameters have been entered, the tool can calculate the output values. All wovens have their own tab with the monthly sales and the monthly material consumption of the yarns that are used to produce that specific woven. As explained earlier, the monthly material consumption of the yarns is thus calculated from the annual material consumption and the monthly woven sales. The wovens and yarns have many output values in common, but a difference between wovens and yarns is that with the wovens the sales are used for the calculations and with the yarns are the material consumptions used for the calculations. In the next part, the wovens are used as an example for the output values, but these output values can also be calculated for the yarns if the sales are replaced by the material consumption. This will enable better estimates of how much material needs to be in stock in the future.

4.2.2.1 Safety stock & reorder level

The monthly sales of the wovens can be used to calculate the total sales, the average monthly sales and the standard deviation in m^2. The average monthly sales and the standard deviation, together with the average lead time of the supplier and the standard deviation of the lead time, are necessary to calculate the deviation of the demand during lead time. If this value is multiplied by the Z-score corresponding to the entered CSL, a safety stock level will be the outcome. The last step that is taken afterwards is determining the reorder level with the safety stock and the lead time of the supplier. The policy that is assumed is the dynamic reorder point policy (r_k,Q). The reorder level/point r_k that is calculated is the lowest stock level at which Company X should place a new order with quantity Q at a particular supplier. The input parameters change/are supplemented over time and therefore the safety stocks and reorder levels will also change within the tool. This change shows why a dynamic value r_k was chosen instead of a fixed value r. When an order is placed when the reorder level is reached, the stock level would drop to the safety stock level at the moment that the order is received at Company X when all variables are average. This means that the monthly sales were average in this period and that there was no deviation in the lead time. The safety stock indicated by the tool has the function of absorbing the deviation in both sales and lead time. This is necessary to achieve the desired CSL.

4.2.2.2 Order quantities

The tool not only calculates the safety stock and the reorder level, but also gives a suggestion about the order quantities. When determining these order quantities, the size of the containers is taken into account. For a number of containers, it is calculated what the costs would be in a year if this order quantity were always used. For example, if for a certain woven an annual quantity is needed that requires at least 10 full containers, this can be purchased in various ways. 10 containers can be ordered once a year, 5 containers can be ordered twice a year, 1 container can be ordered ten times a year etc. All these different options involve different inventory costs and purchasing costs and the tool shows

what these costs are for the options and at which order quantity the total costs are the lowest. The tool calculates for all yarns and wovens what the material costs, holding costs, order costs and total costs are for ordering from 1 to 10 containers per order for that specific yarn or woven. For all items, these considerations are checked and the ideal order quantities are determined for ordering in Europe and Asia. First, it was checked whether the EOQ formula could be used in this case, but this turned out to be difficult because the order costs changed significantly when an extra container was required for an order. That is why the material costs, holding costs, order costs and total costs have been calculated for the different order options. The following formulas have been used for this:

- Annual material cost = annual demand * unit cost (4)
- Annual holding cost = holding cost per year as fraction of the unit cost * unit cost
  * (m^2 or kg per order / 2) (5)
- Annual order cost = (annual demand / m^2 or kg per order) * (container(s) per order * costs container + fixed order cost) (6)
- Annual total cost = annual material cost + annual holding cost + annual order cost (7)

4.3 Tool explanation

After seeing what the input parameters and output values of the tool are, this section will further explain certain choices that were made within the tool.

4.3.1 Order placement options

There are four possible options that can happen with the suppliers, therefore the discussed output parameters deviation demand during lead time, safety inventory and reorder level are calculated four times. The four options are the following:

1. Placing an order at European supplier, items are in stock at the supplier
2. Placing an order at European supplier, items are not in stock and have yet to be produced
3. Placing an order at Asian supplier, items are in stock at the supplier
4. Placing an order at Asian supplier, items are not in stock and have yet to be produced

When Company X wants to place an order, it is necessary to look at their current stock level to determine whether all options are possible. If the current stock level is lower than the calculated reorder level in the tool, it is recommended to look at one of the other options if the desired CSL wants to be achieved. If the current stock level is lower than all the calculated reorder level, it is advised to choose the option with the lowest lead time, in this case, Europe. There is now only a greater chance that a stockout will happen. In an ideal world options 2 and 4 will never be chosen but in the real world it is possible that the ordered quantity is not in stock at the supplier and therefore still has to be produced. By first contacting the specific supplier, Company X can see if options 1 and 3 are possible. When all this has been considered, the option that best suits the situation can be chosen.

4.3.2 Different methods

With this tool, two methods are provided for Company X for the calculation of the safety inventory and reorder levels. There is a method that looks at the sales of specific months and a method that looks at all available monthly sales for an item. The method that looks at specific months calculates, for example, the safety stocks and reorder levels for January based on the sales of January only. This method can take into account months where sales are always high or instead months where sales are always low. This means that on average, lower inventory levels can be maintained because specific consideration is given to what "normal" sales are during that month of the year. This sounds very good in theory, but in practice this method is less easy to use. This method requires a different safety inventory and reorder level for each month, what is very difficult to maintain in practice. For the other method, the safety inventory and the reorder levels are calculated with all the available monthly sales for an item. This method does not look at peak or low sales months but provides a general safety inventory and reorder level. This has the advantage that Company X does not have to switch from one safety inventory and reorder level to another. Another advantage of this method is that unexpected peaks in months where sales are normally low can be better absorbed. This means that the safety inventory and reorder level of this method need to be higher than the average value of the other method. Both methods have their advantages and disadvantages but I would recommend to use the method that looks at all the available monthly sales. The main reason why I would recommend this method is that it is the easiest to use in the real situation. The other method looks better on paper but is difficult to use in real life. In the recommendation section, more explanation is given about this recommendation. The two methods are both provided so Company X can decide itself which method they prefer to use.

4.3.3 Order quantities

For the order placement, a suggestion is given per item about the order quantities and the amount of containers per order. A distinction is made for each item between ordering in Europe and ordering in Asia, but no distinction is made between whether or not the supplier has the items in stock. Whether or not the supplier has the items in stock does influence when an order has to be placed, but the ordered quantity remains the same. The optimal order quantities may differ between the European and the Asian supplier. This is because the costs for an order placement are not the same for the two suppliers. The tool also indicates how often orders should be placed during a year if a certain quantity is purchased per order. However, it is possible that one time something is ordered from Europe and the other time something is ordered from Asia. In this case, the number of annual orders would be somewhere between the value that is calculated for only purchasing at the European supplier and the value that is calculated for only purchasing at the Asian supplier. It is indicated for each yarn and woven what the annual costs would be by ordering 1 to 10 containers in a single order. The box that contains the lowest annual total cost will turn green to indicate the best option according to the tool. Each table has one extra column with the word "Test" stated above it. In the yellow box below this, any number of m^2 or kg can be entered to see what the total costs would be for that specific quantity. In this way, it is also possible to look at quantities that are larger or smaller than the quantities that exactly fit in a full container.

4.4 Flowchart choice supplier

After the explanation of the parameters and the tool itself, a flowchart has been made (figure 11) on how the tool should be interpreted which supplier is the best option in which situation. The flowchart starts with the current inventory level of a product or material and then looks at a number of aspects. The names that are in the boxes are the exact names that are stated in the tool. For example, “Asia (materials are in stock)” is the name that is in the tool and behind this name is the value that should be looked at for that question.

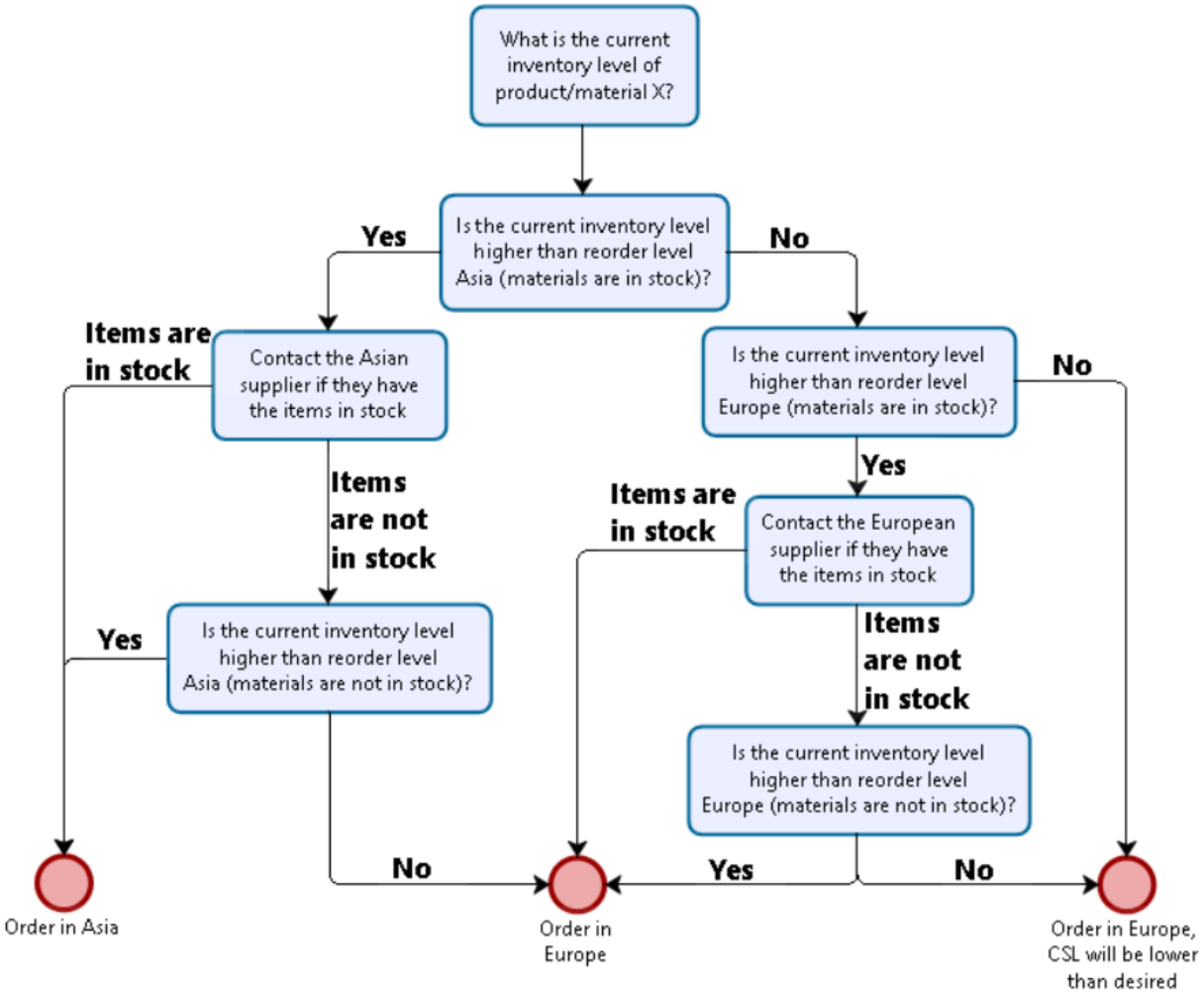

Figure 11: Flowchart choice supplier

The first aspect in the tool that has to be looked at is the value that is stated at the reorder level of the Asian supplier if they have the required items in stock. The reason that the Asian supplier is first looked at is because the Asian supplier is cheaper than the European supplier. This means that if both suppliers are a viable option for a situation, the Asian supplier is preferred. By comparing the current inventory level with the value of the reorder level Asia (materials are in stock), the next step in the flowchart can be looked at. If the answer was “yes” to the first question, the user is then asked to contact the Asian supplier if they have the desired quantity in stock. If this quantity is in stock, it is concluded that it is best to order at the Asian supplier for this situation. If the required quantity is not in stock and the Asian supplier still has to start producing the items, the current inventory level must again be compared with a value from the tool. If the situation arises that it remains unknown whether the supplier has the items in stock, it is recommended to assume that the supplier does not have the items in stock. This is the safest way to achieve the desired CSL. If the required quantity still has to be

produced by the supplier or it remains unknown whether the supplier has the items in stock, the current inventory level must be compared with the value of the reorder level when the Asian supplier does not have the desired quantity in stock. If the current inventory level is higher than the value of the tool, the best option is to still order in Asia, otherwise the best option is to order in Europe. The required quantity can be ordered in Europe without any problems in this situation because if the answer was “yes” to the very first question, it means that the current inventory level is definitely high enough for both options in Europe.

If the answer was “no” to the first question in this flowchart, the option to order from the Asian supplier is dropped, regardless of whether this supplier has the items in stock or not. It must then be checked whether the current inventory level is higher than the value of the reorder level of the European supplier if he had the desired quantity in stock. If the current inventory level is lower, it concludes that the order should be made at the European supplier, but the CSL will be lower than the desired value. There is a greater change of stockouts in this situation and therefore the CSL goes down. If the current inventory level is high enough, the flowchart will indicate again to contact the supplier if they have the desired order quantity in stock. An order can then be placed in Europe without the CSL going down if the European supplier has the items in stock. The last question in the flowchart should be considered when the European supplier does not have the items in stock or when it remains unknown whether the supplier has the items in stock. The current stock quantity has to be compared for the last time and this comparison is made with the value of the reorder level Europe (materials are not in stock). If the current inventory level is larger, the order can be placed in Europe without the CSL going down. In the other scenario, the order is also placed in Europe, only in this case the CSL will go down.

These were the descriptions of all the possible paths of the flowchart and the corresponding conclusions of these paths. The flowchart can give three possible outcomes: order in Asia, order in Europe and order in Europe, but the CSL will go down. There is no option of “placing an order in Asia but the CSL will go down” because in this case it is preferable to order in Europe. If in this case an order is placed in Asia, the purchase costs are lower compared to ordering in Europe but the CSL will probably go down a lot. The CSL is more important than the price difference between the two suppliers. If the supplier is chosen, the order can then be placed. The tool also gives advice on the order quantities of the different products and materials when an order is placed in either Europe or Asia.

4.5 Validation of the tool

Before the tool can be used by Company X, it must be proven that the tool is valid. The reason why validation is important is to prove that the tool can give reliable output values. To check whether the tool is valid, the costs indicated by the tool were compared with the costs that Company X actually incurred. The purchasing costs and the inventory costs of the year 2019 for the PP related yarns and wovens have been used for this comparison. Within the tool, the unit costs of the current supplier and the sales of the year 2019 were used for the calculation of the purchasing and inventory costs. The purchasing costs consist of the material costs and the order costs. The material costs are the unit costs of the materials multiplied by the sales for that period. The order costs are the costs for the containers that must be used annually to ship the materials from the supplier to Company X and the fixed order costs. The holding costs are the costs that Company X incurs when yarns or wovens are present at the company for a certain period of time. For this research, the inventory and holding costs correspond directly with each other. The unit costs of the current supplier and the sales of 2019 are used as input parameters for this calculation.

These total costs provided by the tool have been compared with the real costs of Company X for the year 2019. If the difference between these values is very small, it can be proved that the tool provides accurate and valid outputs. Unfortunately, it was not possible to find a value for the inventory costs of the real situation in 2019. As a result, only the purchasing costs of the real situation are compared with the calculated values of the tool.

The difference between the purchasing costs of the real situation and the calculated purchasing costs is € difference between the purchasing costs of the real situation and the calculated purchasing costs / € purchasing costs of the real situation * 100% = 0,887%. This percentage is so low that this calculation has shown that the tool is valid to a certain extent.

5. Numerical study and results

5.1 Safety stock & reorder level

The most noticeable results of the tool will be discussed in this section. The first topics that will be discussed are the safety stock and reorder values within the tool. If the values indicated by the tool are considered, the values for the safety stock and reorder level may seem relatively high. However, they are not that high when considering the long lead times and the high desired CSLs for the products. Without this level of safety stock, there would very often be stockouts which would result in not achieving the desired CSL. The tool takes into account the data from the last 10 years for wovens and the last 5 years for yarns when determining the safety stocks and the reorder levels. This can also be a reason why the safety stocks and reorder levels look relatively high. If the demand for these yarns and wovens was really high a couple of years ago and the demand for the same yarns and wovens is in the previous year(s) much lower, high values can be ensured to be maintained for the safety stock and reorder level. If the high safety stocks prove to be a problem for Company X due to the high sales of the past, the values of the first years can be filtered out with the tool. In order to do this, the years not to be used must not be selected in the spaces of total in m^2 or kg, average and standard deviation. The tool then calculates the new values of the safety stock and reorder level with the values of the selected years. Changing the researched time period for a product can have a major impact on the level of safety stock and reorder level. Tables 4 and 5 show the reorder levels of the yarns and wovens that the tool calculates when the CSLs are used that are recommended in the recommendations section. Four reorder levels are shown for each yarn and wovens and these four reorders levels are the values for the four order placement options.

Table 4: Reorder levels yarns

Yarns	Europe (materials are in stock)	Europe (materials are not in stock)	Asia (materials are in stock)	Asia (materials are not in stock)
Yarn A	15.689 kg	23.260 kg	28.889 kg	37.229 kg
Yarn B	68.069 kg	101.463 kg	126.518 kg	163.639 kg
Yarn C	59.352 kg	87.736 kg	108.899 kg	140.053 kg
Yarn D	9.900 kg	14.093 kg	17.010 kg	21.284 kg
Yarn E	7.049 kg	10.038 kg	12.124 kg	15.173 kg
Yarn F	7.053 kg	10.160 kg	12.366 kg	15.612 kg
Yarn G	7.143 kg	10.494 kg	12.940 kg	16.573 kg
Yarn H	12.028 kg	17.578 kg	21.596 kg	27.554 kg
Yarn I	6.696 kg	9.840 kg	12.135 kg	15.544 kg
Yarn J	7.358 kg	10.752 kg	13.210 kg	16.853 kg
Yarn K	27.044 kg	40.682 kg	50.912 kg	66.257 kg

Table 5: Reorder levels wovens

Wovens	Europe (materials are in stock)	Europe (materials are not in stock)	Asia (materials are in stock)	Asia (materials are not in stock)
Woven A	90.943 m^2	136.646 m^2	171.412 m^2	222.874 m^2
Woven B	253.093 m^2	376.997 m^2	470.706 m^2	608.493 m^2
Woven C	46.567 m^2	67.346 m^2	82.096 m^2	103.957 m^2
Woven D	8.681 m^2	12.475 m^2	15.158 m^2	19.103 m^2
Woven E	15.164 m^2	21.674 m^2	26.250 m^2	32.947 m^2
Woven F	26.971 m^2	39.497 m^2	48.594 m^2	62.091 m^2
Woven G	13.005 m^2	19.023 m^2	23.385 m^2	29.856 m^2
Woven H	78.156 m^2	118.469 m^2	149.037 m^2	194.910 m^2

5.2 Order quantities

In addition to the safety stock and the reorder level, the tool also provides advice on the order quantities. The annual costs are shown when a certain order quantity is used for every order in a year. The box of the total cost of the order quantity where the costs are the lowest automatically turns green in the tool to indicate which order quantity is the cheapest on an annual basis. Something that is remarkable when looking at the optimal order quantities for all yarns and wovens is that the optimal order quantity is always 1 full container per order. This therefore indicates that with the available information and costs, it is cheaper to have relatively small order quantities and to order these order quantities more often during the year. As a result, orders may have to be placed at the suppliers before the previous order has been delivered to Company X.

Why the tool indicates for all yarns and wovens to order 1 container per order is not difficult to explain. The reason for this is the very low fixed order cost. These fixed order costs are always the same for the placement of an order, regardless of the size of the order. When orders are placed more often in the year, these costs must be paid more often. Another important cost when placing orders is the holding cost. If the order quantity is larger, the holding costs are also higher because a larger number of materials must be placed in stock. In this case for Company X, these holding costs are so much higher than the fixed order costs that it is cheaper to purchase relatively low quantities per order. The costs for the containers ensure that the ideal order quantity is a full container. If a higher value would be used for the fixed order costs, the ideal order quantities for the different yarns and wovens will change. The optimal order quantity is then no longer 1 container for all yarns and wovens, but multiple containers for certain yarns and wovens per order could be the cheapest solution.

5.3 Purchasing & inventory costs

The action problem of this research was to reduce the purchasing and inventory costs. The tool can be used to calculate the expectations of these costs when the yarns and wovens are purchased in a certain way. For these calculations, the order quantities with the lowest annual total costs, i.e. 1 container per order, were used and the budgeted sales and material consumption for the year 2020 were used. The annual material costs, order costs, holding costs and total costs were calculated for four different situations. The four different situations are the following:

1. The current situation so purchasing yarns at the current supplier
2. Purchasing yarns at the potential new European supplier
3. Purchasing yarns at the potential new Asian supplier
4. Purchasing wovens at the potential new Asian supplier

The first situation is one that is not possible in the real situation. This supplier will no longer produce the materials that Company X needs. Nevertheless, it was decided to see what the costs would be for 2020 if Company X would not have had to switch suppliers. These costs are used as a comparison for the other situations. For these calculations, the unit cost of the current supplier were used and the budgeted sales and material consumption for the year 2020.

The other three situations are situations that are possible in the real situation. For the calculations, it is assumed that only yarns or only wovens are purchased from the suppliers in the specific situations. This has been done in order to give a better picture of the influence of purchasing yarns or wovens on the total costs. The costs for the combination for purchasing yarns and wovens are between the values of purchasing only yarns and purchasing only wovens. The costs of the three situations are compared

with the costs of the first situation in order to be able to draw conclusions afterwards. The tables with the costs for these situations have been removed from this report due to confidentiality.

The costs of these three situations can now be compared with the situation in which Company X would not have had to switch suppliers. The table below shows the percentages whether certain costs are lower or higher than situation 1. The costs of situation 1 are assumed to be 0% and negative percentages mean cost savings and positive percentages mean cost increases compared to situation 1.

Table 6: Comparison situations 2, 3 and 4 with situation 1

Situation	**Material cost**	**Order cost**	**Holding cost**	**Total cost**
Europe, only yarns	+ 30,89 %	0 %	+ 23,27 %	**+ 28,97 %**
Asia, only yarns	- 3,72 %	0 %	- 9,24 %	**- 3,64 %**
Asia, only wovens	+ 6,26 %	+ 17,32 %	+ 8,81 %	**+ 6,95 %**

Table 6 shows that the costs are only lower compared with situation 1 if yarns are purchased from the potential new Asian supplier. This means that when it is possible to always purchase yarns from Asia, the combination of purchasing and inventory costs can be reduced by 3,64%. This is probably not always possible in the real situation due to time constraints and therefore sometimes the European supplier must be used. As a result, the percentage of cost reduction of 3,64% can probably decrease slightly. It is difficult to further reduce the costs with the new suppliers because for some yarns the unit costs at both potential new suppliers is higher than the unit cost at the current supplier.

6. Conclusion

6.1 Research questions

Four research questions were formulated at the start of this research. The purpose of these research questions was to use the answers to these questions to solve the action problem and to find an answer to the main research question. Here are the research questions with briefly the conclusions drawn for these questions. Some of these conclusions are further explained in the recommendations section.

1. *Should Company X purchase only yarns, only wovens or a mix of both?*

The best option is to still mainly purchase yarns. An exact number cannot be given for how large the percentage of purchased yarns should be in relation to the percentage of purchased wovens but the percentage of purchased yarns should be a lot higher than the percentage of purchased wovens. The holding costs of yarns are much lower, the flexibility of the production process remains high and Company X has enough production capacity to convert the yarns into wovens. There are a few exceptions when it is advantageous to purchase wovens. These are situations when the demand for the coming period is known and when the Company X's weaving looms can no longer cope with the demand. More about this in the recommendations section.

2. *What is this deliverable flexibility from the Asian supplier with regards to the dynamics of market demand?*

The deliverable flexibility from the Asian supplier is high enough to consider the Asian supplier as a viable option for Company X. An order must be placed a lot earlier, approximately 5 to 6 weeks earlier when looking at the difference in lead time of both suppliers, but the deliverable flexibility is high enough to cope with the dynamics of the market demand.

3. *Is the European supplier, the Asian supplier or a mix of both suppliers the best solution for Company X?*

There are a couple of PP related materials and a lot of different scenarios that have to be looked before choosing a supplier. The tool helps to give advice on which supplier best suits which scenario. When looking at the costs, the Asian supplier is by far the best option. However, it is likely that the Asian supplier cannot always be used due to time constraints and desired high cycle service levels of Company X. In these cases it is better to use the European supplier to keep the flexibility towards the customers as high as possible. A mix of both suppliers is the best solution for Company X. A combination of the suppliers can ensure that Company X remains flexible while also keeping costs as low as possible.

4. *How should the ideal safety stock and reorder level be determined with unpredictable demand and potentially long lead times?*

In the case of Company X, it is ideal to make use of the dynamic reorder point policy (r_k,Q) instead of a fixed value to determine the safety stock and reorder level. The safety stock and reorder level could change due to uncertainties in costs, demand and lead time. A tool has been developed and validated that calculates values for safety stocks and reorder levels. The tool can take into account the uncertainties in costs, demand and lead time and can therefore provide dynamic values for the safety stock and reorder level. Formulas have been found for the safety stock and the reorder level that have been applied in the tool ($Safety\ stock = Z * \sqrt{L * \sigma_D^2 + D^2 * S_L^2}$ and $Reorder\ level = D * L + ss$). Within the tool, several options are given for determining the supplier, the safety stock, the reorder level and the size of the orders in different situations. Finally, Company X itself can choose a CSL for the various yarns and wovens, which influences the level of the safety stock and reorder level.

All conclusions of these four research questions together provide the answer to the main research question: *How should the supply chain for the polypropylene related wovens look like?*

By mainly purchasing yarns from the Asian supplier, it can be ensured that the purchasing and inventory costs are kept as low as possible. In order to make use of the Asian supplier within the supply chain, orders must be placed well in advance due to the relatively long lead times. When time constraints make it difficult to purchase from the Asian supplier, it is better to place orders at the more expensive European supplier in that case. By using dynamic values for the safety stock and the reorder level, it is possible to make an appropriate decision between the European and Asian supplier in all scenarios. These points are all important in shaping the supply chain for the polypropylene related wovens.

6.2 Action problem

The knowledge of the literature, the answers to the research questions and the use of the tool have all helped to ultimately provide an answer to the action problem. The action problem of this research was as follows:

The combination of purchasing and inventory cost of polypropylene related materials at Company X should decrease with 10% while the delivery reliability and the quality of the products will not decrease.

The results of the tool show that the combination of purchasing and inventory cost of polypropylene related materials at Company X could be decreased with **3,64%** while the delivery reliability and the quality of the products will not decrease. Unfortunately, the 10% that was determined at the start cannot be achieved with the new suppliers. At the start, 10% was chosen so that this research had a number to work towards. It is difficult to further reduce the costs beyond 3,64% with the new suppliers because for some yarns the unit costs at both potential new suppliers is higher than the unit cost at the current supplier.

7. Recommendations

In this part of the report are the recommendations for Company X for the future stated. A general recommendation for Company X is to use the tool that was developed during this research. The tool itself already provides recommendations on safety stocks, reorder levels and order quantities. The tool has been designed in such a way that it is not only useful for this research, but can also be used further in the future. In addition to the tool, further recommendations are made on the following topics:

- Europe or Asia
- Yarns or wovens
- Cycle service level
- Further use of the tool

7.1 Europe or Asia

For the choice of supplier, it is recommended to make use of dual sourcing. If the cost perspective is considered, it is cheaper to get the materials from Asia. These costs not only include the unit costs of the materials, but they include the total costs of the purchasing process. So to keep these costs as low as possible, it is advised to purchase from the Asian subsidiary. To ensure that Company X can be as flexible as possible, it is useful to have a supplier with a relatively low lead time at their disposal. Although the European supplier is more expensive, the European supplier can help to cope with an unexpected increase in demand in a short time span. This will reduce the chance of shortages and a loss of profit in the future. The question may arise whether the European supplier is satisfied with being “second choice” but the quantity of products required by Company X in the short term will probably remain large enough that orders are regularly placed at the European supplier. As a result, the cooperation between the European supplier and Company X remains interesting enough for the European supplier.

A combination of both suppliers can ensure that Company X remains flexible while also keeping costs as low as possible. I would recommend Company X to first look at the current stock levels and whether it is possible in this situation to purchase from the Asian supplier. The Asian supplier is a fair amount cheaper than the European supplier and this option ensures that the purchasing costs stay as low as possible. Due to the relatively long lead time, the Asian supplier is not always a viable option. If the materials and products are needed quickly, the better option is to purchase from the European supplier. The tool indicates the turning points when it is the better option to purchase from the Asian or the European supplier.

7.2 Yarns or wovens

In the current situation, only yarns were purchased from the supplier. The Asian subsidiary offers an additional option that wovens can also be purchased directly from the suppliers instead of purchasing yarns from the suppliers that then have to be processed in-house into wovens. My advice, however, is to still mainly purchase yarns from the new suppliers. The reasons why I would recommend purchasing yarns are the following:

- *Lower holding costs.* The holding costs for the yarns are much lower compared to the holding costs for the wovens. When something has to be in stock for a longer period of time, it is better to have the yarns in stock instead of the wovens to keep the costs as low as possible.
- *Flexibility.* A number of yarns can be used in multiple types of wovens. It is therefore more convenient to keep yarn in stock because unexpected orders can then be better accommodated. If unexpected orders have to be taken care of with wovens, all wovens should be in stock at Company X, which is simply more expensive than having yarns in stock.
- *High production capacity Company X.* Company X has the production capacity to convert the purchased yarns into wovens according to the demand of the customers. If large numbers of wovens were to be purchased, it would mean that several weaving looms would come to a standstill. Machines, in this case the weaving looms, that are not engaged in production only cost a company money. When a company has enough production capacity, I would recommend the company to make good use of this production capacity.

There are a number of instances where purchasing wovens has its advantages. In the following situations I would recommend to also purchase wovens, but these situations are the only situations that I would recommend to purchase wovens.

- *Demand is known.* When the demand is known and Company X is therefore sure that they can sell the wovens, it may be better to purchase wovens in this situation. If it is certain that these wovens will be sold, the relatively high holding costs don't have to be taken into consideration. A problem with this is that the wovens have to come from Asia, so the demand/large orders must be known a reasonable time in advance.
- *Weaving looms can't cope with demand.* When there is a treat that the weaving looms will no longer be able to cope with the demand, it can be an option to purchase wovens.

7.3 Cycle service level

The tool that is provided with this research works with various cycle service levels from 95% to 99%. The table below indicates which CSLs are recommended, which are neutral and which are not recommended towards Company X to use in the tool for the different wovens. In appendix C, an explanation is given why these CSLs were chosen for these wovens. There are also tables in this appendix showing how many percent the reorder levels will increase when a higher CSL is chosen.

Table 7: Advice CSL

Advice for CSL	Recommendation	Neutral	Do not recommend
Woven A	98%	95%, 96% and 97%	99%
Woven B	99%	95% and 96%	97% and 98%
Woven C	95%	96%	97%, 98% and 99%
Woven D	97%	95% and 96%	98% and 99%
Woven E	95%	96%, 98% and 99%	97%
Woven F	96%	95%, 97% and 99%	98%
Woven G	98%	95%	96%, 97% and 99%
Woven H	97%	95% and 96%	98% and 99%

7.4 Further use of the tool

The tool is made in such a way that it should help Company X for many years to come. Something that is required for this are appropriate input parameters with which the tool can make calculations. The better these input parameters are, the better the tool can provide advice to Company X. A number of values have been used in this research as input parameters, some of these values are based on assumptions. A couple of assumed values, for example the lead times and the fixed order cost, have a major influence on the output values. If Company X can find better values instead of the assumed values, it is possible for the tool to return more accurate values. That is why it is recommended for Company X to take a good look at the input parameters in the tool, especially the lead time and fixed order cost, to see whether these values are really representative for the real situation. If there are values that are more representative, they can easily be added/adjusted within the tool.

At the moment, two methods are provided in the tool for Company X. One method looks at the specific months and the other method looks at all available monthly sales for an item. An explanation of these two methods is given in the "Tool explanation" section of this report. The method that is recommended for Company X to use is the method that looks at all available monthly sales. This method does indicate higher safety stocks and reorder levels than the other method, but is much easier to use in practice. There is no need to switch every month from safety stock level and reorder level, but simply one safety stock level and reorder level per product can be maintained. This method also makes it easier to deal with unexpected peaks in sales. All in all, the method that looks at all available monthly sales is the most suitable method for Company X and therefore it is recommended that they use it for further use of the tool.

8. Limitations

This research was subject to limitations. Much data was still unknown or became known late in the research because the research looked at potential future suppliers. Company X was not always able to provide some data that was essential for this research, such as unit cost from the European and Asian supplier, because these values were not yet fully known by them early on in the research. As a result, a lot of work was done with assumptions to develop the tool at the start.

Another limitation of this research was caused by the COVID-19 pandemic. The intention at the start of the research was that most of the report would be made at Company X. Due to COVID-19, however, the presence at Company X has been very limited and as a result almost the entire report was made from home. As a result, communication with Company X employees was more difficult to do and took more time. Sometimes this resulted in assumptions being used in some parts of the report and the tool instead of having the real data on these places.

The last limitation I want to mention is the testing of the tool. A limitation in making such a tool for such a research is that it is difficult to test. The tool provides values about the safety inventories and the reorders levels, but it cannot be demonstrated within this research that working with these values will 100% result in the desired CSLs. In the part of the validation of the tool, an attempt has been made to show that the costs indicated by the tool are close to the real values in order to be able to demonstrate something of a validation. This shows that the tool does not just give random output values, but that these values are somewhat valid indications.

References

Babai, M. Z., & Dallery, Y. (2006). *A dynamic inventory control policy under demand, yield and lead time uncertainties*. https://doi.org/10.1109/icsssm.2006.320649

Beemsterboer, B., Land, M., & Teunter, R. (2016, 2016/01/16/). Hybrid MTO-MTS production planning: An explorative study. *European Journal of Operational Research, 248*(2), 453-461. https://doi.org/https://doi.org/10.1016/j.ejor.2015.07.037

Boroń, J., & Bartyla, P. (2014). Optimization of Warehouse Supply by the Methods of Mathematical Programming. In (pp. 117-126).

Bragg, S. (2018). *Ordering costs*. https://www.accountingtools.com/articles/ordering-costs.html

Braglia, M., Gabbrielli, R., & Zammori, F. (2013, May). Stock diffusion theory: a dynamic model for inventory control. *International Journal of Production Research, 51*(10), 3018-3036. https://doi.org/10.1080/00207543.2012.752584

Chiang, C., & Benton, W. C. (1994). Sole sourcing versus dual sourcing under stochastic demands and lead times [Article]. *Naval Research Logistics (NRL), 41*(5), 609-624. https://doi.org/10.1002/1520-6750(199408)41:5<609::AID-NAV3220410503>3.0.CO;2-7

Chopra, S., & Meindl, P. (2016). *Supply Chain Management Strategy, Planning, and Operation* (6 ed.). Pearson.

Chopra, S., Reinhardt, G., & Dada, M. (2004, Win). The effect of lead time uncertainty on safety stocks. *Decision Sciences, 35*(1), 1-24. https://doi.org/10.1111/j.1540-5414.2004.02332.x

Cooper, D. R., & Schindler, P. S. (2018). Business Research Methods. In *Business Research Methods* (12 ed., pp. 151-163). McGraw-Hill Education.

Digiesi, S., Mossa, G., & Mummolo, G. (2013a). Supply lead time uncertainty in a sustainable order quantity inventory model [Article]. *Management and Production Engineering Review, 4*(4), 15-27. https://doi.org/10.2478/mper-2013-0034

Digiesi, S., Mossa, G., & Mummolo, G. (2013b). A sustainable order quantity model under uncertain product demand. IFAC Proceedings Volumes (IFAC-PapersOnline),

Frost, J. (2018). Understanding Probability Distributions. https://statisticsbyjim.com/basics/probability-distributions/

Gupta, V., & Ivanov, D. (2020). Dual sourcing under supply disruption with risk-averse suppliers in the sharing economy [Article]. *International Journal of Production Research, 58*(1), 291-307. https://doi.org/10.1080/00207543.2019.1686189

Heung-Suk, H. (1999, 1999/10/01/). Inventory models for both deteriorating and ameliorating items. *Computers & Industrial Engineering, 37*(1), 257-260. https://doi.org/https://doi.org/10.1016/S0360-8352(99)00068-6

Holmbom, M., & Segerstedt, A. (2014). Economic Order Quantities in production: From Harris to Economic Lot Scheduling Problems [Article]. *International Journal of Production Economics, 155*, 82-90. https://doi.org/10.1016/j.ijpe.2014.03.024

Johnson, F., Leenders, M. R., & Flynn, A. E. (2011). *Purchasing and Supply Management* (14th ed.). McGraw-Hill. https://www.academia.edu/30813377/The_fourteenth_edition_of_Purchasing_and_Supply_Management_focuses_on

Keskin, G. A., Omurca, S. I., Aydin, N., & Ekinci, E. (2015, Oct). A comparative study of production-inventory model for determining effective production quantity and safety stock level. *Applied Mathematical Modelling, 39*(20), 6359-6374. https://doi.org/10.1016/j.apm.2015.01.037

Kim, A. (2019). *Gamma Distribution - Intuition, Derivation and Examples*. https://towardsdatascience.com/gamma-distribution-intuition-derivation-and-examples-55f407423840

King, P. L. (2011). Crack the code, Understandig safety stock and mastering its equations. https://web.mit.edu/2.810/www/files/readings/King_SafetyStock.pdf

Korponai, J., Tóth, Á. B., & Illés, B. (2015). The effect of the demand-changes on the inventories. Annals of DAAAM and Proceedings of the International DAAAM Symposium,

Kouvelis, P., & Li, J. (2012). Contingency Strategies in Managing Supply Systems with Uncertain Lead-Times [Article]. *Production & Operations Management, 21*(1), 161-176. https://doi.org/10.1111/j.1937-5956.2011.01252.x

Ma, D. (2016). Introducing the gamma distribution. https://actuarialmodelingtopics.wordpress.com/2016/04/03/introducing-the-gamma-distribution/

Mattsson, S. A. (2010, Sep). Inventory control in environments with seasonal demand. *Operations Management Research, 3*(3-4), 138-145. https://doi.org/10.1007/s12063-010-0035-1

Meijer, D. (2017). *Probability Theory for Engineers*. https://wwwhome.ewi.utwente.nl/~meijertmj/opgaven3/ReaderProb.pdf

Mirzaee, A. (2017). *Alternative methods for calculating optimal safety stock levels* University of Missouri-Columbia]. https://pdfs.semanticscholar.org/6ad9/2c711c29618c572b5c2d0fe639b55673c2cb.pdf

Mun, J. (2015, 05/11). Understanding and Interpreting S-Curves and CDF Curves (4P).

Ng, P. S., & Zhang, F. (2016). An Improved Hybrid Model for Order Quantity Allocation and Supplier Risk Exposure. *International Journal of Fuzzy System Applications, 5*(3), 120-147. https://doi.org/10.4018/ijfsa.2016070107

Rouse, M. (2017, March 2017). *Dual sourcing*. https://searcherp.techtarget.com/definition/dual-sourcing

Rumyantsev, S., & Netessine, S. (2007). What can be learned from classical inventory models? A cross-industry exploratory investigation [Article]. *Manufacturing and Service Operations Management, 9*(4), 409-429. https://doi.org/10.1287/msom.1070.0166

Sajadieh, M. S., & Eshghi, K. (2009, 2009/12/01/). Sole versus dual sourcing under order dependent lead times and prices. *Computers & Operations Research, 36*(12), 3272-3280. https://doi.org/https://doi.org/10.1016/j.cor.2009.03.001

Taylor, B. W. (2006). *Introduction to Management Science* (10 ed.). https://flylib.com/books/en/3.287.1.224/1/

Vaqari, A. (2020). *Total Cost of Ownership (TCO) – The 3 Key Components*. https://www.purchasing-procurement-center.com/total-cost-of-ownership.html

Vernimmen, B., Dullaert, W., Willeme, P., & Witlox, F. (2008, Sep). Using the inventory-theoretic framework to determine cost-minimizing supply strategies in a stochastic setting. *International Journal of Production Economics, 115*(1), 248-259. https://doi.org/10.1016/j.ijpe.2008.05.015

Wang, P., Zinn, W., & Croxton, K. L. (2010). Sizing Inventory When Lead Time and Demand are Correlated [Article]. *Production & Operations Management, 19*(4), 480-484. https://doi.org/10.1111/j.1937-5956.2009.01109.x

What Is the Difference Between Weft and Warp? (2014). https://www.reference.com/world-view/difference-between-weft-warp-f99c925cdabed904

Willemain, T. (2019). *Top 3 Most Common Inventory Control Policies*. https://smartcorp.com/b-policy/inventory-control-policies-software/

Appendix

A. Systematic literature review

Table 8: Exclusion criteria

Number	Criteria	Reason for exclusion
1	Non company related sources	For this research, we are only interested in safety stocks that are related to companies
2	Main focus of the source is on production	The stock and order process is more interesting for this research
3	Source is not relevant to uncertainty	For this research, it is more interesting to look at sources that take uncertain demand and/or lead time in account
4	Source has a focus on limitations that are not interesting for this research e.g. order size constraints	Things like order size constraints are not issues for this research

Table 9: Search protocol Scopus

Search string	Scope	Date range	Number of entries
"Safety stock" AND "reorder level"	Title, keywords and abstract	All dates	16
"Safety stock" AND "economic order quantity"	Title, keywords and abstract	All dates	49
"Safety stock" AND unpredictable	Title, keywords and abstract	All dates	9
"Safety stock" AND model AND excel	Title, keywords and abstract	All dates	3
"Safety stock" AND "long lead time"	Title, keywords and abstract	All dates	10

Table 10: Search protocol Web of Science

Search string	Scope	Date range	Number of entries
Safety stock AND reorder level	Title, keywords and abstract	All dates	51
Safety stock AND economic order quantity	Title, keywords and abstract	All dates	37
Safety stock AND unpredictable	Title, keywords and abstract	All dates	7
Safety stock AND model AND excel	Title, keywords and abstract	All dates	6
Safety stock AND long lead time	Title, keywords and abstract	All dates	49

Table 11: Search protocol Business Source Elite

Search string	Scope	Date range	Number of entries
Safety stock AND reorder level	Title, keywords and abstract	All dates	11
Safety stock AND economic order quantity	Title, keywords and abstract	All dates	22
Safety stock AND unpredictable	Title, keywords and abstract	All dates	4
Safety stock AND model AND excel	Title, keywords and abstract	All dates	4
Safety stock AND long lead time	Title, keywords and abstract	All dates	12

Table 12: Selection for review

Total in EndNote	**290**
Removing duplicates	-73
Removing non company related sources based on keywords and abstract	-39
Removing sources with a focus on production	-26
Removing sources that are not relevant to uncertainty	-108
Removing sources with a focus on limitations that are not interesting for the research	-21
Removed after complete reading	-12
Total selected for review	**11**

Table 13: Conceptual matrix

Articles	**Concepts**						
	Safety stock	Reorder level	Economic order quantity	Unpredictable	Model	Excel	Long lead time
Babai and Dallery (2006)	X	X		X			X
Braglia et al. (2013)	X	X	X	X	X		
Chopra et al. (2004)	X	X		X			X
Digiesi et al. (2013a)	X	X	X	X			X
Digiesi et al. (2013b)	X	X	X	X	X		
Keskin et al. (2015)	X	X		X	X		
Korponai et al. (2015)	X		X	X	X		
Kouvelis and Li (2012)	X			X	X		X
Mattsson (2010)	X	X	X	X	X	X	X
Vernimmen et al. (2008)	X	X		X	X		X
Wang et al. (2010)	X	X		X			X

Table 14: Conceptual matrix with content

Journal / series	Title	Author(s) (year)	Operationalization	Key findings
2006 International Conference on Service Systems and Service Management, Vols 1 and 2, Proceedings	A dynamic inventory control policy under demand, yield and lead time uncertainties	M. Z. Babai & Y. Dallery (2006)	Determining reorder policy with demand and lead time uncertainties	With the cycle service level and a sequential approach, the reorder policy can be computed. Even when the demand and lead time are uncertain can this be used.
International Journal of Production Research	Stock diffusion theory: a dynamic model for inventory control	M. Braglia, R. Gabbrielli & F. Zammori (2013)	Stock Diffusion Theory and Markov process, a mathematical model for inventory management	The model presented in this article can be used even if the demand pattern isn't exactly known and the demand is not stationary.
Decision Sciences	The effect of lead time uncertainty on safety stock	S. Chopra, G. Reinhardt & M. Dada (2004)	Influence of standard deviation of lead time on safety stock considerations	Demand uncertainty, replenishment lead time and lead time uncertainty are the three main components that affect safety stock. Also examples are shown about the difference between normal approximation and the exact value of safety stocks.
Management and Production Engineering Review	Supply lead time uncertainty in a sustainable order quantity inventory model	S. Digiesi, G. Mossa & G. Mummolo (2013)	Sustainable order quantity (SOQ) and economic order quantity (EOQ) with lead time uncertainty	When the lead time is uncertain, more relaxed logistics could be more effective than just-in-time logistics. In this article is also the SOQ and EOQ defined in case of stochastic variability of supply lead time.
IFAC Proceedings Volumes (IFAC-PapersOnline)	A sustainable order quantity model under uncertain product demand	S. Digiesi, G. Mossa & G. Mummolo (2013)	SOQ and EOQ and their relation with the safety stock	Transport and safety stock costs affect the best options for order/lot sizes. The sizing of safety stock is carried out with the trade-off between shortage costs and holding costs.

Applied Mathematical Modelling	A comparative study of production-inventory model for determining effective production quantity and safety stock level	G. A. Keskin, S. I. Omurca, N. Aydin & E. Ekinci (2015)	Mathematical programming to determine stock levels considering constraints	This article shows an algorithm that takes multiple parameters in account to solve supply chain management problems efficiently. This is used to determine ideal stock levels.
Annals of DAAAM and Proceedings of the International DAAAM Symposium	The effect of the demand-changes on the inventories	J. Korponai, Á. B. Tóth & B. Illés (2015)	Relationship between deterministic and stochastic changes of demands and stock levels	A target stock level can be reached by decreasing uncertainty and fluctuations with a more accurate forecast and increasing the safety stocks to cover these fluctuating demands
Production & Operations Management	Contingency Strategies in Managing Supply Systems with Uncertain Lead-Times	P. Kouvelis & J. Li (2012)	Ex-ante planning for disruption safety stock (DSS) and ex-post dynamic emergency response (DER)	A decreased DSS means that the cost of shortages are reduced but an increased DSS results in higher holding costs. An DER decides dynamically when an emergency order has to be placed.
Operations Management Research	Inventory control in environments with seasonal demand	S. A. Mattsson (2010)	The impact of seasonal variations on the order sizes and the stock quantities	The consideration of using seasonal variations in your calculations is not always the same. If the seasonal variations are not big, a fixed economic order quantity can be as cost efficient as taking this variation in consideration.
International Journal of Production Economics	Using the inventory-theoretic framework to determine cost-minimizing supply strategies in a	B. Vernimmen, W. Dullaert, P. Willeme & F. Witlox (2008)	Demand during lead time (DDLT) and the corresponding distributions	Higher average lead times result in more normally distributed DDLT, as a consequence of the Central Limit Theorem. Assuming the normal distribution for DDLT is not always correct.

	stochastic setting			
Production & Operations Management	Sizing Inventory When Lead Time and Demand are Correlated	P. Wang, W. Zinn & K. L. Croxton (2010)	The correlation between lead time and demand and their relation to inventory level calculations	This article shows formulas to compute average and variability of demand when lead time and demand are correlated. This way, it's possible to calculate acceptable stock levels.

B. Table CSL

Table 15: CSL

Desired CSL	**95%**	**96%**	**97%**	**98%**	**99%**
Woven A	0,97572	0,9834	0,987	0,99037	0,99673
Woven B	0,97362	0,98644	0,99402	0,99515	0,99547
Woven C	0,95438	0,98248	0,999218	0,999885	0,9999873
Woven D	0,96505	0,97895	0,98687	0,99836	0,99964
Woven E	0,99175	0,99572	0,99793	0,99823	0,99932
Woven F	0,96829	0,98374	0,99522	0,99896	0,99947
Woven G	0,97871	0,98253	0,98311	0,98332	0,9942
Woven H	0,94023	0,95406	0,96992	0,99273	0,99855

C. Advice CSL

The percentages in the tables show how much the reorder levels will increase when a higher CSL is chosen for a specific woven. For all four purchasing options, it is shown how these reorder levels change. An example: The reorder level of purchasing Woven A in Europe while the supplier has the materials in stock will increase with 5,2% percent when a CSL of 96% is used instead of a CSL of 95%.

Table 16: Increase reorder levels woven A

Woven A	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	5,2%	3,0%	3,5%	11,1%
Europe (materials are not in stock)	4,6%	2,7%	3,1%	9,9%
Asia (materials are in stock)	4,3%	2,5%	2,9%	9,4%
Asia (materials are not in stock)	3,9%	2,3%	2,7%	8,6%

I would recommend using a CSL of 98% for Woven A because the difference between the reorder levels of 95% and 98% isn't that big. Woven A is a woven that has a decent amount of sales so I would recommend choosing for 98% in this case. I wouldn't recommend 99% because the difference between 98% and 99% is considerably bigger and I don't think that this difference is worth it.

Table 17: Increase reorder levels woven B

Woven B	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	9,1%	9,3%	2,0%	0,6%
Europe (materials are not in stock)	8,1%	8,3%	1,8%	0,6%
Asia (materials are in stock)	7,6%	7,8%	1,7%	0,6%
Asia (materials are not in stock)	6,9%	7,2%	1,6%	0,5%

For Woven B, I would recommend to use a CSL of 99% because Woven B is the woven that is sold the most. It is important to keep the availability of this woven as high as possible. I wouldn't recommend using 97% and 98% because the difference between 97% and 99% is small. If you want to use 97% or 98%, you might as well use 99%.

Table 18: Increase reorder levels woven C

Woven C	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	20,2%	42,2%	14,7%	13,0%
Europe (materials are not in stock)	18,9%	40,0%	14,1%	12,5%
Asia (materials are in stock)	18,2%	38,7%	13,8%	12,3%
Asia (materials are not in stock)	17,2%	37,0%	13,3%	11,9%

I would recommend using a CSL of 95% for Woven C because the differences between the reorder levels of the different CSLs are very high. I wouldn't recommend using a CSL higher than 96% because the reorder levels will be increased by approximately 40% when a CSL of 97% is used. I don't think that's worth it for a product with relatively low sales.

Table 19: Increase reorder levels woven D

Woven D	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	9,7%	7,6%	26,8%	13,0%
Europe (materials are not in stock)	9,1%	7,2%	25,3%	12,4%
Asia (materials are in stock)	8,7%	6,9%	24,4%	12,1%
Asia (materials are not in stock)	8,2%	6,5%	23,3%	11,6%

A CSL of 97% is recommended for Woven D because the increase to 98% and 99% is really high. It is budgeted that the sales of Woven D will increase this year compared to other years so that's why I decided to recommend 97% instead of 95% and 96%.

Table 20: Increase reorder levels woven E

Woven E	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	8,2%	7,8%	1,5%	8,5%
Europe (materials are not in stock)	7,8%	7,4%	1,4%	8,2%
Asia (materials are in stock)	7,5%	7,2%	1,4%	7,9%
Asia (materials are not in stock)	7,2%	6,9%	1,3%	7,7%

For Woven E, I would recommend to use a CSL of 95% because it is assumed that the sales of Woven E will be 0 this year so I think that it isn't necessary to work with the highest CSLs for this woven. If I had to say which CSL I wouldn't recommend in this case, it would be 97% because then you might as well choose 98% with that little difference.

Table 21: Increase reorder levels woven F

Woven F	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	11,3%	16,4%	15,1%	5,3%
Europe (materials are not in stock)	10,4%	15,1%	14,1%	5,0%
Asia (materials are in stock)	9,9%	14,4%	13,6%	4,8%
Asia (materials are not in stock)	9,2%	13,6%	12,8%	4,6%

I would recommend a CSL of 96% for Woven F because Woven F has a decent amount of sales so I would recommend 96% over 95%. The CSL that I wouldn't recommend in this case is 98% because the difference isn't too big compared to a CSL of 99%.

Table 22: Increase reorder levels woven G

Woven G	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	3,1%	0,5%	0,2%	14,4%
Europe (materials are not in stock)	2,8%	0,5%	0,2%	13,4%
Asia (materials are in stock)	2,7%	0,4%	0,2%	12,8%
Asia (materials are not in stock)	2,5%	0,4%	0,2%	12,0%

A CSL of 98% is recommended for Woven G because the differences between 95% and 98% aren't that big. I wouldn't recommend 96% and 97% because the differences are very small compared to 98%. I also wouldn't recommend 99% because the difference is significantly bigger than the other CSLs and I don't think it is necessary for this woven.

Table 23: Increase reorder levels woven H

Woven H	**95% -> 96%**	**96% -> 97%**	**97% -> 98%**	**98% -> 99%**
Europe (materials are in stock)	5,1%	7,3%	19,8%	15,7%
Europe (materials are not in stock)	4,5%	6,5%	17,6%	14,2%
Asia (materials are in stock)	4,2%	6,0%	16,5%	13,4%
Asia (materials are not in stock)	3,8%	5,5%	15,1%	12,5%

For the last woven, Woven H, I would recommend to use a CSL of 97% because after 97%, the reorder levels are increasing a lot more than before 97%. This is the reason why I won't recommend using 98% or 99% for Woven H.