IMPROVING THE DELIVERY RELIABILITY AT COMPANY X

BSc Industrial Engineering and Management

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PREFACE

Dear reader,

This research has been taking up an important part of my life in the past year. Being able to contribute and apply the acquired knowledge during my bachelor's has resulted in satisfying results. Working together with people from different backgrounds was fun and educational. There were some bumps along the way in my private life. This, however, did not compromise the quality of this document. Looking back, it has been an incredible adventure that has now been completed.

The help and support from my University of Twente supervisors Dennis and Sebastian has played a key part in the successful completion of this research. The detailed feedback and interesting discussions have increased the quality of this assignment. For this, I would like to thank them deeply. Also, my Company X supervisors and colleagues, in particular, Supervisors X and Colleagues X certainly deserve acknowledgment. Thank you for teaching me lessons that are not covered in university. The interviews with Company X Group colleagues X have given further insights into the organization for which I want to thank them as well. Iris, Josefien, and Yur, my peers at the University of Twente, have also provided useful contributions to this document.

Finally, I want to thank any other who has helped me along the way, because of you this report has become a success!

Camiel IJpma

MANAGEMENT SUMMARY

This research is conducted at Company X as a graduation assignment for the Bachelor Industrial Engineering and Management at the University of Twente. Company X is a multinational company, originating from Country X, and operates in more than 20 countries. The company offers a wide range of paints and coatings for Customers X. Company X is located in City X and is part of the Company X Group. In 2022, the net sales of the group were approximately €X.

We focus on the Dutch location, Company X B.V., where problems with delivering products reliably have occurred. This results in a decrease in customer satisfaction. Customers have therefore diverted to other paint suppliers, resulting in a reduction in sales. We define delivery reliability as the fraction of on-time order lines from Company X to its customers. Customer order lines represent individual products within a customer's order, providing detailed information for our research. The average delivery reliability is 91%, by looking at the customer order lines from January 2020 to March 2023. We investigate the effects of optimizing the tinting policy and stock levels on this delivery reliability while limiting the increase in overall inventory value.

Company X orders a product from the manufacturing site either ready-made or as a base paint (tinted). Ready-made means that the product is colored at the manufacturing facility. Tinted means that the product is ordered as a base product and tinted in-house (in City X), using colorants. The advantage of tinting in-house is that the point of customization is postponed. In this way, demand is aggregated which results in several advantages. Tinted is, however, not always the best choice since several other variables influence the decision. In this research, we designed a Ready-made or Tinted Decision Model (RTDM) that guides the decision of whether to tint in-house or to order the product ready-made. The advantages of aggregating demand are considered, but other input values like the desired cycle service level, holding cost, order placement cost, lead time, and particularly, the additional cost of tinting in-house are also considered. The tinting decision with the lowest total cost is eventually the decision that we take.

The outcome of the model is that the holding and ordering costs are lower for products that are tinted in-house. At the same time, the cost of the product itself plays a substantial part in the cheapest solution. Typically, 90% of the total costs lie in the cost of the product itself, according to our model. Therefore, the reduction in ordering and holding costs only influences the tinting decision if product costs are somewhat similar. The product cost for tinted items is the base paint + 25% in-house tinting cost. In some cases, the base paint excluding this 25% is currently as expensive as the ready-made. According to the model, it is unlikely that tinting in-house will then be the cheapest solution. However, if product costs (including the 25% tinting fee for tinted) are similar, the model shows that tinted becomes more interesting because of the aggregation advantages. In our generated data, the advantage of aggregation is 7% of the total cost. Within a group of products, the user can investigate which product should be kept ready-made, and which should be tinted in-house. This is done by ranking them according to the average weekly total cost per liter. Optimizing the policy of tinting using the RTDM

reduces the overall inventory cost for the same desired CSL. Therefore, using this policy, the delivery reliability can increase at Company X while the increase in overall average inventory value is limited.

Recommendations (for further research) for Company X include applying the RTDM across the whole organization. Moreover, one could automatically generate the input values, by linking it to the preferred Business Intelligence tool. This would increase the correctness of the model. Finally, we would suggest to cooperate across the entire supply chain. The cheapest tinting decision for a product for Company X might not be the most cost-effective solution for that product for the entire supply chain. Upstream, we for example have production-related costs that could influence the decision. Costs that we currently ignore further down the supply chain are costs of complaints, quality, and returns. These could also impact the decision and cooperation would help to minimize these costs.

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LIST OF ABBREVIATIONS

An industry-specific list of abbreviations:

RTDM = Ready-made or Tinted Decision Model
ITP = Internal Transfer Price
KOMO = “Keuring en Onderzoek van Materialen voor Openbare werken”
= Inspection and Examination of Materials for Public Works
RM = Ready-made
T = Tinted
IBC = Intermediate Bulk Container
SKU = Stock Keeping Unit
SLOB = Slow Moving and Obsolete

1. INTRODUCTION

This thesis is written to finalize the Bachelor Industrial Engineering and Management at the University of Twente. The research is conducted at and aimed for Company X which is part of the Company X Group.

1.1. Company description

Company X is a multinational company originating from Country X. Company X offers a wide range of paints and coatings for Customers X. Coatings for wood, metal, plastic, and minerals are part of their portfolio. The company is operating in more than 20 countries, employing approximately 1,500 people. Company X was established in Year X and is currently one of Country X's largest family-owned businesses. In 2022, the net sales of the company were approximately €X (Company X Group, 2023).

Company X is located in City X and is part of the Company X Group. In 2016, the Country X paint manufacturer acquired Company Y. This painting company had experience in the production of water-based paints, stains, and varnishes. Existing products, product names, and client contracts of Company Y stayed the same (Source X, 2016). The growth potential of the Benelux region was the main reason for Company X to acquire Company Y.

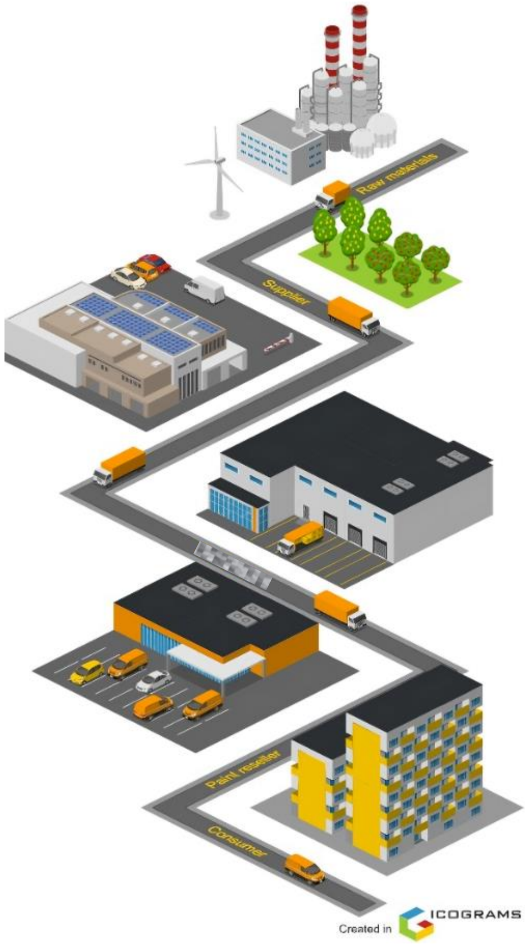
In 2020, the decision was made to transfer the production facility in the Netherlands to its sister companies in Country X and Country Y, where larger and more advanced production facilities were available. As a consequence of the production transfer, seven employees had to be let go (AuthorX, 2020). Company X in the Netherlands shifted because of this from a so-called production country to a sales country. From April 2021 onwards, the production was handed over to the Company X factories. This change meant that Company X became more dependent on these production facilities which added more complexity to the supply chain.

GENERIC STRATEGY

Company X is an organization that applies the Differentiation strategy which is one of Porter's Generic Strategies (Porter, 1985). Company X has products that are unique and of higher quality than those of competitors. An example of this strategy is the KOMO certificate which applies to a large range of Company X products. This is a very important certificate that is difficult to achieve and maintain. Limited coating producers have acquired these certificates. The requirements for a KOMO certificate have been determined independently. Moreover, quality is being monitored by independent experts who continuously conduct objective research. This makes KOMO not just any certificate. Because of the premium price point, customers expect high-quality products, service, and reliable deliveries.

1.2. Company context

In this section, we provide more details on the relevant context to understand the research problem. We start with the supply chain.



1.2.1. SUPPLY CHAIN OVERVIEW

In Figure 1, a visualization of the supply chain is given. Raw materials are ordered by the manufacturing sites of Company X. The manufacturing sites are the only suppliers of Company X, conversely, Company X is one of these suppliers' customers. An internal transfer price (ITP) system is used for pricing the products within Company X, primarily to comply with tax legislation. Within Company X, the ITP is the cost of raw materials, packaging materials, and labor costs, with a margin that results in a 4% to 5% EBIT for internal sales. For Country X and Country Y, this margin is 33% and 38%, respectively. Once the products have arrived in the Netherlands, they will be put on stock and possibly tinted. After this, the products will be transported to Company X's customers.

1.2.2. CUSTOMERS

Most customers of Company X are located in the Benelux region. The office and warehouse are located in City X. Most of the products are sold to the manufacturing industry and paint resellers. Problems with delivering products reliably have occurred over time. This results in a decrease in customer satisfaction. Customers have therefore diverted to other paint suppliers, resulting in a reduction in sales. Increasing delivery reliability would result in a better financial situation for Company X. From January 2020 up and until March 2023, the delivery reliability of customer order lines from the Dutch warehouse to the customers has been 91%. Here, customer order lines represent individual products within a customer's order, providing detailed information for our research. The low delivery reliability, together with long lead times, causes customers to leave Company X and look for alternative sources. More information concerning delivery reliability is given in Chapter 2.

1.2.3. SUPPLIERS

Company X closed its paint production facility in April 2021. This meant that lead times and lead time uncertainty increased, which harmed customer satisfaction and delivery reliability. However, this was a management decision that will not be undone. It would be too costly to move the production facility back to the Netherlands and therefore this option is left out of consideration in this research. Company X needs to order its products from other manufacturing sister companies. Figure 2 shows that Company X in Country X and Country Y are the largest suppliers of Company X B.V. We focus on these countries since they represent more than 97% of all goods bought internally by the Netherlands. The Country Y factory, located in City Y, is one of the main reasons for the low delivery reliability from Company X. There is a backlog of products, which makes it hard to fulfill orders on time. Company X has to deal with this situation. The problems in Country Y cannot be controlled by the Netherlands. The effect of this is that the lead time is 25 days or more, which is not acceptable from a commercial point of view according to the Sales Director at Company X. Fixing these problems in City Y lies outside the scope of this thesis.

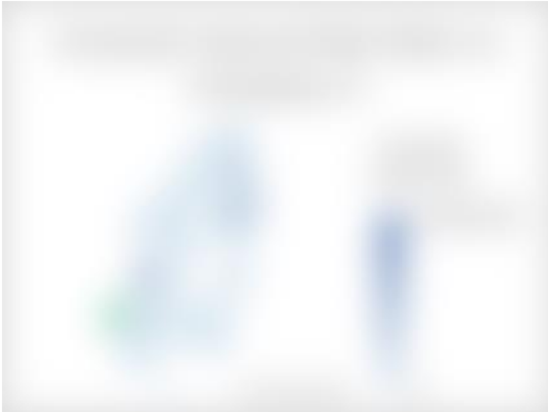


Figure 2 Invoiced internal Net Sales to Company X (January 2020 - March 2023)

However, lead time is an important factor influencing (safety) stock levels. To get insights into this, it is important to get an overview of how lead times are affected and what the impact is on Company X. A further analysis on this can be found in Chapter 2.

1.2.4. COMPOSITION OF PAINT

For a full context of the situation, it is crucial to learn more about the operations at Company X. An important task is the process of coloring (tinting) paint. To tint a product, we need a base and colorant(s). Every end product consists of a different type of base paint. Adding coloring paste to this base will result in the tinted product. For this part, interviews have been performed with the commercial portfolio manager and the color matching specialist at Company X.

Base paint

The base paint is the most important constituent of paint. It is the end-product without colorant. The volume of the desired end product is mostly base paint. A base paint consists of binders, solvents, and additives. Binders are used for their adhesive characteristics, holding the paint together. Solvents in paint are added to dissolve the other ingredients. Additives are used to include additional characteristics to the paint. The protective, adhesive, and elastic characteristics of the end-product paint are mostly determined by the base paint. For the product "Product Y", which is a metal paint, there are two options available. One would be BASE PAINT 3, the other WHITE BASE PAINT 1. So the combination of the product, together with the

Figure 3 Visualization of base paint and colorant

option leads to a unique option for tinting. We call this the base paint. Not all colors can be made with the PRODUCT Y BASE PAINT 3, this is also the case for the PRODUCT Y WHITE BASE PAINT 1. However, all available colors can be made using either the first or the second product. Some products have only one option, while others have many.

Colorant

Another key characteristic of paint is that it is decorative. This is partly determined by the color of the paint. A colorant is added to the base paint to create the desired color. The amount of colorant that needs to be added to a liter can ranges from 2.5 ml to 150 ml. Company X has designed a set of rules per tinting group in which the amount of colorant needs to be such that the characteristics of the end product will not deviate. Characteristics such as drying time and adhesion could be negatively influenced if the volume of colorants lies outside the advised range.

Tinting systems

Company X makes use of four tinting systems: X, Y, Z, and A. X is only used for Product Z products and this system will slowly be phased out. Y, Z, and A are group coloring systems, meaning that these are used throughout the whole company. Unlike X, which is only used in the Netherlands. Y can be used for water-based paints. A for solvent-based paints. Z could be used for both, this system is mostly used for the industrial products which Company X offers. A tinting system consists of multiple coloring pastes.

Table 1 Characteristics of tinting systems

Tinting system	Number of colorants	Number of base paints
X	23	49
Y	19	220
Z	14	143
A	18	36
Total	74	448

Company X makes use of both 16 and 32-canister tinting machines, meaning that a maximum of two tinting systems can be used per machine.

1.2.5. PROCESS OF TINTING: READY-MADE AND TINTED PRODUCTS

In Figure 4, an overview of the process of both ready-made and tinted products can be found. Differences between both can be identified using this diagram.

Ready-made products are tinted at suppliers. Company X can choose from an infinite number of colors. A color is ordered and this particular color will be manufactured and transported to the Netherlands. Then, the product is either put on stock or transported to the customer of Company X.

Tinted products are tinted at Company X in the Netherlands. Company X can choose from many base paints. There are currently 448 active (available for order). Next to this, 74 colorants could be ordered. These base paints and colorants are either put on stock or tinted into the desired color (infinitely many options) such that they can be transported to the customer of Company X.

Although it is possible to tint the products in infinitely many colors, this is not done. A limited number of colors are available for sale.

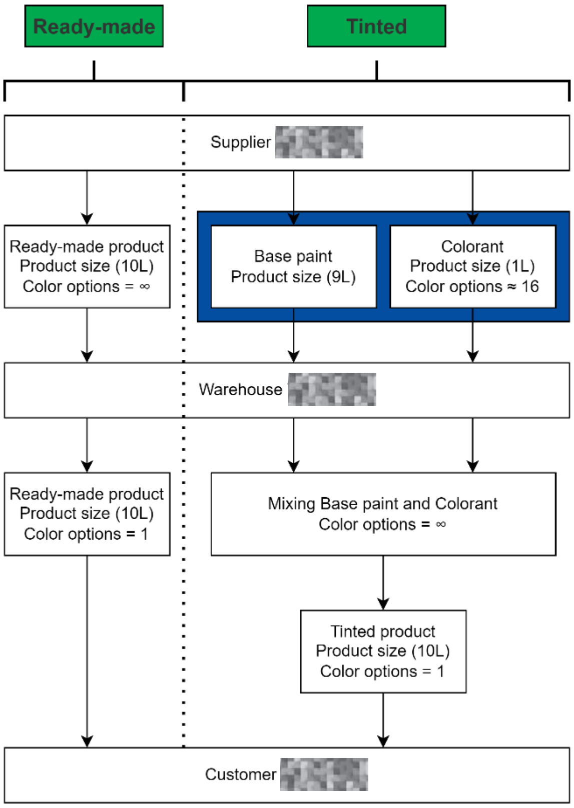


Figure 4 Process of ready-made and tinted products

1.2.6. INVENTORY POLICY

The inventory policy is the set of guidelines that manages inventory and replenishment decisions. The adjustment of the inventory policy affects delivery reliability. In the following, two different adjustments are discussed which are interesting for this thesis project.

Stock levels

Increasing stock for certain products will increase delivery reliability. However, carrying costs will increase as well. These are the costs associated with keeping inventory. The current value of inventory lies between €1.5 and €1.6 million; this monetary value cannot be used for other projects and is therefore not desired to be increased unnecessarily. Also, the number of obsolete products (1.5% in 2022) should not increase but preferably decrease. However, it is sometimes justified to increase stock levels. This depends on the effect that it has on the delivery reliability. Colorants are for example important to keep in stock since a lot of end-products depend on them. But at the same time, costs should not skyrocket. It would be highly valuable for Company X to find a way to increase delivery reliability, using a model, while keeping the same inventory value by optimizing stock levels.

Improving forecasting is not an explicit topic of this research. However, estimates of demand are needed to determine what the desired stock levels are. For this, parameters, based on the data that is available, are determined. This demand information is used to further analyze and improve inventory management.

Tinting

To improve delivery reliability and reduce inventory costs, more tinting could be done in-house. As explained, paints at Company X are either ready-made or tinted. Tinting improves flexibility since a large number of paints and coatings can be made using a smaller number of ingredients. Moreover, reducing the number of ready-made paints that need to be put on stock can reduce inventory costs. Unsold ready-made products can namely often not be sold to other customers because they are already pre-made in a particular color. Tinted items are colored on demand whenever an order is received, which means that the customization point is postponed. A disadvantage of tinting is that for large batches the use of coloring pastes often becomes more expensive than the use of ready-made products. Also, it would require more time from the warehouse personnel in City X since tinting requires additional handling and therefore takes more time. A further analysis of the effect of tinting on delivery reliability can be found in Chapter 2.

1.3. Identification of core problem

This section discusses the core problem identification. An identified core problem lets us work toward a solution. We start with the action problem.

1.3.1. ACTION PROBLEM

The action problem as described by Company X is that some customers have stopped buying due to products not being delivered on time. According to the Benelux Sales Director, around €1.5 million of annual sales has been lost because of low delivery reliability. If products are delivered on time, then sales could potentially increase by 15%. But, it is important to also take the stock levels into account. High stock levels lead to increased inventory carrying costs, which could decrease the product margin. Additionally, there is the risk of obsolescence when the expiration date is exceeded.

The delivery reliability is calculated in the following way:

$$Delivery\ reliability = \frac{Number\ of\ order\ lines\ delivered\ on\ time\ in\ full}{Total\ number\ of\ order\ lines} \times 100\% \quad \text{Eq. 1}$$

Remarks:

- *Delivery time from Company X to its customers is one day.*
- *Cancelled order lines are not on time*

The target delivery reliability is 96%. This has been defined by the Company X Group. However, the current percentage is lower. The current delivery reliability is 91% if we look at the customer order lines from January 2020 to March 2023 from Company X B.V. to all its customers.

1.3.2. PROBLEM CLUSTER

The following problem cluster is made to show a schematic overview of the identification of the core problem:

The focus of this research will be on optimizing the policy of ordering paints ready-made or tinted. Optimizing this has a positive effect on the delivery reliability to customers of Company X The low delivery reliability results in unsatisfied customers, leading to a decrease in customers and thus declining sales. Together with overstocking some items, which results in higher carrying costs and thus high COGS, this leads to a decrease in profit.

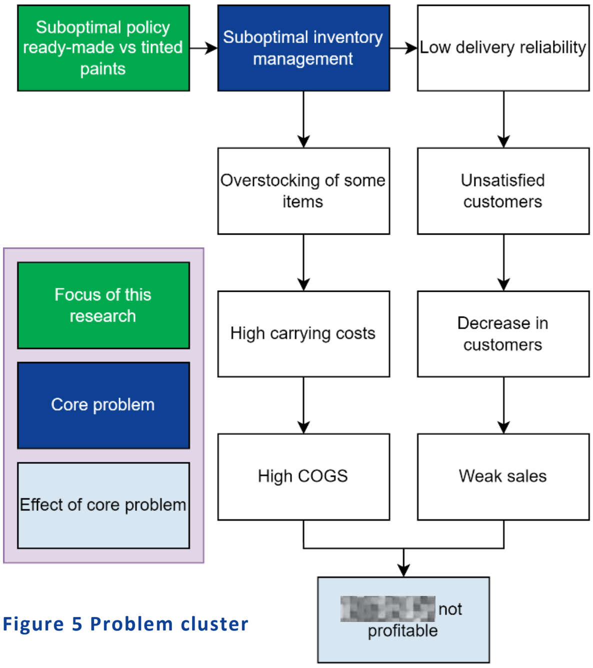


Figure 5 Problem cluster

1.3.3. CORE PROBLEM

The core problem is: “How to increase the delivery reliability from Company X B.V. to its customers from 91% while limiting the increase in the overall average inventory value.”

1.3.4. NORM AND REALITY

It is unrealistic to currently set the Company X group target percentage of 96% delivery reliability on average for all customers of Company X B.V. as the norm for this research. This would namely result in a significant increase in the overall average inventory value. Therefore, Company X should be able to see what an increased budget for the overall average inventory value of a product could mean for its delivery reliability. For this, we use the model that calculates the most cost-effective decision for ordering products ready-made or tinted. For all customers, the delivery reliability is 91% on average (from January 2020 up and until March 2023). It is important to keep the lead time in mind. This plays a key role in the current poor delivery reliability. The lead time is a bit more than 7.5 days on average, with a standard deviation of 14.2 days. Customer satisfaction, and eventually sales, are also influenced by this. Moreover, the required stock levels increase with a decrease in desired lead time. The norm would be to deliver within a week. A further analysis can be found in Chapter 2.

1.4. Problem-solving approach

This problem-solving approach consists of research questions that provide the structure and procedure to come to a solution. The main research question is: How to increase the delivery reliability from Company X to its customers while limiting the increase in the overall average inventory value by looking at ready-made and tinted products and their corresponding stock?

1.4.1. CURRENT SITUATION

It is crucial to get a clear picture of the current situation. Identifying the current state of the delivery reliability and ordering products ready-made or tinted, together with their stock levels, is covered in Chapter 2.

What is the current delivery reliability and lead time from Company X B.V. to its customers?

We start by looking into the delivery reliability and lead time data such that an accurate picture can be made of the magnitude of the problems. This results in more information about when and why it goes wrong.

What is the current decision-making policy of ordering products ready-made or tinted?

An overview of factors that influence and eventually determine the decision to order ready-made or tinted is presented in this part. This helps us understand the reasons why this choice is made. Variables like demand and costs are covered in Chapter 2. This is needed for the model that aims to increase delivery reliability.

What are the stock levels of ready-made and tinted products?

The availability of products plays an important role in delivery reliability. Therefore, the current stock levels and value of ready-made and tinted products are displayed also in Chapter 2. This shows us what the current division of the inventory is.

What are the effects of ready-made and tinted products on delivery reliability?

Identifying what the effects of ready-made and tinted products are on delivery reliability is finally discussed in Chapter 2. Improvements in delivery reliability are made when the effects are known.

1.4.2. LITERATURE REVIEW

The literature review is used to acquire knowledge from the literature to solve the problem. This framework aims to gather useful academic knowledge to find a solution for Company X.

What is the effect of inventory pooling on delivery reliability?

The effect of tinting products instead of ordering them ready-made is that we consolidate/pool/centralize/aggregate inventory. This is called inventory pooling and its effect on delivery reliability is investigated in Chapter 3.

Which variables can influence the decision to order products ready-made or tinted?

Determining variables that influence the decision to order products ready-made or tinted are also covered in Chapter 3. These variables are used for the solution design (Chapter 4).

How can the economic order quantity and reorder point for ready-made and tinted products be determined?

An investigation of the approach to determine which order quantities and reorder points are best for ready-made and tinted products is finally done in Chapter 3. This policy results in average stock levels.

1.4.3. SOLUTION DESIGN

In Chapter 4, the reviewed literature is applied to create a model. This model is designed to increase delivery reliability while limiting the increase in overall average inventory value. The model aims to realistically depict the inventory process at Company X.

How to implement the variables that influence the decision of ordering products ready-made or tinted into a model?

The structure of the model is determined by the variables that influence the decision to order products ready-made or tinted. The implementation of this is discussed in Chapter 4.

How to implement the reorder point, economic order quantity, and safety stock for ready-made and tinted products into a model?

To accurately display the inventory process, reorder points and order quantities need to be calculated, resulting in an average stock level. This, and the implementation of it in the existing structure, is done in Chapter 4 as well.

1.4.4. RESULTS

The goal of this research is to increase delivery reliability as an effect of using the designed solution. Ordering policies and stock levels are attached to products using the defined variables.

What new suggestion for ready-made or tinted is made and how does it compare to the current situation?

Based on the calculations of the model, new suggestions for either ready-made or tinted are made. A comparison between both is described in Chapter 5.

What delivery reliability comes with which inventory costs?

This model shows which products should be either ready-made or tinted, what their stock levels are, and what the delivery reliability is from Company X to its customers. Finally, an investigation is done about what delivery reliability comes with which costs.

1.4.5. CONCLUSION

In the conclusion, we address the main points from this research. We moreover evaluate and discuss the gained knowledge.

What are the main conclusions from our model?

We work towards conclusions, based on the results that we gathered. The main conclusions let us understand what the key findings were.

What are the assumptions that have been made and the limitations of the proposed model?

Assumptions and limitations of the model are present since it is impossible to create a model that exactly meets reality. These assumptions and limitations are defined in Chapter 6 such that the management of the organization knows this.

What suggestions for further research do we have?

We are not able to fully research our topic. So, we finally mention the suggestions that we have for further research.

Together, these research questions provide the steps to follow to solve the problem. This problem-solving approach shows the main trajectory and structure of this research.

1.4.6. DELIVERABLE

The deliverable is a model in Excel that calculates the decisions to be made in inventory management. More specifically, a model that calculates the cheapest decision for whether a product should be ready-made or tinted. Furthermore, we calculate the reorder levels, economic order quantities, and safety stock for these products, staying closely to current practices and making minor adjustments to ensure a streamlined timeline. The deliverable aims to improve delivery reliability while limiting the increase in overall average inventory value. The tool uses several variables to determine the correct choice. Several scenarios can be chosen such that the model represents reality as accurately as possible.

Input variables:

- Cost information
  - Base product
  - Tinting
  - Ready-made product
- Demand characteristics
- Lead time characteristics
- Desired cycle service level
- Holding cost
- Order placement cost

Output variables:

- Cheapest ordering decision (ready-made or tinted)
- Reorder point
- Economic order quantity
- Expected inventory level
- Expected inventory value
- Fill rate
- Total weekly cost

The deliverable is easy to use such that correct decisions are made. Moreover, accurate results should be produced, given the input of the company. The model can be used for all products. All locations of the Company X group can make use of this model by performing minor adjustments.

In this chapter, relevant context is given for this research, together with the research problem. We found out what the supply chain looks like, how the process of tinting works, and that low delivery reliability causes problems at Company X. The norm and reality were covered such that the objectives of this thesis are clear. This was followed by the problem-solving approach, an overall structure. In the following chapter, a deeper analysis of the current situation can be found.

2. CURRENT SITUATION

The current situation regarding delivery reliability from Company X B.V. to its customers, decision-making policy of ordering products ready-made or tinted, current stock levels of these products, and effects of these on the delivery reliability are examined in this chapter. This chapter shows possible improvement opportunities for the company that can be used to increase delivery reliability. The research question of this chapter is: What is the current delivery reliability and stock for ready-made and tinted products?

2.1. Delivery reliability

First, an analysis is done on the current delivery reliability from Company X B.V. to all customers. For this, we make use of customer order line data ranging from January 2020 up and until March 2023. Customer order lines describe any item that is sold to a customer. In this period, 36,530 orders were placed while there were 67,482 order lines. So an order contains approximately 1.85 different products.

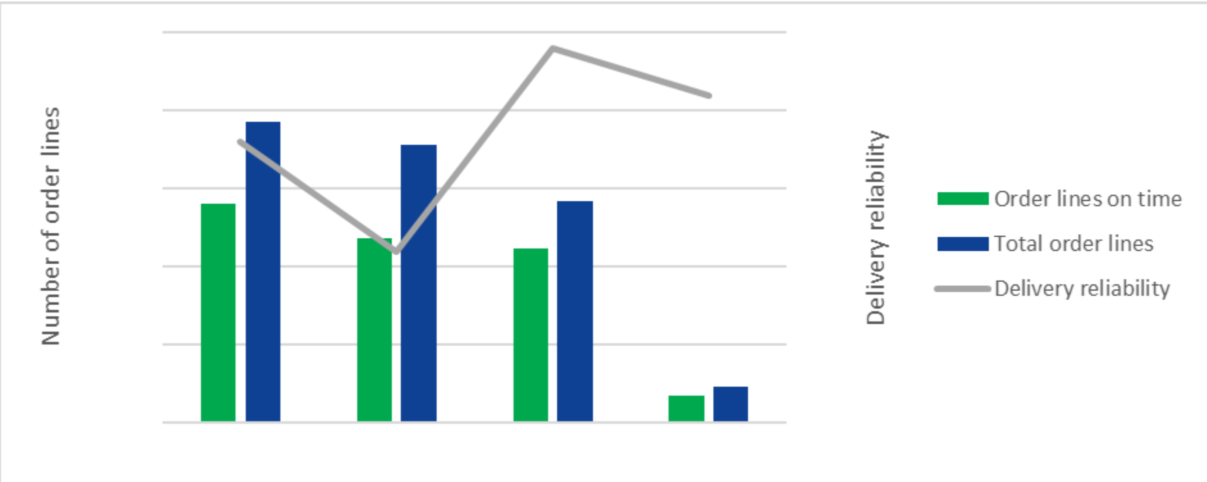


Figure 6 Delivery reliability based on order lines per year from Company X to its customers (January 2020 - March 2023)

We see that the average delivery reliability for these customer order lines is 91%, ranging from 83% in 2021 to 99% in 2022. Not all orders have the same size. To get a broader picture of the situation, we examine what the percentage of on-time weight is. It could for example be the case that smaller order lines are consistently on time, while larger, heavier order lines are often late. This could result in a more favorable appearance than it is.

Table 2 Fraction of weight in kilograms on time per year from Company X to its customers (January 2020 - March 2023)

Year	Weight on time (kg)	Total weight (kg)	Fraction of kg on time
2020	1,487,416	1,984,327	75%
2021	2,165,109	3,272,806	66%
2022	1,446,274	1,765,563	82%
2023	200,197	256,556	78%
Overall	5,298,996	7,279,252	73%

Analyzing the data based on weight results in a percentage of on-time weight of 92%. We can conclude that the difference in percentage between delivery reliability and on-time weight is minor (1% in total). If we classify the weights of the order lines into 3 categories (light, medium, and heavy) we get the following results:

Table 3 Fraction of order lines on time per category from Company X to its customers (January 2020 - March 2023)

Year	Light order lines (0 kg – 11.24 kg)	Medium order lines (11.28 kg – 45.6 kg)	Heavy order lines (45.76 kg – 20,160 kg)
2020	[illegible]	[illegible]	[illegible]
2021	[illegible]	[illegible]	[illegible]
2022	[illegible]	[illegible]	[illegible]
2023	[illegible]	[illegible]	[illegible]
Overall	[illegible]	[illegible]	[illegible]

We do not see large differences between the different weight categories of the order lines. Based on this section, we can conclude that the delivery reliability (fraction of on-time order lines), fraction of on-time weight, and delivery reliability per weight category from Company X B.V. to its customers is low for a longer time. This means that it is not a temporary problem. We do see that the delivery reliability was particularly low in 2021, partly caused by the removal of the production facilities in the Netherlands.

We also investigated how reliable the deliveries were for each customer, assigning equal significance to each. This resulted in an average percentage of on-time deliveries of 93%. The top 20 customers in terms of total value sold get 96% of the deliveries from Company X on time. If we exclude these 20 customers, we again get an average delivery reliability of 93%. So, this means that not only the large or small customers experience the problem. We furthermore investigated the on-time performance for each product by again assigning equal significance to each. This resulted in an average fraction of on-time products of 82%. The top 20 products in terms of total value sold get 99% of the products from Company X on time. Again, excluding these 20 products results in an average delivery reliability of 82%. We see that the delivery reliability is particularly low for SKUs with weak sales. The 1,000 SKUs with the lowest sales have an average delivery reliability of 72%. In general, we see a decline in average delivery reliability as the sales per SKU decrease. Overall, we can conclude that the problem can be targeted as a re-occurring and business-wide problem. We observed that especially poor-selling SKUs have a low delivery reliability.

2.2. Lead time

An important cause of the unreliable deliveries is the slow suppliers of Company X. We consider lead times at Company X in this section. Long lead times result in decreased stock availability, which consequently leads to weak delivery reliability. The length of the lead time also affects inventory costs.

First, we consider the lead times of the main suppliers of Company X B.V. In Table 3, we can see the average lead time and standard deviation of this lead time from Country X and Country Y to the Netherlands.

Table 4 Average lead time in days per order from Country X and Country Y (January 2020 – March 2023)

Country	Average lead time (days)	Standard deviation (days)	Total net sales (%)
Country X	[illegible]	[illegible]	[illegible]
Country Y	[illegible]	[illegible]	[illegible]

In Figure 7, we see that a peak is visible in 2021. Production problems at the factory in Company Y are the cause of this. The production site in City X stopped this year as well. This escalated delivery problems in that year for the Netherlands and was an important cause for many customers to walk away.

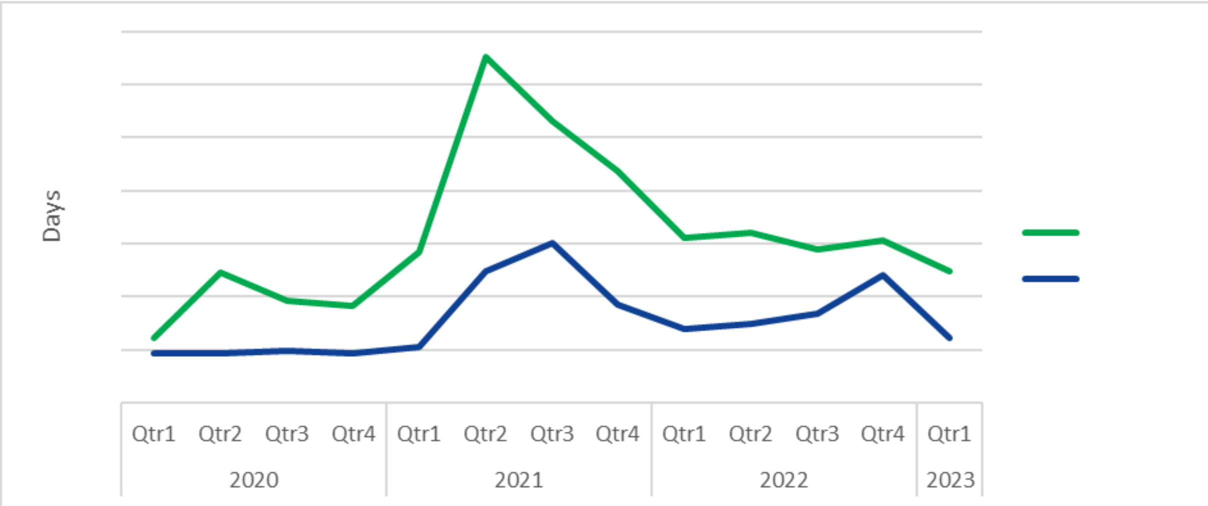


Figure 7 Average lead times from suppliers to Company X

Long lead times from suppliers do not necessarily result in long lead times for customers. Ultimately, this research focuses on the deliveries from Company X B.V. to its customers. Figure 8 is used to examine this. We see that lead times have a decreasing trend from mid-2021 onwards.

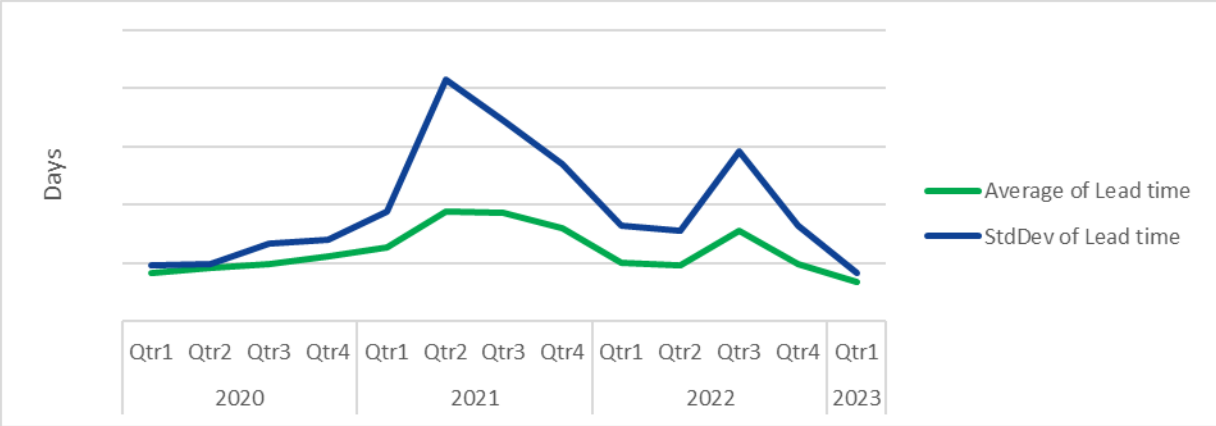


Figure 8 Lead times from Company X to its customers

It can be concluded that the warehouse in City X reduces lead time. We see the effect of the production closure of the Netherlands in this graph. This closure happened in April 2021 and we see a peak around this date. Although suppliers were the cause of major delivery problems for the Netherlands, there are ways to optimize inventory even further. The policy of tinting and ready-made products is investigated in the following section.

2.3. Decision-making policy of ordering products ready-made or tinted

Certain variables are considered at Company X for deciding whether to order a product ready-made from its suppliers or to buy it as a base paint and tint it, using colorants. The local product manager of a production country is the decision-maker in this situation. The sales countries, which are dependent on the production countries, can request changes. Company X wants certain products to be ready-made and others to be tinted. The procedure for requesting these changes is only to some degree based on variables/facts. Important variables that influence this decision are mentioned in this section.

2.3.1. DEMAND

Both the magnitude and variability of demand are relevant. Some customers regularly order Intermediate Bulk Containers (IBCs), these are tanks that have a total capacity of 1,000 liters. The margin mostly drops for these customers since sales are high. If these IBC orders are always in the same color, Company X could for example order them ready-made.

Variable low demand could mean that it is better to order the product as a base paint. Putting a ready-made on stock would then significantly increase the carrying costs. Demand is aggregated when the base paint is attached to multiple orders. A sudden decrease or stop in demand could very well happen. If it is a ready-made product, we cannot adjust it anymore. This leads to stock without demand and therefore has a negative effect on the profit of Company X. If demand had stopped for a tinted product, then no coloring would have happened yet. Tinting is done just before shipment.

For the sake of simplicity, we assume that demand is normally distributed. Modeling demand in this way results in a stable and predictable framework for managing inventory. It could be the case that demand does not follow the parameters that we defined. We know that our model does not perfectly align with reality, so this should be kept in mind during decision-making. More about this normal demand assumption is written in Chapter 6.

2.3.2. COSTS

Opting for a ready-made or tinted product has an impact on the associated costs. Ready-made products are cheaper to produce per liter since cheaper industrial colorants are used at suppliers. To compensate for this, Company X B.V. asks for a 25% fee for tinting products in the Netherlands. Because of this, customers prefer to get ready-made products. On average, costs for tinting lie 25% higher. This could, however, be different per color. Some colors need more colorants than others. The decision to order a product ready-made or tinted is made by Company X. The price per liter for customers keeps this 25% tinting fee into account. A profit margin is added on top of this such that Company X ensures that money is made while selling paint. If a custom color is requested, customers often pay more. These are mainly tinted in the Netherlands because of the low volumes (but not always).

Let us look at an example, the costs are per liter:

Table 5 Example of material costs for ordering an SKU ready-made or tinted

SKU Name	Volume (L) in 2023	Base costs (€)	Colorant costs (€)	Total tinting costs (€)	Ready-made costs (€)
Product P	8,076	4.98	0.99	5.97	5.04

We see that the total costs for the tinted item lie more than 18% higher than ordering it ready-made, for this SKU. It can therefore be concluded that tinting is more expensive in terms of costs. The above-mentioned costs for tinting are covered by the fixed 25% tinting cost since, as said, colorant costs are not always this high.

Labor cost is an important factor to keep in mind. A tinted item requires more time to make than a ready-made item. This time is spent on preparations, tinting itself, and quality control. Currently, this time is available since the logistic personnel is not working at full capacity. However, if Company X decides to tint a lot of products in the Netherlands then it leads to an increase in costs. This also holds for the equipment costs. New tinting machines could be needed to meet demand. The operating costs of equipment could also increase since the machines are used more with an increase in tinting.

Table 6 Equipment at Company X B.V.

Equipment	Quantity
16-canister tinting machine	[redacted]
32-canister tinting machine	[redacted]
IBC (1,000L) tinting (manual)	[redacted]

2.3.3. FEASIBILITY

Not all products should be tinted in the Netherlands, even if they could. Some products need a large amount of colorant to come to the desired color. So then it would be technically possible, but not financially interesting if large volumes are ordered. There are also some products that Company X sells which cannot be tinted at all. 95% of the products can be tinted and this is what the focus of this research will be on.

In this section, we looked into the decision-making process of ready-made and tinted items. For a lot of items, it is currently preferred to order a product ready-made because of the higher costs of tinting. Except for products with low and volatile demand, where the advantages of flexibility outweigh the costs.

2.4. Inventory level of ready-made and tinted products

The inventory levels are analyzed in this section to show what the current state is. The trend of inventory value from May 2021 up and until September 2023 has been upwards. From a total value of €949,317 to €1,441,791. The average over this period has been €1,334,184.

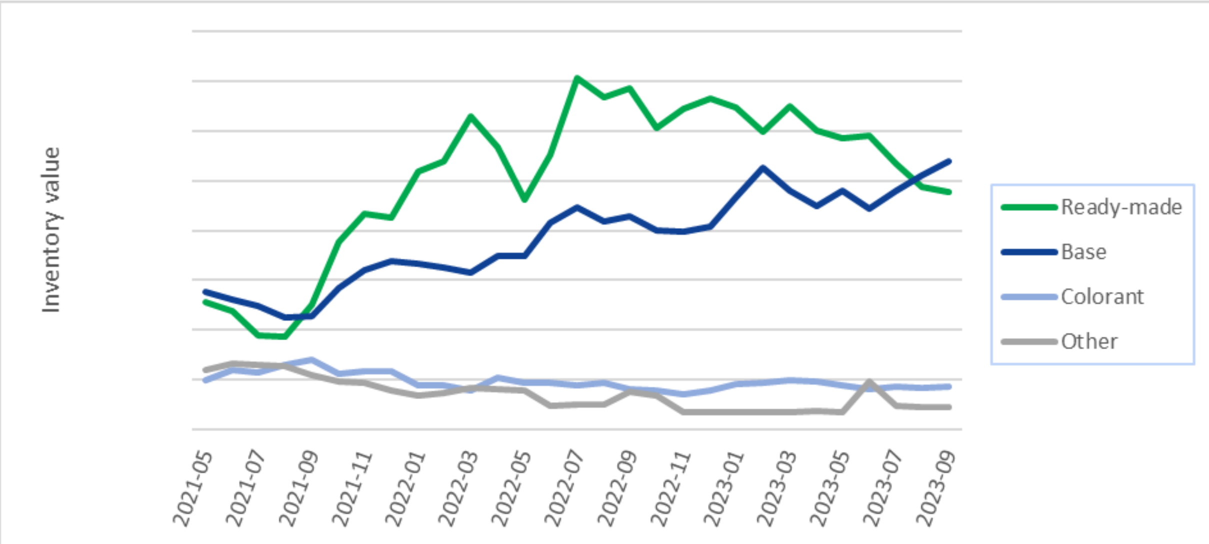


Figure 9 Inventory value at Company X B.V.

The inventory value has been split up into ready-made, base, colorant, and other products. We can see what the division of products is in the warehouse. We see a decline in ready-mades from July 2022 onwards. This reduction is made by disposing of unsold paints or by selling them for a large discount. These unsold paints are often in a pre-made color, resulting in a decrease in flexibility when a customer stops buying. We see an upward trend for base products over time. This can be explained by the fact that Company X has been in the possession of an IBC tinting machine for not that long. The increase in inventory value over time results in increased carrying costs. Optimizing inventory therefore continues to be a crucial focus point.

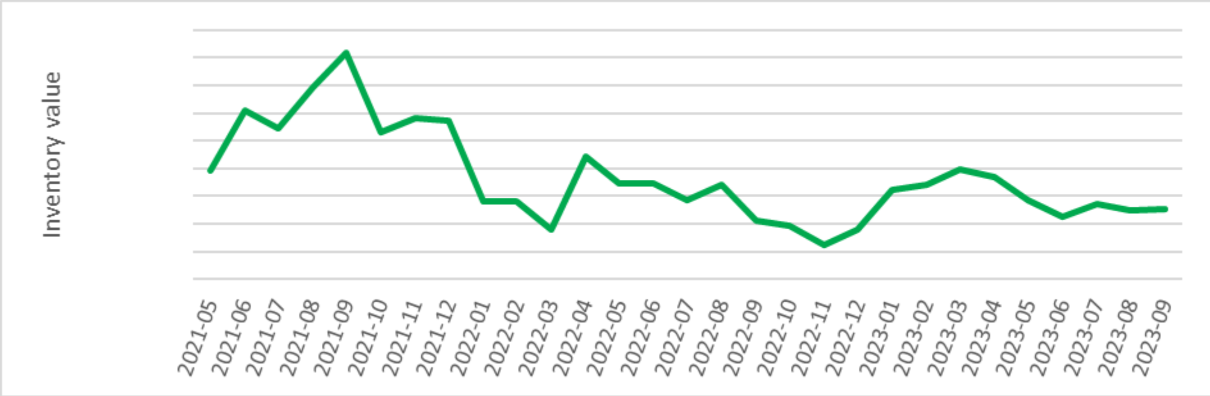


Figure 10 Value of colorants in inventory at Company X B.V.

If we zoom in on the value of colorants in inventory at Company X, we see a slight downward trend in value. We would expect the value of colorants to increase with the increase in the value of base paints. Company X has highly likely held too much inventory of it. This would explain the high number of obsolete colorants. Moreover, Company X has recently started to buy 10L colorant cans instead of 1L for some colorants which are cheaper per liter. However, if the number of ready-made products decreases further, it could be that an increase is imminent. Compared to ready-made and base products, the total value is low. However, the value per liter is €38.05, while the average overall is €5.89. So, colorants are an expensive part of the composition of paint. Luckily, the base provides the majority of the paint content.

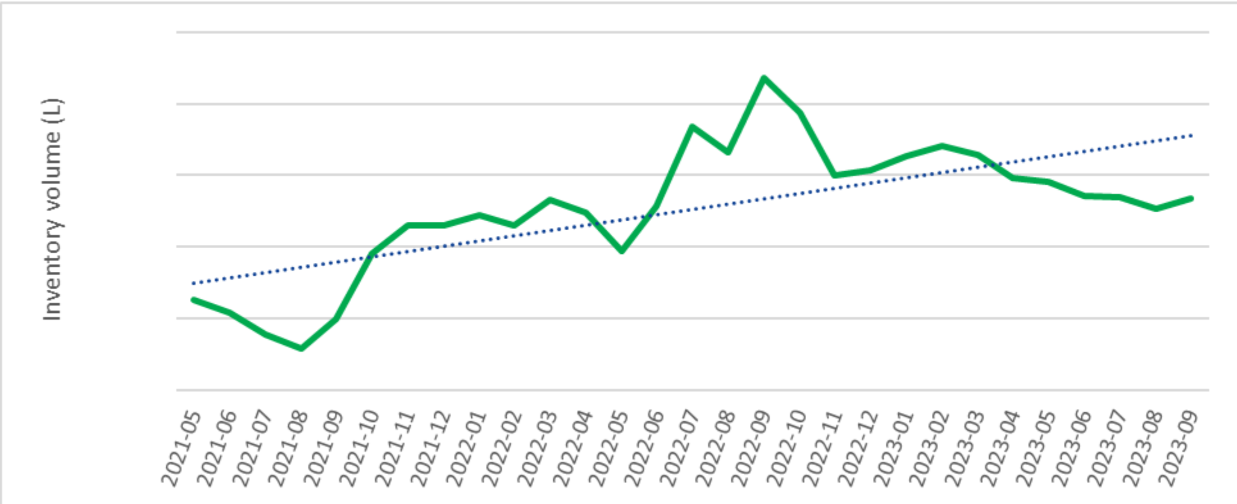


Figure 11 Inventory volume at Company X B.V.

The inventory volume increases with approximately 4,655 liters every month, by looking at the linear trendline from May 2021 up and until September 2023. We also see that the inventory volume is decreasing from September 2022 onwards. This is caused by the disposal of Slow Moving and Obsolete (SLOB) products. A high inventory volume has a negative effect on the carrying cost. The aim is to increase delivery reliability while limiting the increase in inventory value. The volume that Company X carries has a large influence on this.

2.5. Effects of ready-made and tinted products on delivery reliability

We can conclude that tinting indeed has a significant effect on delivery reliability. Currently, most orders are ready-made. In total, Company X B.V. had 67,482 order lines. 45,220 order lines (67%) were ready-made while 22,262 (33%) were tinted.

Table 7 Delivery reliability ready-made or tinted at Company X B.V. (January 2020 - March 2023)

	Order lines on time	Total order lines	Delivery reliability
Ready-made	[redacted]	[redacted]	[redacted]
Tinted	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]

The delivery reliability of ready-made items between January 2020 and March 2023 is 89% on average. For tinted products, this is 94% which is a substantial difference. So, after analyzing the different approaches the conclusion can be made to mainly focus on the decision to make a product ready-made or tinted. This is connected to the availability of base paints and colorants, so at the same time, research is done to optimize this by looking at their inventory levels.

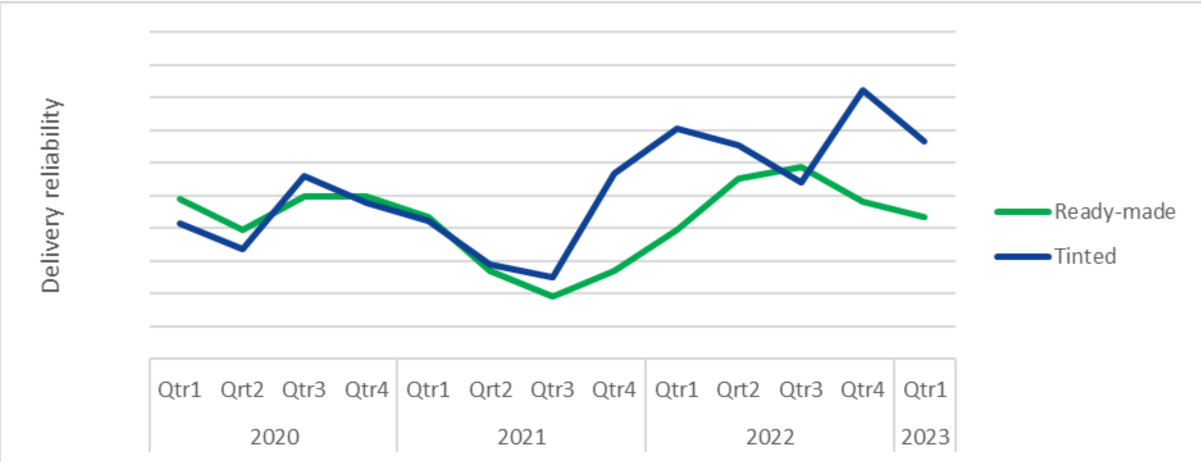


Figure 12 Delivery reliability ready-made and tinted from Company X B.V. to its customers

If we further analyze this data, we find that 2021 was the worst year in terms of delivery reliability for both ready-made and tinted items. The delivery reliability was 82% for ready-made items and 86% for tinted items. This is, again, partly the result of the closure of the production facility in the Netherlands which happened in April 2021. From May 2021 onwards, tinted items were delivered more reliably than ready-made items. The delivery reliability was 96% and 87%, respectively, in this period.

We found interesting insights by looking at historical data. We saw that most items (67%) are sold ready-made. The delivery reliability is higher for items that are tinted in the Netherlands. We displayed the delivery reliability of both over time. Especially after the closure of the production facility stockouts occurred less for tinted items, resulting in an increased delivery reliability. Tinting results in an increase in flexibility since we delay the point of customization until a later point in the supply chain. Chapter 3 provides a further analysis of the effect of this so-called postponement and component commonality on delivery reliability.

2.6. Effects of ready-made and tinted products on lead time

We have discussed the importance of lead time. In this section, we will separate the lead times based on whether a product is sold ready-made (Case RM) or tinted (Case T). Average lead times could, if low, result in competitive advantages and thus increased sales.

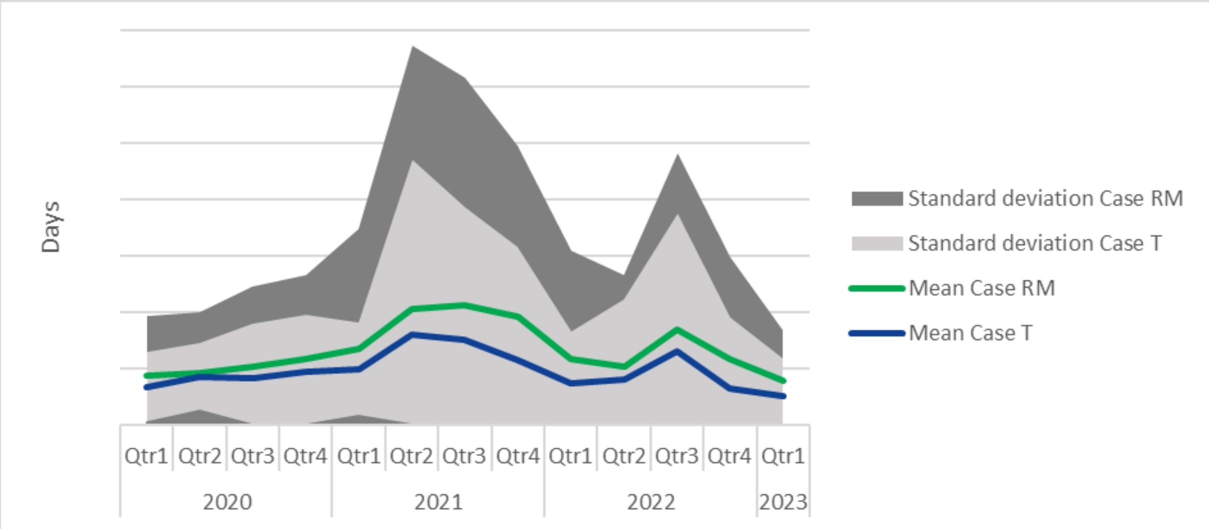


Figure 13 Effects of ready-made and tinted products on lead time from Company X B.V. to its customers

The graph clearly shows that tinting paint in City X results in a lower average lead time. The difference is 1.81 days from January 2020 to March 2023. Next to average lead time, we discussed that the standard deviation of lead time is needed to get a full picture. The graph shows us that the same holds for the standard deviation of lead time. Tinted items are delivered faster and also with a lower standard deviation. The standard deviation of tinted products lies on average 4.34 days lower than ready-made products.

From the data, it can be concluded that the lead times of tinted items are more favorable in comparison to ready-made items. Lower lead times with lower standard deviations result in a lower amount of stock that is needed to achieve a given delivery reliability.

This chapter aimed to provide insights into the current situation at Company X. We saw that delivery reliability problems have and are still playing an important role in the loss of sales. This is not (only) caused by the lack of inventory optimization in the Netherlands. The manufacturing sites have also contributed to this. The process of ordering paints ready-made or to order them as base paints with colorants is not yet optimized. Based on historical data we identified that tinted items score higher in terms of delivery reliability compared to ready-made items. This difference is partially caused by high lead times from the suppliers. But also because base paints, together with the colorants, result in more variations of the product being in stock. More on lead time as an input variable is mentioned in Chapter 4. In Chapter 3, the effects of tinting are investigated by analyzing literature about this. Decision-making in this field is challenging, therefore, decision variables are carefully selected, and performance measures are assessed. We need these relevant input and output inventory parameters for our model to optimize inventories at Company X.

3. LITERATURE REVIEW

We saw that the current delivery reliability from Company X B.V. to its customers is insufficient. We have also split up the numbers based on products that are ready-made and tinted. The effects of this decision were displayed in the previous section based on historical data. We saw that on average, delivery reliability and lead times were more favorable for tinted products. In this chapter, we research academic literature to find out whether there is proof for this.

This literature review starts with the effects of inventory pooling. We also discuss the theory of component commonality. This will be done together with the delay of the customization point, which happens when the paint is tinted. This process is also known as postponement. Thereafter, variables that affect the decision to tint or to produce ready-made are examined. Literature concerning the reorder point, economic order quantity, and safety stock are also explored. This leads to crucial information for the solution design.

3.1. Effect of tinting on delivery reliability

This section researches the effect of tinting on delivery reliability. We can aggregate demand by tinting products in a later stage of the supply chain. This results in aggregation/centralization of inventory. The seminal paper of Eppen (1979) describes the "Effects of centralization on expected costs in a multi-location newsboy problem". Further research on this, together with component commonality and postponement, is done by Chopra (2019).

3.1.1. EFFECTS OF CENTRALIZATION ON TOTAL COSTS

Centralization is the consolidation of demand from several locations. In Eppen's work, the total costs for a completely decentralized and centralized system are compared. He states that:

- Total cost decentralized system

$$TC_D = K \sum_{i=1}^{N} \sigma_i \qquad \text{Eq. 2}$$

- Total cost centralized system

$$TC_C = K \sqrt{\sum_{i=1}^{N} \sigma_i^2 + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sigma_i \sigma_j \rho_{ij}} \qquad \text{Eq. 3}$$

Where TC_D represents the total cost of a completely decentralized system; TC_C represents the total cost of a completely centralized system; K represents the expected holding and penalty cost at a source of demand when the optimal number of items are on hand at the beginning of the period; N represents the number of sources of demand; i and j represent location i and j; ρ_{ij} represents the correlation coefficient of μ_i and μ_j, where μ_i and μ_j is the demand from location i and j, respectively.

From this, we can draw the following results:

- $TC_D \geq TC_C$
- If $\rho_{ij} = 1$ for all i and j then $TC_D = TC_C$

Key findings from this work are summarized below:

- The expected holding and penalty costs are lower in a centralized system than those in a decentralized system.
- The height of the savings depends on the correlation of demands, uncorrelated demand leads to more savings than correlated demand.
- For uncorrelated and identical demands, the costs increase as the square root of the number of consolidated demands.

These results are relevant to this research. The costs of ordering a ready-made item could surpass the costs of tinting items in the Netherlands if we look at the holding and penalty costs. This results in savings caused by this centralization effect. This impacts the cheapest ordering decision, there are however other costs like the product costs that have an impact on this.

3.1.2. EFFECTS OF CENTRALIZATION ON SAFETY INVENTORY

Chopra (2019) also covers the effects of centralization. More specifically, the effects on safety inventory.

He states that:

$$A = \frac{F_S^{-1}(CSL) \times \sqrt{L} \times H}{\mu_C} \times (\sum_{i=1}^{k} \sigma_i - \sigma_C) \quad \text{Eq. 4}$$

Where A is the holding cost saving on aggregation per unit sold; CSL represents the desired Cycle Service Level (probability of preventing a stockout); L represents the replenishment lead time; H represents the holding cost per unit; D^C represents the mean of the aggregate demand; k represents the number of regions that we are aggregating across (regions here being different variations from the same base product); σ_i represents the standard deviation of periodic demand in region i, i = 1, …, k; σ_C represents the standard deviation of the aggregate demand.

From this, we can see that the safety inventory savings on aggregation increase:

- With the desired cycle service level (CSL).
- With the replenishment lead time (L).
- With the holding cost (H).
- With the coefficient of variation ($\frac{\sigma}{\mu}$) of demand.
- As the correlation coefficients decrease.

3.1.3. COMPONENT COMMONALITY

Chopra (2019) also discusses that using common components in a product leads to aggregation. Paint consists of multiple components. Ordering paint as base paints with colorants results in a component commonality. The combination of these components can result in a large amount of products with a color.

Ready-made products do not consist of common components when delivered at the Dutch warehouse. For these products, the uncertainty of demand is the same as the uncertainty of demand for the finished product. The larger the number of components in each finished product, the larger the demand uncertainty. This consequently leads to higher safety inventory levels. It would therefore be useful to design products with common components. Then, the demand for each component (base paints and colorants) is an aggregation of the demand for all the finished products (base paint X colored using colorants Y) of which the component is part. Demand for finished products is less predictable than demand for the components. A paint manufacturer could predict that in spring, an increase in paint X is expected. However, it is more difficult to predict that in spring, an increase in paint X in color Z is expected. This results in the fact that lower component inventories are required.

3.1.4. POSTPONEMENT

Tinting paint results in a delay in product customization. This phenomenon is called postponement. The example of mixing paint is also used by Chopra (2019).

"For example, the final mixing of paint today is done at the retail store after the customer has selected the color he or she wants. Thus, paint variety is produced only when demand is known with certainty. Postponement coupled with component commonality allows paint retailers to carry significantly lower safety inventories than in the past, when mixing was done at the paint factory. In the past, the factory manager had to forecast paint demand by color when planning production. Today, a factory manager needs to forecast only aggregate paint demand because mixing has been postponed until after customer demand is known. As a result, each retail store primarily carries aggregate inventory in the form of base paint that is configured to the appropriate color based on customer demand." (Chopra, 2019)

We see that postponing product customization has a positive effect on safety inventories. The same delivery reliability can be achieved with less safety inventory. Conversely, a higher delivery reliability can be achieved with the same safety inventory.

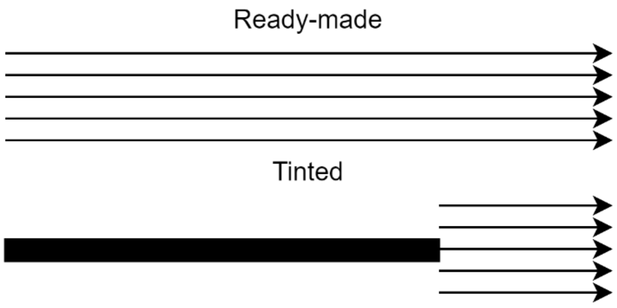


Figure 14 Supply Chain flows without (ready-made) and with (tinted) postponement (Chopra, 2019)

Research on postponement is also done by Graman and Bukovinsky (2005). According to their research, postponement has positive effects on customer service levels, inventory levels, and the standard deviations of forecast errors. They define three types of postponement.

Time postponement

Delaying the differentiation of the product (tinting paint) to as late as possible. House paint is a classic example according to Graman and Bukovinsky (2005):

"House paint is a classic example of time postponement. The unique color selected by the customer at the point of sale is produced by adding the necessary pigment while the customer is present and can be performed in a length of time that is acceptable to the customer."

For this research, differentiation is done at either the factory or the distribution center. Postponing it until the retailers' shops would increase flexibility further. This, however, is only financially possible if customers buy enough products since a tinting machine is an investment for Company X.

Form postponement

Keeping the product generic longer. This is achieved by increasing the modularization and component commonality of the product. For Company X, packaging postponement could be particularly interesting. Bulk products are shipped to the distribution center. The paint is then packaged (in different package sizes) only after demand is known. This postpones the customization point.

Partial postponement

"Recent studies suggest that any amount of postponement is beneficial from the perspectives of improved customer service level and/or reduced inventory investment. There is, however, a cost associated with postponement because production costs with postponement are typically higher than without it." (Graman & Bukovinsky, 2005)

According to Graman and Bukovinsky (2005), partial postponement can result in a substantial part of the benefits. Goods with a higher degree of certainty could for example be non-postponed (ready-made) while goods that are sold with a lower degree of uncertainty could be postponed (tinted). This hybrid strategy combines the advantages of low-cost production methods with the flexibility of tinting. This is referred to as partial/tailored postponement and this is the strategy that we implement for Company X.

3.2. Standard and customized products with postponement

In this section, we analyze the research that is done by Zheng et al. (2022). The main goal is to find out how manufacturers, retailers, and the supply chain as a whole can make the best decision when a combination of both customized and standard products is made. The results are measured for a decentralized and centralized system. The researchers consider two kinds of products; standard products (ready-mades) and general components for customized products (base paints). A manufacturer (paint factory) and retailer (Company X B.V.) are considered. Two stages are considered; in Stage 1, demand is uncertain and in Stage 2, demand is known.

The retailer and manufacturer are not cooperating in a decentralized system. The first order decision of the retailer is independent of the cost parameters of the customized products. It is only influenced by the parameters of the standard products. In a centralized system, the manufacturer and retailer are owned by one firm (like Company X). This means that the objective shifts to maximizing total expected profit in the centralized system. Some takeaways from this research are relevant to Company X.

TAKEAWAYS

If the total cost of the production of customized products remains constant (base paint + tinting costs) then the optimal production quantity of ready-made products increases if: the cost of preparing base paints increases, the cost of tinting increases, and the salvage value of ready-made products increases. Conversely, the optimal production quantity of base paints increases if: the cost of preparing base paints decreases, the cost of tinting decreases, and the salvage value of base paints increases. A ready-made product cannot be sold to other customers if demand stops. However, if customers are more "flexible", so either ordering yellow or red matters less, then the inclusion of the salvage value would be interesting. We do not cover the salvage value of ready-made products or base paints in this research. In the research, it is concluded that the total expected profits under a decentralized system are lower compared to a centralized system. The situation that is described is different from Company X, but important takeaways can be concluded from this. The most important one is that cooperating is beneficial for the profits of the entire supply chain. So, this could also be adopted to this research. Manufacturers could alter their decisions by looking at the overall benefits of the supply chain. This also holds vice versa, for Company X B.V. In Chapter 6, a further look is taken at the incorporation of the salvage value and recommendations on this so-called cost-sharing contract are provided.

3.3. Decision variables and performance measures that influence the ordering decision

To make a model that determines the cheapest decision, either ordering a product ready-made or as a base paint and tint in-house, we need decision variables and performance measures. Performance measures are dependent on the decision variables (Beamon, 1998). Together, these are used to model supply chains. For example, the decision variable "inventory levels" affects the performance measure "fill rate". Ways to analyze performance and design, using decision variables and performance measures, of the supply chain are described by Beamon (1998).

3.3.1. DECISION VARIABLES (INPUT)

Decision variables are chosen such that the performance measures are optimized. To model the process at Company X, multiple decision variables are used. Beamon discusses several decision variables for supply chain modeling (Beamon, 1998). An example is given, if possible, for each decision variable:

- **Production/distribution scheduling**: Manufacturing of paint scheduling and distribution.

- **Inventory levels**: Volume of raw materials, base paints, colorants, and final products to keep in inventory.
- **Number of stages**: Number of stages to keep in mind during modeling. Supplier – Company X B.V. – Customer
- **Distribution Center – customer assignment**: Which customers will be served by which DC? The DC in City X serves the Benelux region.
- **Plant–product assignment**: Which products are made at which factories?
- **Buyer–supplier relationships**: Which aspects of the buyer-supplier relationship are critical?
- **Product differentiation step specification**: Step in the process by which the product should be differentiated or specialized. Thus, tinting at the supplier, or in the Dutch warehouse.
- **Number of product types held in inventory**: Number of different finished good types (Product X, Product Y) in inventory.

For this model, the focus lies on the decision of product differentiation step specification. This is the main decision variable for this research. Optimization of performance measures is our aim, given this decision variable. From this, the cheapest decision of either ordering the product ready-made (step of specification lies at the supplier) or ordering the product as a base and colorant (step of specification lies at Company X B.V.) is chosen.

3.3.2. PERFORMANCE MEASURES (OUTPUT)

Establishing performance measures is crucial in assessing whether the decision variable to order ready-made or tinted products has a positive influence on the supply chain. For performance measuring, the categories qualitative and quantitative are both used (Beamon, 1998).

Qualitative performance measures

The qualitative measurements cannot be numerically measured. This results in the fact that these measures are not being used for the model. However, this does not mean that their impact should be neglected. This is why these measures are discussed below, again, using the context of Company X:

- **Customer satisfaction**: Internal and external customer satisfaction. This is the level to which customers are content with the paint.
- **Flexibility**: The level at which the supply chain can handle disruptions and other random events.
- **Information and material flow integration**: The degree to which different Company X sites communicate and deliver materials to one another.
- **Effective risk management**: How Company X reacts to the effects of risks is covered by this performance measure.
- **Supplier performance**: With which reliability do suppliers of raw materials deliver to the Company X production sites?

These performance measures need to be kept in mind during decision-making. The abovementioned five qualitative performance measures are identified to be important (Beamon, 1998).

Quantitative performance measures

Other performance measures can be described numerically. They can be categorized into measures based on “cost or profit” and “customer responsiveness” (Beamon, 1998).

Cost or profit

- **Cost minimization**: Minimizing cost for Company X B.V. or for the whole supply chain.
- **Sales maximization**: Maximization of the value of sales.
- **Profit maximization**: Maximization of sales minus costs.
- **Inventory investment minimization**: Minimization of the inventory costs (both holding and product costs).
- **Return on investment maximization**: Maximization of the ratio of profit to investment to produce that profit.

Customer responsiveness

- **Fill rate maximization**: Maximization of fraction of customer orders that are filled on time.
- **Product lateness minimization**: Minimization of promised and actual delivery dates.
- **Customer response time minimization**: Minimization of time between order placement and delivery at the customer.
- **Lead time minimization**: Minimization of time between the start of paint manufacturing and process finalization.
- **Function duplication minimization**: Minimization of the number of business functions that are done by more than one business entity.

Interesting quantitative performance measures for the model have been described above, and together with the decision variables, these form a solid structure for the model.

3.4. Economic order quantity, reorder point and safety stock

Next to the decision to order a product ready-made or tinted, we look at the inventory levels that are attached to it. For this, we will use the “managerial” R, Q Model, where we rely on the input from managers that define the customer service level target (Hofer, 2020).

3.4.1. ECONOMIC ORDER QUANTITY

The Economic Order Quantity (EOQ) has been developed by Ford W. Harris (1913). It is used to calculate the order quantity that minimizes the sum of order placement and holding costs. This formula is used to optimize inventory and therefore reduce costs. The output is the economic order quantity which is the advised amount to purchase for Company X B.V. This formula is part of the model.

3.4.2. REORDER POINT

We also need a Reorder Point (ROP). This is the point at which a new order should be placed to avoid a stockout. This formula has the aim to optimize inventory levels and consequently reduce costs, like the EOQ. The model for Company X also incorporates this reorder point.

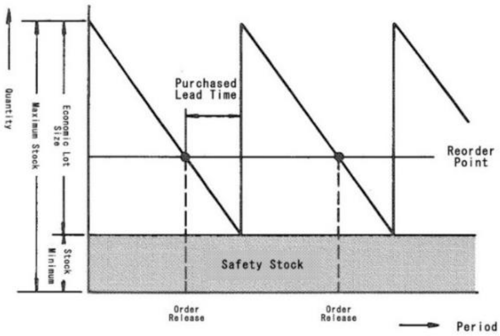


Figure 15 EOQ and ROP visualization (Lu, 2013)

3.4.3. SAFETY STOCK AND DELIVERY RELIABILITY METRICS

To prevent stock-outs, Company X makes use of safety stock. The height of the safety inventory is determined by the following four factors, according to Chopra (2019):

- Desired level of delivery reliability
- Uncertainty of supply
- Uncertainty of demand
- Inventory replenishment policies

Delivery reliability metrics

Sales, costs, and customer satisfaction are examples of performance measures that are influenced by delivery reliability metrics. These metrics describe the ability of a company to deliver products on time. We discuss two metrics in this section that are relevant to the “managerial” R, Q Model (Hofer, 2020).

- **In-stock rate or cycle service level (type I service level)**: The in-stock rate is the percentage of cycles with no stockout. An order cycle is the time between ordering and the delivery from the supplier. The number of stockouts during a cycle is divided by all cycles, this results in the in-stock rate. We can see this rate as the “frequency” of in-stock events.
- **Fill rate (type II service level):** The fill rate is the percentage of demand filled from on-hand inventory. The on-hand inventory is divided by the demand over the period, this results in the fill rate. We can see this rate as the “magnitude” of service offered. This is important for customers and accurately displays the delivery reliability to customers of Company X B.V.

We concluded in the first section that the effects of delaying the customization point (postponement) and aggregating demand have a positive effect on costs and delivery reliability. The second section covered possible decision variables and performance measures that are used in the model to calculate the cheapest ordering decision. Finally, we discussed the economic order quantity, reorder point and safety inventory such that the inventory levels for these ready-made paints, base paints, and colorants are optimized. We have also looked at delivery reliability metrics. The fill rate measures the delivery reliability (in the way we defined it) more accurately than the cycle service level. However, for computational simplicity and user-friendliness of the model, it is not used as an input variable. But, this does not mean that we do not use the gathered information. The fill rate is measured as an output variable and can thus be analyzed by the user as well. In Chapter 4, we cover this solution design.

4. SOLUTION DESIGN

In this chapter, we discuss the application of the reviewed literature to a decision model. More specifically, a model that calculates the best decision of whether to order a product ready-made or as a base. This chapter is designed to apply our gained knowledge. The requirements, necessary information, and underlying calculations are discussed in this chapter. The outcome of the model is described in Chapter 5.

4.1. Requirements

The Ready-made or Tinted Decision Model has some requirements to be useful for Company X:

- The cheapest ordering decision for Company X B.V. (either ready-made or tinted).
- Possibility to change input variables to accurately depict the current situation.
- Model usable in a user-friendly manner.

These requirements form the major guideline for this model. The cheapest ordering decision is the most important outcome of this research. The costs depend on numerous variables, as could be seen in Chapter 3. As expected, the model needs to be easy to use. This requires us to closely look at the complexity of the model, and reduce this if possible. This results in a transparent and clear procedure from which the decision emerges. Next to the overall cheapest decision, we develop an extension. This enables the user to calculate the cheapest decision for a range of items that belong to the same base. It could very well be that the overall cheapest decision differs from the outcome of the extension. Demand for some items might for example be high and stable, which reduces the aggregation advantages. These could then have the ready-made tinting decision as an optimal choice whereas items with uncertain and low demand should be tinted in-house.

4.2. Necessary information

The main framework of the model is derived from equations, provided by literature. For the equations, and thus, the model to function properly, accurate input variables and values for these variables are necessary. This section covers the input variables that we need for our model (Chopra, 2019). In the following section, we use Case RM for ready-made items. We use Case T for tinted items. A more elaborate explanation of these cases can be found in the next section.

- <u>Cycle service level</u> (CSL): The fraction of replenishment cycles that end with all the customer demand being met. This CSL is managerially defined. Increasing it results in higher costs, and decreasing it possibly results in unsatisfied customers.
- <u>Holding cost</u> (H): The weekly cost of carrying one unit in inventory, as a fraction of the unit cost of the product. Storing inventory is not free of charge. This together with the cost of capital and the cost of paints becoming obsolete results in the holding cost.

- Order placement cost (S): All costs that do not vary with the size of the order but are incurred each time an order is placed. This fixed setup cost consists of costs for transport and administration and does not change if a larger or smaller volume is ordered.
- Costs base product (C_B): Cost of the base product per liter, not tinted into a specific color. This is based on the Internal Price List (ITP).
- Tinting cost (C_t): Cost of tinting paint in the warehouse, as a percentage that needs to be added on top of the price of the base product. This is done to compensate for the (extra) costs of colorants, equipment, and labor.
- Costs tinted product (C_T): Costs of the tinted product per liter, tinted into a specific color in the warehouse of the Netherlands.
- Costs ready-made product (C_{RM}): Cost of the ready-made product per liter, tinted into a specific color at the supplier.
- Mean lead time (μ_L): The average time elapsed in weeks between when an order is placed and when it is received. For Company X B.V. this is the time between ordering a paint at the factory and when it is delivered at the warehouse. For Case RM we have μ_{LRM}, for Case T we have μ_{LT}, for the mean lead time of ready-mades and tinted items, respectively.
- Standard deviation of lead time (σ_L): The standard deviation of time elapsed in weeks between when an order is placed and when it is received. For Case RM we have σ_{LRM}, for Case T we have σ_{LT}, for the standard deviation of lead time of ready-mades and tinted items, respectively.
- Mean demand (μ_D): The average weekly demand. For Case RM we have μ_{DRM}, for Case T we have μ_{DT}, for the mean demand of ready-mades and tinted items, respectively. μ_{DT} is not an input value, it is calculated using μ_{DRM}, this is explained in the following section.
- Standard deviation of demand (σ_D): The standard deviation of weekly demand. For Case RM we have σ_{DRM}, for Case T we have σ_{DT}, for the standard deviation of demand of ready-mades and tinted items, respectively. σ_{DT} is not an input value, it is calculated using σ_{DRM}, this is explained in the following section.

The defined input variables form an overview of the situation at Company X B.V. This crucial information is used for our model. How the model eventually calculates the most cost-effective decision is described in the following section. This is the core of the model.

4.3. Model description

In this section, we discuss the underlying calculations in the model now that the input variables have been defined. In Chapter 3, several equations and theories have been discussed already. Here, we put the explored literature and findings into practice for Company X. First, the underlying calculations are covered.

4.3.1. BASE PAINT VERSUS READY-MADE

We distinguish between tinted paint (Case T) and ready-made paint (Case RM) in the model. The calculations that follow from both cases are similar. However, in the beginning, a vital difference takes place. The user of the model needs to insert the characteristics of supplier lead time for both cases. The mean supplier lead time (μ_L), and standard deviation of supplier lead time (σ_L) are important. We also need the mean ready-made demand (μ_{DRM}) and standard deviation of ready-made demand (σ_{DRM}) from Company X B.V. The user needs to stick to the same timeframe. For our model, designed for Company X, weeks are chosen. Choosing a different timeframe is possible, however, if this is the case, the user should stay consistent.

Case RM: The user can list the abovementioned demand characteristics (μ_{LRM}, σ_{LRM} μ_{DRM}, σ_{DRM}) for 10 different ready-made colors in total (belonging to the same base product). According to the product manager of Company X B.V., this is sufficient. These demand characteristics can be identified based on historical data. More on this is written in Chapter 6.

Case T: The user only needs to list the lead time characteristics for the base product (μ_{LT}, σ_{LT}), belonging to the ready-made colors. The μ_{DT} and the σ_{DT} are calculated using the demand characteristics of Case RM. For this, we use the theory that is described by Eppen (1979). Demand is aggregated:

$$\mu_{DT} = \sum_{i=1}^{i=10} \mu_{DRMi} \quad \text{Eq. 5}$$

$$\sigma_{DT} = \sqrt{\sum_{i=1}^{i=10} {\sigma_{DRMi}}^2} \quad \text{Eq. 6}$$

We assume uncorrelated demand between the ready-made products. This means that the correlation coefficient is zero. This simplifies the equation and enhances the user-friendliness of the model. But, has effects on the outcome. Uncorrelated demand leads to more savings than correlated demand. This means that the standard deviation of aggregated demand during lead time is possibly higher in real life. So, this could potentially incorrectly tilt the cheapest decision according to the model towards tinting in-house. In Chapter 6, more on this assumption is mentioned.

4.3.2. SAFETY STOCK

An important factor that influences the decision-making process is the amount of safety stock that is needed, given a desired cycle service level. We use the following equation for this.

$$SS = F_s^{-1}(CSL) \times \sigma_{DL} \quad \text{Eq. 7}$$

In our model, we enable the user to make use of the standard deviation of lead time, if applicable. Therefore, the way in which we calculate σ_{DL} is done as follows:

$$\sigma_{DL} = \sqrt{\mu_L \times {\sigma_D}^2 + {\mu_D}^2 \times {\sigma_L}^2} \quad \text{Eq. 8}$$

The multiplication of the Z-score and the standard deviation of lead time demand results in the safety stock for the product. The safety stock of the base paint and the safety stock of the ready-made paint are both calculated in this way. However, for the ready-mades, we sum the safety stocks of each color such that we can compare it with the safety stock of the base products.

4.3.3. REORDER POINT

The reorder point is also calculated, to accurately display the inventory process. We simply add the mean of lead time demand and the safety stock. The reorder point aims to help the user in the ordering process by showing at which inventory level a new order should be placed, given the input variables.

It is calculated using the following equation:

$$ROP = (\mu_D \times \mu_L) + SS \quad \text{Eq. 9}$$

The same calculation method holds for Case T and RM, based on different input values.

4.3.4. ECONOMIC ORDER QUANTITY

Next to the safety stock, the economic order quantity (EOQ) is also covered in Chapter 3 using findings from Harris (1913). This equation enables Company X to calculate the quantity to order. Some input variables are needed to come to this quantity. We need the mean demand (μ_D), order placement cost (S), holding cost (H), and the product cost.

$$EOQ = \sqrt{\frac{2 \times \mu_D \times S}{H \times C}} \quad \text{Eq. 10}$$

The EOQ assumes that demand is certain over time. This is not the case for our model. Again, more on this is written in Chapter 6. Using this EOQ, we can calculate several values that are necessary to accurately compare Case T and Case RM. These are explained below.

4.3.5. EXPECTED HOLDING COST

Dividing the EOQ by two results in the cycle inventory. This is the average inventory in a supply chain due to either purchases in lot size or production quantities that exceed the orders demanded by the customer (Chopra, 2019).

Adding the safety stock to this cycle inventory gives us the expected inventory level. The expected inventory levels, given a desired cycle service level, are of crucial importance for our decision-making model. The way of calculating this value is denoted below:

$$E(IL) = \frac{EOQ}{2} + SS \quad \text{Eq. 11}$$

Going from the expected inventory level to the expected inventory value is slightly different for Case T and Case RM. Both procedures are discussed in the following part.

Case T: We need to know what the cost of the tinted product is. This is the cost of the base product plus the cost of tinting in City X (added as a percentage to the base product). This percentage is also an input value and could potentially decrease if more paint is tinted in-house such that Company X B.V. takes advantage of economies of scale.

$$C_T = C_B + C_t \quad \text{Eq. 12}$$

Multiplying the cost of the tinted product with the expected inventory level results in the expected total inventory value.

$$E(IV_T) = C_T \times E(IL_T) \quad \text{Eq. 13}$$

Case RM: For the ready-made products, calculating the expected inventory value is straightforward. We multiply the expected inventory level by the cost of the ready-made product. This gives us the expected inventory value, for that specific ready-made product. For comparison purposes, we add all expected inventory values, and this results in a total inventory value for Case RM.

$$E(IV) = \sum_{i=1}^{i=10} C_{RMi} \times E(IL_{RMi}) \quad \text{Eq. 14}$$

Multiplying the (total) expected inventory value with the holding cost per week (as a percentage of the ITP) results in the expected (total) holding cost for both cases.

$$E(H) = H \times E(IV) \quad \text{Eq. 15}$$

This is an important cost that is considered in the model.

4.3.6. EXPECTED ORDER COST

Next to the expected holding cost, we determine the expected order cost for both cases. To calculate this value, we first calculate the expected number of orders. This is the number of orders that Company X B.V. places to the supplier in a week. The expected number of orders is calculated by dividing the mean demand by the EOQ. Multiplying this value with the order placement cost (also known as the setup cost) results in the expected total order cost.

$$E(O) = \frac{\mu_D}{EOQ} \times S \quad \text{Eq. 16}$$

The calculation for Case T and RM is the same, however, based on different input values.

4.3.7. PRODUCT COST

Next to the holding and order cost we also take the effect of the product cost into account. This is different for both cases:

Case T: For case T, the product cost is the cost for the base paint + 25%. This covers the additional tinting cost in the Netherlands. We take the product cost into account since it influences our decision. High costs for base paint decrease the possibility of tinted items being the best solution.

$$E(P_T) = \mu_{DT} \times C_T \qquad \text{Eq. 17}$$

Case RM: The product cost of ready-made items, tinted at the factory, also influences the decision. We are taking this into account by looking at the ITP list. If ready-made items are more expensive than tinted items then it will become difficult for it to be the best solution.

$$E(P_{RM}) = \sum_{i=1}^{i=10} \mu_{DRMi} \times C_{RMi} \qquad \text{Eq. 18}$$

4.3.8. FILL RATE

The fill rate gives us additional information about the delivery reliability of Company X B.V. To determine this, we first need to calculate the expected shortage per replenishment cycle (ESC).

$$ESC = -SS[1 - F_s\left(\frac{SS}{\sigma_{DL}}\right)] + \sigma_{DL} f_s\left(\frac{SS}{\sigma_{DL}}\right) \qquad \text{Eq. 19}$$

Where $F_s(\dots)$ represents the standard normal cumulative distribution function; $f_s(\dots)$ represents the standard normal density function. From this, we calculate the fill rate using the following equation:

$$fr = \frac{EOQ - ESC}{EOQ} \qquad \text{Eq. 20}$$

This fill rate is not used as an input variable, in light of the user-friendliness of the model. We have therefore listed it in this section since we use the fill rate as an output value. More on this is mentioned in Chapter 5.

4.3.9. DECISION-MAKING

The model aimed to determine the cheapest decision of either ordering a product tinted (Case T) or ready-made (Case RM) while limiting the increase in overall average inventory value. In our model, we calculate the total weekly cost by adding the total holding, order, and product cost. We compare both cases and the lowest is the best decision.

Cheapest solution: We calculate the total cost for both cases by adding the expected holding, ordering, and product costs. This results in the following equation:

$$E(TC) = E(H) + E(O) + E(P) \qquad \text{Eq. 21}$$

The case with the lowest cost ($E(TC)_T$ or $E(TC)_{RM}$) is automatically the best decision. This solution results in the lowest costs overall. An extension is developed to give additional insights.

Extension: It could be that the overall best decision is different from the decision of a specific ready-made product. This extension enables the user to compare which ready-made product potentially could result in the highest benefits if it were tinted. This ranking is based on the expected total weekly costs per liter because this enables us to objectively compare the ready-made products.

$$E(TC_{RMi})\ per\ liter = \frac{E(H_{RMi}) + E(O_{RMi}) + E(P_{RMi})}{\mu_{DRMi}} \qquad \text{Eq. 22}$$

There are situations in which some items should be kept ready-made. We can identify these products by comparing the total cost per liter of the ready-made with the tinted item. If the total cost per liter of the ready-made item lies lower than the total cost per liter of the tinted item, then we know that we should keep the remaining products as ready-made. The following equation is used to calculate the expected total weekly cost per liter of Case T.

$$E(TC_T)\ per\ liter = \frac{E(H_T) + E(O_T) + E(P_T)}{\mu_{DT}} \qquad \text{Eq. 23}$$

We now know the expected total costs per liter for ready-mades; $E(TC_{RMi})\ per\ liter$ and tinted items; $E(TC_T)\ per\ liter$. The lowest is the cheapest decision for that specific item. If a ready-made turns out to cost more then we should delete this product from our model (this product should be tinted in-house). After this, the user can restart the model and calculate the input values based on the new situation.

In this chapter, we discussed the model that calculates the cheapest decision of the two cases: ready-made (Case RM) or tinted (Case T). We defined input variables, walked through the underlying calculations, formulated output variables and we were eventually able to calculate relevant results from this. This chapter has brought the requirements and objectives of the problem into a model and has provided the base of Chapter 5, which discusses the main findings of the model.

5. RESULTS

In Chapter 4, we designed a solution for the action problem. The so-called RTDM (Ready-made or Tinted Decision Model) can be tailored to a specific real-life scenario. It is therefore applicable to the company and could result in genuine savings if used properly. This chapter presents and discusses the results. So, we evaluate the outcomes of the decision model. Not only the decision itself but also the (possible) cost savings, impact on safety stock, and effect on delivery reliability. We use a data input button to generate a random potential situation for Company X B.V. While using these input values for 10 products, we walk through the results and try to establish managerial guidelines. Assumptions and limitations of the model are described in Chapter 6.

5.1. Ready-made or Tinted Decision Model

First, we show what the model looks like. More details about the RTDM are given in the following sections.

Ready-made or Tinted Decision Model	
Input values	
Desired CSL	95%
Weekly holding cost (% of ITP)	5%
Order placement cost	€ 500.00
Cost base product (per liter)	€ 5.00
Tinting cost (added as a percentage to base product)	20%
Z-score	1.64

Legend
Green/White = required changeable input value
Light green/black = possible changeable input values
Gray/Green = calculations
Gray/Blue = output
Blue/White = conclusion
Light blue/Black = comments
Gold/Black = base paint/tinted related
Brown/Black = ready-made related

Delete input values

Generate sample data

Comments on fill rate						
	Desired fill rat	0.89		Desired fr	0.89
	Gu(z)	0.99685496	1.25	StDev of lead	587.37
	z	1.22652812		EOQ	5322.91
	Desired ESC	585.519712		Desired ESC	585.5197122
	ss	0		ss	600.7963415
				Actual ESC	75.12893664

Comments on assumptions: Demand follows normal distribution, no correlation (demand is independent)

Demand is not necessarily identically distributed

Time is measured in weeks, demand is measured in liters

Input values base product	
Base product	
Cost tinted product (per liter)	€ 6.00
Mean lead time supplier (weeks)	3
StDev of lead time supplier (week	0
Mean demand in liters (per week)	8500
StDev of demand in liters (per we	339.12
Coefficient of variation	4%

Input values ready-made product											
Ready-made product	*Total*	1	2	3	4	5	6	7	8	9	10
Cost ready-made product (per liter)		€ 6.00	€ 6.00	€ 6.00	€ 6.00	€ 6.00	€ 6.00	€ 6.00	€ 6.00	€ 6.00	€ 6.00
Mean lead time supplier (weeks)		3	3	3	3	3	3	3	3	3	3
StDev of lead time supplier (weeks)		0	0	0	0	0	0	0	0	0	0
Mean demand in liters (per week)	8500.00	2000	1000	1000	1000	1000	500	500	500	500	500
StDev of demand in liters (per week)		250	100	100	100	100	50	50	50	50	50
Var of demand in liters (per week)		62500	10000	10000	10000	10000	2500	2500	2500	2500	2500
Coefficient of variation		13%	10%	10%	10%	10%	10%	10%	10%	10%	10%

Output values base product	
Base product	
Mean of lead time demand	25500.00
StDev of lead time demand	587.37
Total safety stock	966.13
Economic order quantity	5322.91
Total Cycle inventory	2661.45
Expected total inventory level	3627.59
Expected total inventory value	€ 21,765.52
Expected total holding cost	€ 1,088.28
Expected total number of orders per week	1.60
Expected total weekly order costs	€ 798.44
Expected weekly product cost tint	€ 51,000.00
Reorder point	26466.13
ESC	12.27
Fill rate	100%
Weekly costs per liter	€ 6.22
Percentage of cost	100%
Total weekly cost tinted	€ 52,886.71

Output values ready-made product											
Ready-made product	*Total*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Mean of lead time demand		6000.00	3000.00	3000.00	3000.00	3000.00	1500.00	1500.00	1500.00	1500.00	1500.00
StDev of lead time demand		433.01	173.21	173.21	173.21	173.21	86.60	86.60	86.60	86.60	86.60
Safety stock	2564.07	712.24	284.90	284.90	284.90	284.90	142.45	142.45	142.45	142.45	142.45
Economic order quantity		2581.99	1825.74	1825.74	1825.74	1825.74	1290.99	1290.99	1290.99	1290.99	1290.99
Cycle inventory	8169.96	1290.99	912.87	912.87	912.87	912.87	645.50	645.50	645.50	645.50	645.50
Expected inventory level	10734.04	2003.24	1197.77	1197.77	1197.77	1197.77	787.95	787.95	787.95	787.95	787.95
Expected inventory value	€ 64,404.22	12019.42	7186.61	7186.61	7186.61	7186.61	4727.67	4727.67	4727.67	4727.67	4727.67
Expected total holding cost	€ 3,220.21										
Expected number of orders per week	4.90	0.77	0.55	0.55	0.55	0.55	0.39	0.39	0.39	0.39	0.39
Expected weekly order costs	€ 2,450.99	€ 387.30	€ 273.86	€ 273.86	€ 273.86	€ 273.86	€ 193.65	€ 193.65	€ 193.65	€ 193.65	€ 193.65
Expected weekly product cost ready-made	€ 51,000.00	€ 12,000.00	€ 6,000.00	€ 6,000.00	€ 6,000.00	€ 6,000.00	€ 3,000.00	€ 3,000.00	€ 3,000.00	€ 3,000.00	€ 3,000.00
Reorder point		6712.24	3284.90	3284.90	3284.90	3284.90	1642.45	1642.45	1642.45	1642.45	1642.45
ESC		9.05	3.62	3.62	3.62	3.62	1.81	1.81	1.81	1.81	1.81
Fill rate		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Weekly costs per liter		€ 6.49	€ 6.63	€ 6.63	€ 6.63	€ 6.63	€ 6.86	€ 6.86	€ 6.86	€ 6.86	€ 6.86
Percentage of cost		23%	12%	12%	12%	12%	6%	6%	6%	6%	6%
Total weekly cost ready-made	€ 56,671.20										

Cheapest decision:	Tinted is cheaper overall									
Extension:	Ranking of which one would be most interesting to keep as a ready-made:	1	2	2	2	2	6	6	6	6	6

Figure 16 RTDM (1/2)

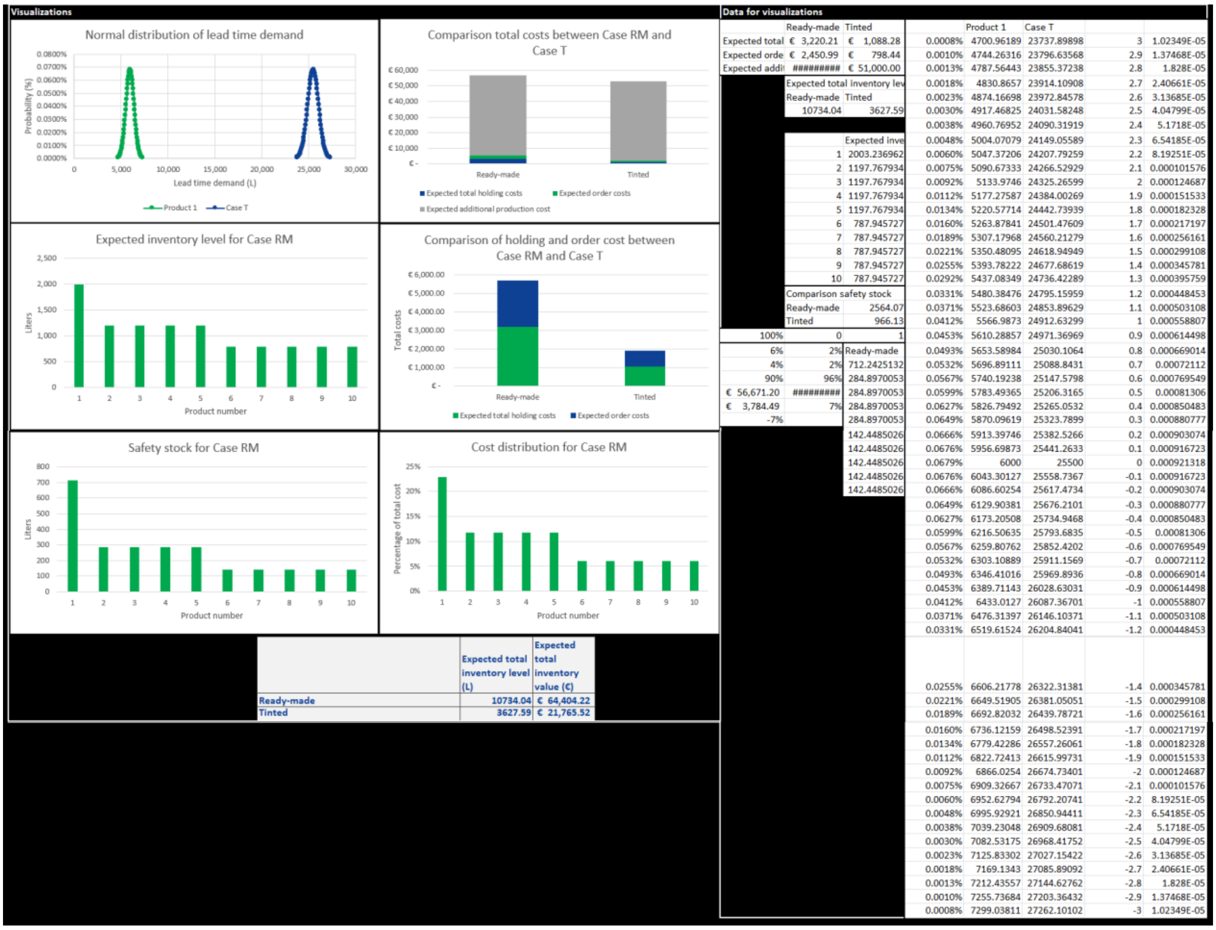


Figure 17 RTDM (2/2)

Figures 16 and 17 result in a general idea of the RTDM. Now, it is time to dive deeper into the model. We first compare inventories between both cases.

5.2. Inventory comparison

The comparison of inventory at Company X B.V. between the two cases (Tinted and Ready-Made) is key for understanding what the effects are. Our model takes this into account and from this, we can draw relevant results. The inventory level, consisting of both safety stock and cycle inventory is discussed here.

5.2.1. SAFETY STOCK

We discussed the way of calculating the safety stock in our model in Chapter 4. For the Case RM, we have 10 different ready-made colors belonging to the same base paint. A safety stock is calculated for each product. Some products need more safety stock than others to come to the same desired CSL. This depends on the input values that are provided by the user. The effect of aggregation is visible if we compare the safety stock of Case RM (Ready-Made) with Case T (Tinted) for our generated case.

Table 8 Safety stock of generated data

	Safety stock (L)	Safety stock (€)
Ready-made	2,564	15,384
Tinted	966	5,797

We see that, in this case, the total safety stock is much larger for ready-made products. In general, we can conclude from the RTDM that the larger the number of individual ready-made item demands, the larger this aggregation advantage becomes. Conversely, if there is only one ready-made product that could be tinted, the safety stock is the same as the base paint. For this case, we assume that lead time parameters for ready-made and tinted items are the same. This is done for comparison purposes. The aggregated safety stock of tinted items is never larger than the combined safety stock of all individual ready-made items. We thus see that the aggregation of demand has a positive effect on the safety stock. In our model, the user can also insert the standard deviation of lead time itself. The effects of this are substantial and almost diminish the effects of inventory pooling on safety stock.

5.2.2. CYCLE INVENTORY

The economic order quantity could differ for every ready-made paint, this depends on the input values. The aggregated economic order quantity for the base paint is almost always different from the ready-mades. An exception for this is if only one ready-made is considered to be tinted and all other input values are the same. We see that the aggregation advantages also hold for the cycle inventory. If we compare the cycle inventories then we see that the fraction of cycle inventory belonging to ready-mades is 50% or higher.

Order placement cost: If we increase the ordering costs, then the economic order quantities increase for both cases. The cycle inventory ($\frac{EOQ}{2}$) therefore also increases. We can conclude from our results that the total cycle inventory is almost always larger for the ready-made items. However, changing the order placement costs does not influence the percentual difference in cycle inventory between the cases (i.e. the ratio between them stays the same).

Holding cost: The EOQ is also influenced by the holding costs. Increasing this results in a lowered economic order quantity for both cases. This namely reduces the expected inventory level. We again see that the percentual difference in cycle inventory is not affected by this change.

5.2.3. EXPECTED INVENTORY LEVEL

Adding the safety stock and the cycle inventory results in the expected inventory level (Equation 16). We saw that safety stock and cycle inventory both decrease as aggregation in demand increases. Moreover, we saw that the percentual difference in cycle inventory between the two cases is not affected by either changing the order placement cost or the holding cost. For our generated data, we again see that the Case RM has a higher expected total inventory level.

Table 9 Expected total inventory level of generated data

	Expected total inventory level (L)	Expected total inventory value (€)
Ready-made	10,734	64,404
Tinted	3,628	21,766

Table 9 gives us a broad insight into the expected inventory levels for both cases. So, we can conclude that the inventory levels decrease if more paint is tinted in-house. Aggregating these inventories results in lower necessary levels to acquire the same cycle service level.

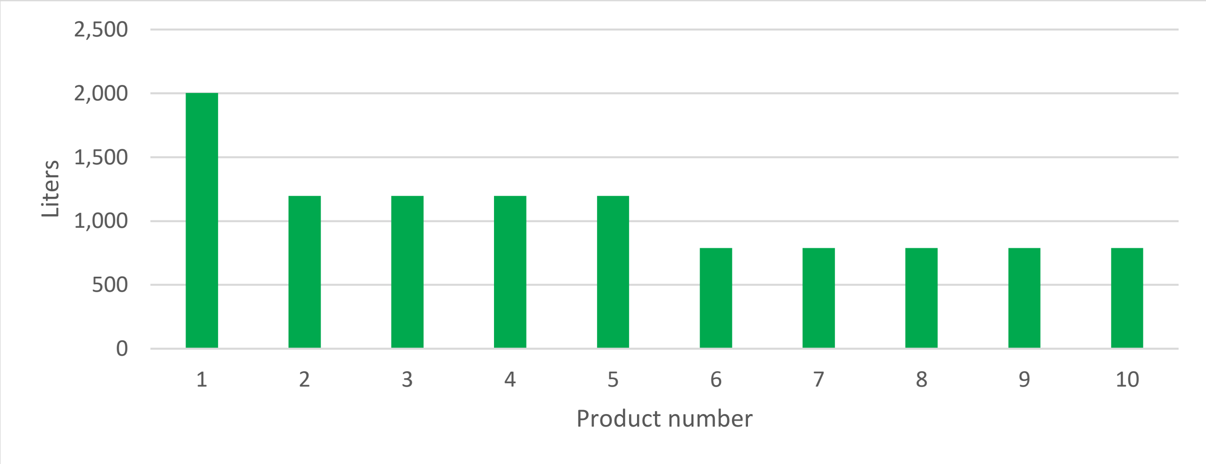


Figure 18 Expected inventory level for Case RM

Splitting the expected inventory levels into specific products gives insights into how the inventory levels are formed. Every individual ready-made product has its own inventory, some more than others.

5.3. Cost comparison

Three relevant costs are considered in our model: holding cost, order cost, and product cost. We cover each cost in a separate part. The sum of all costs leads to the cheapest solution, either ready-made or tinted. We start with the cost of holding inventory. This is based on the inventory level which we discussed earlier.

5.3.1. HOLDING COST COMPARISON

The holding cost is the cost of carrying inventory. This is based on the expected inventory level. More aggregation leads to a larger difference between the holding cost of either ready-made or tinted items. The inventory level and thus the holding cost of tinted lies lower, except if only one ready-made is considered to be tinted because then there is no difference.

In our generated case, we have 10 products that are considered to be tinted. We see that tinting would result in a 66% lower holding cost. However, reducing the number of aggregated products from 10 to 2 results in a decrease of (only) 27%. This shows that a base paint that could potentially aggregate 10 ready-made items results in significantly greater savings in holding cost than a base paint that would only aggregate 2 ready-made items.

We discussed the differences in holding cost between the cases by varying the number of products that are possibly tinted and by looking at what the effects are of changing the input variables. We also discussed the output values. However, we still need to discuss the effect of changing demand and lead time parameters on this cost. This is done in the following part.

Lead time parameters

Lead time from the supplier influences the holding cost. With our model, we can analyze what the effects are exactly. Changing the average lead time results in a change in safety stock and therefore a change in holding cost. We see that the benefits of tinting paint in-house for, in our case, 10 products outweigh the cost of increasing the lead time of tinted items. So, this would mean that the supplier of Company X B.V. has more time to produce base products than ready-mades while still achieving the same CSL. Of course, more costs influence the decision. But this is an interesting insight.

The standard deviation of lead time has a significant effect on safety stock. We see that the above-mentioned insight does not hold for the standard deviation of lead time. Increasing the standard deviation of lead time from zero to one week results in a large increase in holding cost which is not covered by the advantages of aggregation. Thus, the standard deviation of lead time from the supplier for base paints and ready-mades has serious effects on the cheapest overall decision if a difference is visible.

Demand parameters

Increasing the average demand affects the economic order quantity, and therefore, the holding cost as well. Although a change in demand influences both Case T and Case RM, the effects are different. We logically see that a higher demand results in higher holding costs. The difference in cost increases between the two cases if demand increases (because of seasonality for example). The holding cost for ready-made items increases if this is the case.

The safety stock and therefore the holding cost is also influenced by the standard deviation of demand. In our model, we also take this into account. The standard deviation of demand is also linked between both cases. We see that the advantage of aggregation increases if the demand for each ready-made has similar standard deviations. One outlier could have a serious effect on this.

We saw that the holding cost of tinted items is always lower. The difference between the two cases is not fixed. This depends on the values that the user puts in the model. The cheapest decision can not be made yet, this also depends on the ordering and product cost.

5.3.2. ORDER COST COMPARISON

In our model, we use the EOQ for calculating the cycle inventory. But, for the ordering cost, it is used to determine the expected number of orders in a week. The results of the model concerning these ordering costs are elaborated in this section.

The desired number of orders that should be placed in a week depends on the order placement cost. For Case RM, each individual product has another outcome for the expected number of orders. Case T only has one outcome. If we sum all EOQs for Case RM, then this is higher than Case T. However, if we look per product, the EOQ of the tinted items is higher. This means that each order contains more liters and therefore the order frequency is lower overall. Practically, this means that fewer trucks are necessary to transport the goods which is both economically and environmentally friendly. Multiplying the expected number of orders with the order placement cost results in the total ordering costs. This is always equal to or higher than the ready-made case.

Figure 19 Transportation of goods between supplier and Company X B.V.

The percentual difference does not change if we adjust the order placement cost, as previously stated. There are input values that do have an impact on this. The distribution of average demand for ready-made items for example. If the average demand across all ready-mades is similar, then the advantage of ordering costs for tinting increases.

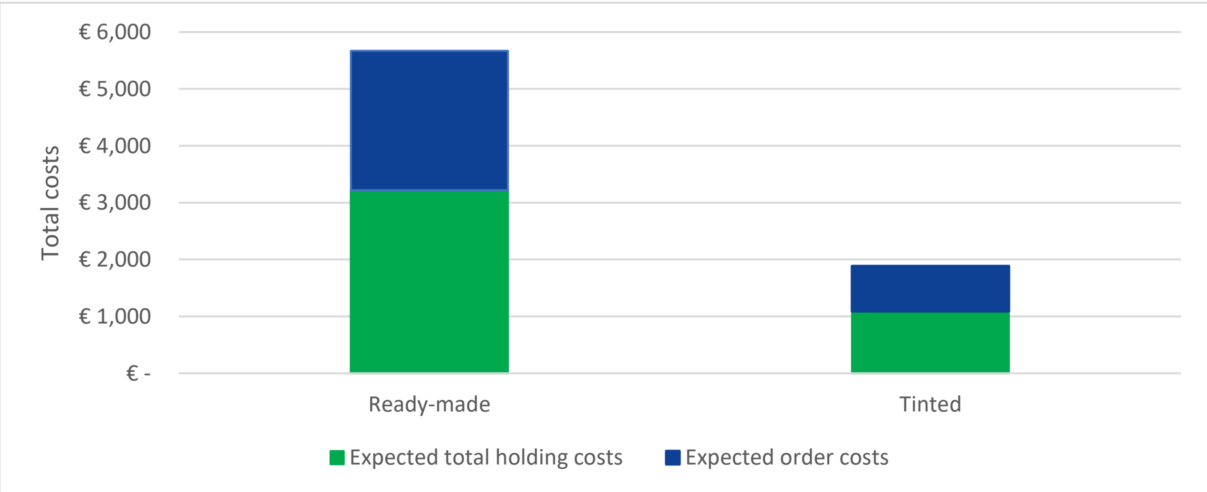


Figure 20 Comparison of holding and order cost between Case RM and Case T

The results of our generated input data show that there are considerable cost savings if the products are tinted in the Dutch warehouse. This is caused by both a reduction in holding and ordering costs. The more aggregation, the larger this difference will become. Tinted is never more expensive than ready-made by looking at these costs. However, another cost is necessary to create the full picture of the situation. The product cost forms a major part of the costs and without it, no decision can be made. So, the next topic is the product cost of both cases.

5.3.3. PRODUCT COST COMPARISON

An untouched topic is the product price of the products. This is the main component of the total costs and therefore has a large influence on the eventual decision. This section aims to result in a full understanding of the elements that influence this product cost.

In the model, we enable the user to insert multiple input variables that determine the eventual product cost. The first required input variable is the cost of the base product per liter. The price of the base product alone is only part of the story. We namely also need the tinting cost. This is the percentage that needs to be added on top of the price of the base product. This is currently set at 25%, however, this could be reduced if we take advantage of the possible economies of scale. Additionally, ready-made products also have a price. This could differ per ready-made product, the user can insert this in the model as well. Tinting costs of ready-made products are already part of this price.

If there is no difference between the cost of a tinted product and a ready-made product, like our generated input data, we get the following figure:

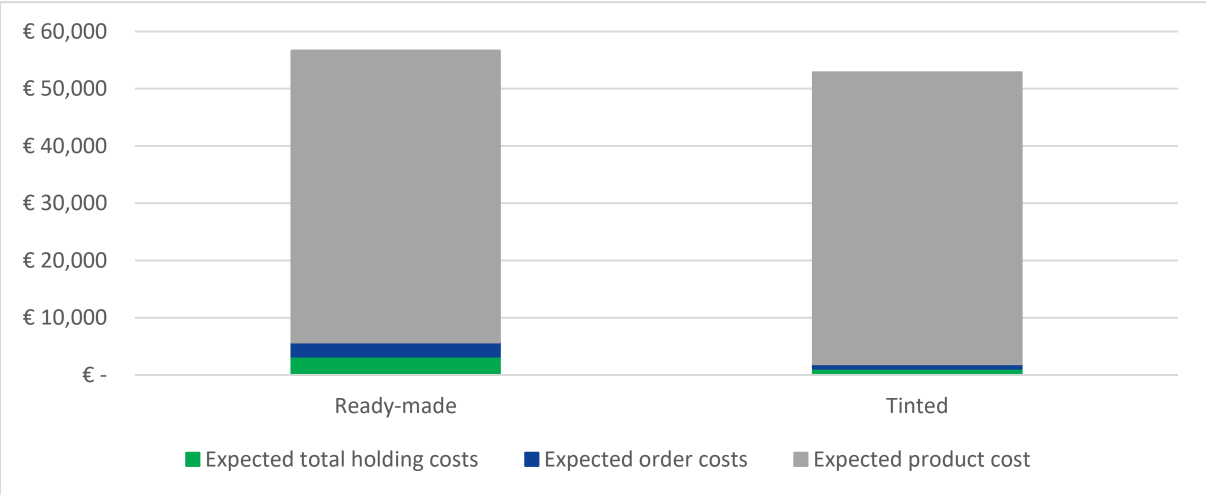


Figure 21 Comparison of total cost between Case RM and Case T

The expected product cost forms the majority of the total cost. The holding, and ordering costs are almost not visible for the tinted case. Since the tinted product cost (base paint + in-house tinting cost percentage) and the ready-made product cost are the same, we see that the difference in costs is the same as in Figure 20.

By changing the price of the base paint, we can investigate at which price ready-made becomes the cheapest solution. We saw that currently tinted has the lower price. However, if the price of the base paint is 37 cents higher per liter (€5.00 to €5.37) the cheapest decision shifts to ready-made. So, a relatively small increase makes ready-made paint more interesting. Conversely, lowering the price of base paint results in a shift of the cheapest solution to tinted. Another way to make tinted more interesting is to increase the price of ready-made paint. This is, of course, not the perfect solution since this increases total cost. A combination of both methods could also be applied.

Currently, tinted items are generally more expensive than ready-mades at Company X. For some products, the base paint has the same price as the ready-made paint. There are even cases in which the ready-made is cheaper than the base paint. If this is the case, then it will become (very) difficult to take advantage of the aggregation advantages since most of the costs are determined by the product price.

Figure 22 Comparison in ITP October 2023: Ready-made versus Base paint versus Tinted

The figure shows that there are indeed products for which base paint is more expensive than ready-made paint. Adding the 25% tinting cost on top of this base paint results in a difference that cannot be bridged with the advantages of aggregation. As explained, lowering the Internal Transfer Price (product price) could result in a shift in the cheapest solution.

5.4. Delivery reliability comparison

The main goal of this assignment was to increase the delivery reliability while limiting the increase in inventory value. Using our model, we gained insights into the decision of either ordering a product ready-made or tinted. We saw that the costs depend on several variables and thus the cheapest decision as well. In this section, we discuss what these changes mean for the delivery reliability from Company X B.V. to its customers.

5.4.1. CYCLE SERVICE LEVEL

The user can increase or decrease the desired cycle service level. In this way, we can determine what the effects of this input variable are on the cost and therefore the cheapest solution. Increasing the CSL results in a direct increase in the safety stock, and therefore, the holding cost also increases. This means that the overall impact of aggregation on the decision increases if the CSL increases. We also see that the difference in holding cost between Case T and Case RM also increases. In other words, it becomes financially more interesting to tint in-house.

5.4.2. FILL RATE

We have designed our model around the CSL. The fill rate would, however, come closer to the delivery reliability in the way that we have defined it in Equation 1. The fill rate namely looks at the immediate on-hand availability of products, while the CSL looks at the performance over a replenishment cycle. Delivery reliability, in the way we defined it, looks at the on-time order lines and is thus more closely connected to the fill rate which also looks at the immediate fulfillment of customer orders from existing inventory at the moment when the order is placed. We assume that on-hand products will be on time to make the connection between fill rate and delivery reliability.

As noted earlier, the fill rate is used in our model as an output value. We see in our model that the fill rate is not the same for all ready-made products. Especially if the lead time demand for a ready-made product is much higher than that of the other products.

Example: Let us look at our generated data input file and adjust the CSL to 80%. We increase the standard deviation of demand for ready-made product 1 to 2000L (instead of 250L). We see that the fill rate of product 1 drops from 98% to 85% because of this increase, while the remaining ready-made products stay on a fill rate of 99%. Case T shows us that the average fill rate for aggregated demand drops from 99% to 93%. So, to increase the fill rate we would need to stock more.

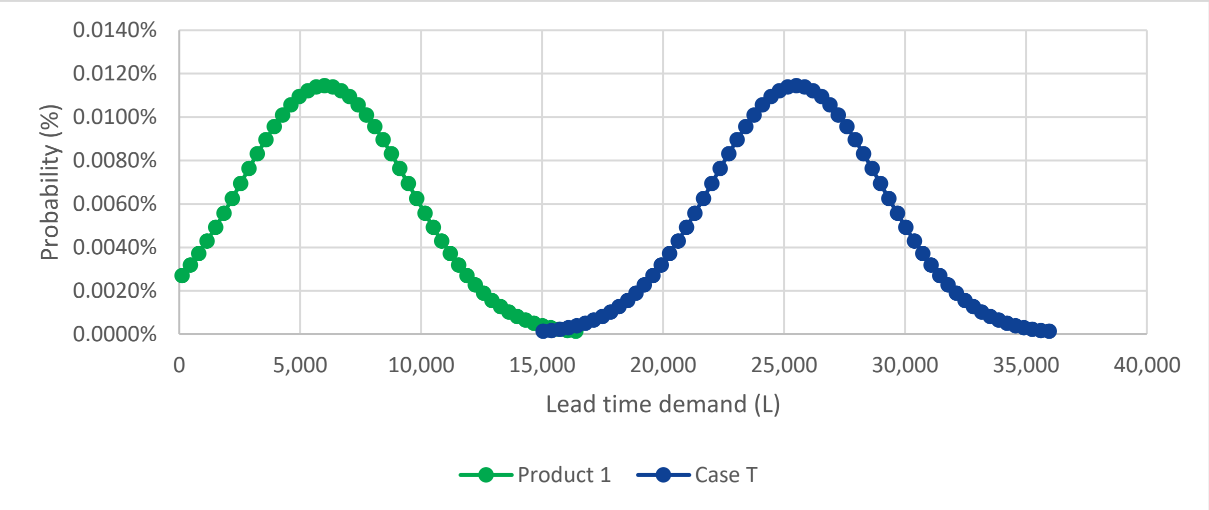


Figure 23 Normal distribution of lead time demand

The lead time demand of the abovementioned example is visualized in Figure 25. We can see that the shapes of both graphs are similar. However, the coefficients of variation are unalike. Product 1 has a coefficient of variation of 58% while Case T has 14%, in this example. Values thus deviate more from the mean for product 1 in comparison with Case T. This affects the fill rate.

In general, we can conclude that, for Case T, the fill rate is constant because demand is aggregated. However, for Case RM, there are different fill rates for different products. The fill rate of product 1 could have a completely different fill rate than product 2. In the next chapter, we evaluate what the cheapest decision is for Company X B.V.

5.5. Ready-made or tinted decision comparison

In the previous sections of this chapter, the outcomes of the model have been described. The inventory levels, total costs, and delivery reliability metrics have been analyzed for both decisions. This section explains what the cheapest decision is. Moreover, a ranking is described to further optimize the inventory.

5.5.1. CHEAPEST DECISION

The addition of all relevant costs results in the decision for Company X. Our model calculates the total weekly cost for both cases. The lowest cost is automatically the best decision. We saw that the fill rate is another key output variable to keep in mind by the user.

Our model enables the user to investigate which ready-made products account for most costs in the process. The visualization for our generated input data is given below:

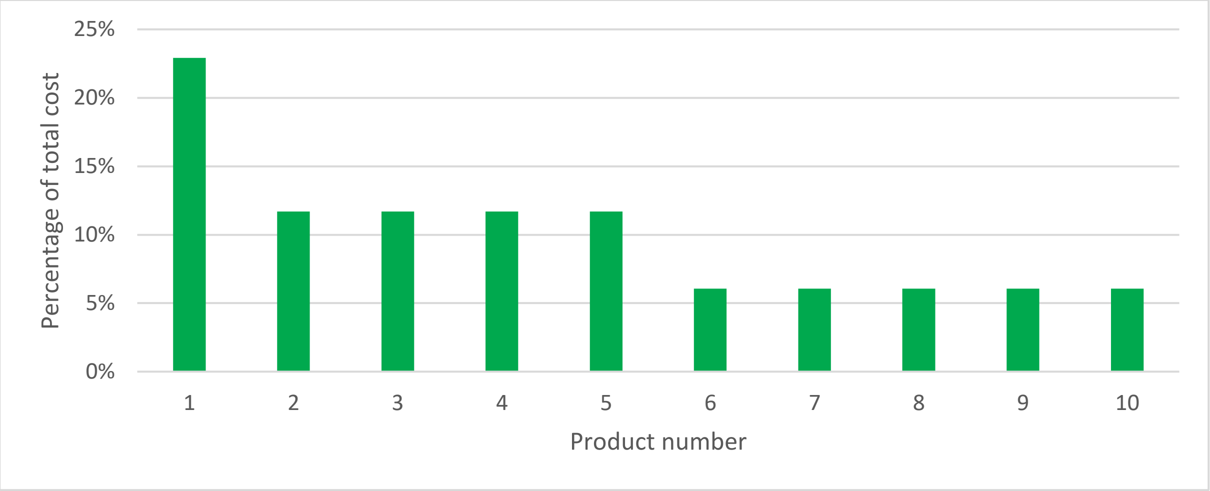


Figure 24 Cost distribution for Case RM

The figure shows that most costs are allocated to product 1. In this case, it is caused by the mean demand which is highest for this product. In this case, the weekly cost per liter are lowest. This measure is a crucial element for our ranking mechanism. This is covered in the following part.

5.5.2. RANKING

The ranking allows the user of the RTDM to examine which ready-made product(s) should be tinted first. We look at the weekly total cost per liter. The model shows for which ready-made product, this value is highest. This means that this product negatively influences the ready-made case. The cells are conditionally formatted. This results in an easy-to-use iterative process in which the user deletes the content of the input variables of the ready-made that scores highest on the ranking (i.e. the product shift from ready-made to tinted). This is namely the product that benefits most from being tinted. There are situations in which the model gets a new cheapest overall decision, after shifting a certain product from ready-made to tinted. This means that at that point, the user should stop shifting products since this would negatively influence the total costs. The remaining products should be kept as a ready-made, while the deleted products should be tinted. This extension results in a cheaper solution than the overall best decision.

High selling, cheap ready-made products are the products that should be kept as a ready-made. However, expensive products with high demand (and lead time) variability, are perfect candidates for in-house tinting. With our model, we are able to evaluate this and come to an (overall) cheapest decision while limiting the increase in inventory value. In the next chapter, we discuss these results and formulate a conclusion.

6. CONCLUSION AND RECOMMENDATIONS

In this chapter, we derive the conclusions from the researched topics. We have seen that a low delivery reliability has resulted in problems at Company X. One of the causes for this is the suboptimal policy of ready-made versus tinted paints. A model was created that calculates the cheapest decision. We have thus found an implementable solution which helps Company X in decision-making. This, together with the other relevant insights helps Company X in moving forward.

6.1. Conclusion

Delivery reliability from Company X B.V. to its customers has been the main cause of the reduction in sales. This is both caused by suppliers and suboptimal inventory management. This research has focused on improving the delivery reliability by optimizing the policy of ready-made versus tinted paints.

Aggregation of demand is the core topic of this research. This is achieved through tinting paint in-house. The effect of this is a reduced overall standard deviation, caused by this aggregation effect. Tinting leads to postponement of customization point in the supply chain. This, in turn, improves flexibility since the base paint is only tinted when demand is known.

Our model was designed with the aim of proofing that the abovementioned theory also holds, and is relevant for, Company X. We enable the user to create actual situations and scenarios by providing applicable input variables. The calculations, based on the described literature, result in interesting output variables and the cheapest decision. This decision minimizes total cost, given a desired cycle service level. Next to this, the user can see what the accompanied fill rate is. So, therefore, we also indirectly improve the delivery reliability from Company X B.V. to its customers.

Next to the overall cheapest solution, we developed an extension. This shows which ready-made products (tinted at the supplier) should be tinted first, by ranking them. After iteratively applying this method, the user is able to conclude which should be tinted and which should continue to be ordered as a ready-made.

The RTDM results in an optimized tinting policy, while obtaining the same desired CSL. This results in lower cost compared to the current situation in which the decision is mostly based on “feeling” and product costs. In our results, we showed what the effect of Case T (tinted) and Case RM (ready-made) were. We could conclude that Case T is cheaper than or equal to Case RM by looking at the holding and order cost only (if lead times from the supplier are the same). We saw, however, that the product cost formed a large percentage of the total cost. So, if Company X wants to benefit from the advantages of aggregated inventory, the costs of the tinted and ready-made paint should not differ with a large amount. Otherwise, tinting in-house (Case T) does not become the overall cheapest solution. In the next part, we discuss recommendations for the company.

6.2. Recommendations

This section is used to outline several recommendations, this is based on the research. The aim is to provide guidance on the actions that could be taken by Company X.

Implement the RTDM: The implementation of the RTDM would be the first recommendation. Possibly into Qlik Sence or Microsoft Power BI which are the current Business Intelligence tools that are being used by Company X. It would be recommended to also deploy this model across all Company X locations, if successful at Company X B.V. in the Netherlands. This would namely result in even more cost savings for the company as a whole.

Accurately calculate input values: The outcome of the model is based on the input values that the user provides. Therefore, these should be carefully determined. Input values that deviate largely from reality result in an incorrect solution. It is for example especially difficult and time-consuming to determine demand and lead time parameters per product. Therefore, the recommendation is to automatically calculate these input values in particular by connecting it to the preferred business intelligence tool. In this way, human errors are reduced. A general understanding of distributions and determination of parameters is namely necessary to accurately determine especially these values. We would therefore also enhance user-friendliness. The more data we have for these values, the more accurately the demand parameters become. Other input values like the product prices require less calculation. Moreover, input values like the weekly holding cost or the order placement cost need to be calculated once and do not have to be recomputed for every tinting decision. It is therefore less important to calculate these values automatically.

Reduce Internal Transfer Price of base paint in comparison with ready-made paint: The influence of the product price on the cheapest solution is substantial. The advantages of aggregated inventory possibly outweigh the extra costs of tinting in-house. If not, Company X could reduce the ITP of base paints such that Case T still becomes the cheapest decision. This can be done if the manufacturing site takes the costs of either producing a ready-made or a base paint into account. It is possible that a base paint is cheaper in terms of ITP because less handling is required by the manufacturing site and paint can be produced in larger batches since demand is aggregated. In general, we can state that more in-house tinting would reduce the holding and ordering costs.

Improve cooperation between Company X locations: Currently, Company X B.V. would only benefit from the advantages of aggregation. But, as also stated in the research of Zheng et al. (2022), the benefits could also be shared across the supply chain. This could practically mean for Company X B.V. that the cost advantages of tinting in-house, and therefore reducing the holding and ordering cost, are shared. However, it could also be the case that production benefits either from tinted or ready-made paints. This cost currently does not influence the RTDM, but would be another interesting factor that could play a role. Generally, a cooperation (contract) reduces overall costs (Zheng et al., 2022). The recommendation would be to also implement the centralized system. To do this, Company X B.V. should also take the total cost at the production site into consideration. The addition of the total cost of both Company X B.V. and the manufacturer results in the cost for the entire company. Then, the cheapest overall tinting policy should be chosen. This could be different from the decentralized optimum since production is not taken into account in the RTDM.

These recommendations are listed in the order of priority. This means that the implementation of the RTDM has the highest priority. The abovementioned recommendations could help Company X (B.V.) in becoming more efficient. In the next section, we discuss the interpretation of the results of this research.

6.3. Discussion

In this section, we discuss the interpretation of the results, together with the assumptions and limitations. The output of the model has provided us with key insights. Some of them were unexpected. The product cost (ITP) has a larger influence on the cheapest solution than expected. The standard deviation of lead time from the supplier is another input variable which has unexpected effects. The percentual difference between the total cost of Case T and Case RM decreases rapidly.

6.3.1. ASSUMPTIONS

For the RTDM, several assumptions were made. These are necessary since we are otherwise unable to analytically evaluate the situation. Some assumptions deviate more from reality than others.

Demand and lead time normally distributed: For analytical reasons, we assume the demand and lead time to be normally distributed. This assumption has impact on the accuracy of the outcome. Inaccurate predictions could occur if demand or lead time significantly deviates from normal demand. However, also by looking at the ease of implementation, this assumption is justifiable.

No correlation between ready-made products: In our model, we assume the correlation between ready-made products to be zero. In theory, this correlation coefficient could have a value ranging anywhere between -1 and +1. We assume this, again, because of user-friendliness and analytical simplicity. Including the effects of correlation certainly has impact on the eventual cheapest decision. However, the choice is justified because of the abovementioned reasons. The model is a representation of reality, not reality itself. For further research, we would advice to also take this correlation into account.

Utilization of the EOQ with stochastic demand: Our model assumes that demand is normally distributed. While the classic EOQ considers a constant demand rate, we use it for our case as well. The EOQ model is namely a relatively robust tool in inventory optimization. It is an easy way to set good lot sizes and therefore helps us to determine the cheapest solution in the RTDM. Optimizing the EOQ would result in further improvements, but is not part of our research for the sake of simplicity.

Using 10 ready-made products in the RTDM: We enable the user to insert a maximum of 10 products in our model. This is namely “enough” according to the Commercial Portfolio Manager. Scaling the model is (easily) possible, but to keep everything in an understandable overview, it is kept in this way.

Not all ready-made products that could be made using the base paint need to be taken into consideration. Only the products ready-mades that are kept in stock in the Dutch warehouse.

The listed assumptions were necessary to successfully finalize the model. These, together with other factors, result in limitations of our study. They lie outside our control, but result in a transparent understanding of the constraints of the research.

6.3.2. LIMITATIONS

The limitations of this research are the set of answers that could not be answered by this research. We discuss this to emphasize and acknowledge that these are present.

Our model contains some weaknesses, like any other model. We do not know if the user of the model at Company X is able to accurately calculate input values. This has not been automized (yet) and this therefore increases the risk that a suboptimal solution is generated. Another limitation is the applicability of this model on the whole organization. Variables that influence the decision could namely be different at other organizations. We for example have limited insights in what the effect of more tinting would be on a production country (i.e. a country possessing a factory). We reduced our scope to products that are customized by tinting, perhaps the research would be applicable to other products (or even other kinds of organizations as well). Therefore, in the next section, suggestions for further research are given.

6.4. Suggestions for further research

After analyzing the assumptions and limitations, we now work towards recommendations for further research. This section outlines potential interesting additions to the discussed topics.

The RTDM depends, as discussed, on what the user inserts. Automizing the input by using the preferred business intelligence tools results in more accurate input data. This would be beneficial for the process since results are optimized while the user-friendliness of the model is not compromised. In this way, results could be received faster as well. The ultimate model would only require the name of the products as user input. The model would then, based on the attached input values, calculate the cheapest solution. This would simplify the operating procedure for the user, while the output values are not affected. Demand parameters, based on the connected historical sales of the requested product, would be automatically calculated. Then, we would also be able to calculate and thus take the correlation between the ready-mades into account which further improves the model. The ultimate model would be able to allocate a specific product to either ready-made or tinted without any human input.

Automation of the calculation procedure of the extension would result in further improvements of the RTDM. This would namely reduce the need for users to edit the input variables (based on this ranking) and would therefore reduce the risk of human errors. It can be done in a relatively straightforward way by developing a VBA code. The code should automatically delete the ready-mades with the lowest total weekly costs per liter until the costs of ready-made items are lower per liter than tinted items.

“Deleting” here means that this specific ready-made item should be tinted in-house. The remaining products in the list should be ordered ready-made, according to the model. This reduces workload and improves accuracy since Excel does not make mistakes.

Incorporating the cost of returns, production, complaints, and quality would further refine the RTDM. This, together with taking the salvage value of the products into account, results in a more accurate representation of reality. Also, the small batch charge that Company X needs to pay to the supplier if small orders are placed is currently not integrated in the model. Due to time constraints, we were not able to incorporate this. But, embedding these values is relatively straightforward. So, this would be a suggestion for further research.

The cheapest tinting solution depends on the total cost savings. In this research, we have only taken the effects on Company X B.V. into account. Cooperation between the different Company X sites could be a topic for further discussion. Possibly by using cooperation contracts and incorporating the effects of the ready-made or tinted decision on the supply chain as a whole. Company X B.V. is part of the Company X Group, so the company should not shoot itself in the foot. We could also deploy the RTDM at all Company X locations.

Deploying the RTDM across the whole organization would result in increased benefits. Doing so is not simple. The further research would have to incorporate geographical, economical, operational and many other differences that exist between the different locations in which Company X is situated. If a successful implementation is carried out, the RTDM would influence the whole organization. This would increase the delivery reliability and cost savings even more.

Applying this research at different industries could potentially be interesting as well. These companies should have some form of customization in its operations for this research to be relevant. Investigating in what way postponing the point of customization affects these other organizations is our final suggestion for further research.

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