Inventory policy design for chisel tips at Rottink Zuigerverenfabriek

Bachelor Thesis

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23rd of January 2024

ROTTINK Zuigerverenfabriek BV

UNIVERSITY OF TWENTE.

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Research information

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Publication date:	23rd of January 2024
Version:	2.0
Number of pages:	47
Number of appendices:	3

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Foreword

Dear reader,

In front of you lies the bachelor thesis "inventory policy design for chisel tips at Rottink Zuigerverenfabriek". This research performed at Rottink Zuigerverenfabriek in Almelo forms the final assignment for my bachelor Industrial Engineering and Management.

My gratitude goes out to everyone at the company who helped me to do this assignment. Special thanks to Wim Embsen and Kitty Kuipers who were always available and willing to help with any issue I ran into. Their guidance and feedback during my time at the company were of great help.

I also want to express my gratitude to my supervisors at the university for helping me complete my first research. A special thanks to Matthieu, for his extensive feedback and guidance during the execution of this assignment.

Lastly, I want to thank all my friends and family for their unwavering support and trust throughout the whole graduation adventure.

I hope you enjoy reading my thesis.

Ivan Miocevic

Management summary

Problem context

Rottink, a piston ring manufacturer, wants to reduce costs and the number of stockouts in inventory management of their tools. Moreover, they aim at reducing the number of separate orders and thereby the associated administrative work.

This research specifically focusses on the 96 chisel tip SKUs, Rottink's primary tool category. Rottink sources its chisel tips from three suppliers. The lead time for chisel tips at Rottink is maximally 48 hours. In the current inventory policy, inventory management is ad hoc based on the subjective judgement of the warehouse manager. Orders are initiated when the last package of a SKU is taken. Following this rule, one can assume that if a quantity X is ordered at day Y and the subsequent order is placed at day Z, the demand between days Y and Z corresponds to X. Chisel tips are mostly packaged in batches of 10, occasionally in batches of 5. One package is enough to fulfil lead time demand. However, production employees do not always notify the warehouse manager that the last package is taken. This causes delay in order initiation which can cause a stockout. The only data available on tool inventory are the history of tool order placements. From this data, a dataset is created containing the history of chisel tip order placements through a 5-year timeframe (2018-2022). The demand rates of chisel tips are extracted from these data based on the above-mentioned assumption.

Annual demand is on average 64 units, with a median of 13 units and a mode of 4 units. Some SKUs, based on singular demand, were ordered once or twice through the 5-year timeframe. There also exists a group of fast-moving chisel tips. The average annual demand for these SKUs is over 100 units. A significant difference exists in chisel tips required on singular bases or on regular bases. The SKUs required on regular bases fit the description of deterministic demand. The SKUs required on singular bases have stochastic demand and are not ordered for inventory but for single-use purposes. Therefore, these SKUs fall outside inventory management.

Through the design of a new inventory policy, Rottink aims to reduce inventory management costs and the number of separate orders. A complementary new warehouse procedure is designed to prevent the occurrence of stockouts. Through the execution of a problem-solving approach, the following research question is addressed:

How to design a new inventory policy to optimize inventory management for Rottink BV's chisel tip inventory?

Current inventory policy

An analysis on Rottink's increase in tool costs through the year 2022 made clear that exceptional inflation, not inventory management, drove tool costs up significantly.

For most chisel tips, except for the most fast-moving chisel tips, the order quantity fulfils demand for a longer period, indicating a large order quantity. As a result, a chisel tip requires less than 2 orders per year on average. Still, the number of separate orders for or including chisel tips is large. Therefore, there are only 1,7 SKUs on average per order. Order costs are incurred when the order value does not exceed a certain monetary value. Order costs are incurred in roughly 20% of the orders and amount to just over €1.000,00 annually. Holding costs amount to €3.500,00 per year on average and indicate drawbacks of the sizable order quantities. Lot size-based discounts saved €180,00 over a five-year period, an insignificant amount. Therefore, they are omitted from the new inventory policy. The new inventory model must be deterministic and multi-item. Multi-item replenishment should increase the number of SKUs per order and reduce the number of separate orders. Rottink also requires a new warehouse procedure for stockout prevention.

Literature

Through a literature study, inventory models are theoretically examined on pertinence for the joint-replenishment decision at Rottink. The Chan and Chiu heuristic (Chan & Chiu, 1997) is analysed in detail as it emerged as most suited in a comparison analysis with other inventory models. The Chan and Chiu heuristic performs well with less accurate demand forecasts as is the case at Rottink. The heuristic has promising results with an inefficiency within 10% of the optimum. Importantly for Rottink, the heuristic is extremely simple in its functioning. It is initially regarded as most suited for chisel tip management at Rottink.

Regarding the new warehouse procedure aimed at preventing stockouts, part of the solution involves transitioning from verbal agreements to transparent and accessible guidelines depicted in a Business Process Model (BPM). This graphical representation is comprehensive and enhances seamless operation, important elements in Rottink's warehouse workflow.

New inventory policy

In the new inventory policy, orders are still initiated when the last package of a SKU is taken. After order initiation, the joint-replenishment decision based on the Chan and Chiu heuristic decides which chisel tip SKUs are included and in which quantity. A sensitivity analysis indicates that the optimal timeframe for the heuristic is 24 months long. The length of the time periods depends on which key aspect has priority, the financial performance, or the administrative efficiency. At Rottink, the aim is to reduce costs while reducing the number of separate orders. Then, using time periods of 3 days is the optimal decision. Coordinated joint-replenishment in the new inventory policy notably increases the average number of SKUs per order from 1,7 to 1,9, leading to a 5% reduction in order costs, and reducing the number of separate orders. This is remarkable considering the 15% reduction in average order quantities. These are reduced as the holding cost rate has significant influence on order quantities in the new inventory policy.

In the new warehouse procedure employees are supposed to take only the needed amount of the required chisel tip and leave the package with the remaining chisel tips in inventory. The error of an unreturned package is thus no longer possible. A container for last packages is introduced, aimed to prevent delay of order initiation. The container is considered a significant improvement by the warehouse manager and production employees. The necessity of observing all inventory levels every time an order is initiated is questioned. This is resolved as the heuristic performs well with demands of zero, eliminating the need to extract exact inventory levels of SKUs with high inventory, as demand to fulfil will be zero in these cases.

Implementation

For successful implementation, employee engagement through informative sessions aimed at familiarization with policy changes and underlying logic is crucial. Recalling employees on guidelines through various methods assists the prevention of errors in adherence. Guidance to the warehouse manager until able to carry out all activities independently is important. By embracing a proactive and inclusive implementation strategy, Rottink mitigates risks and ensures a smooth integration of the new inventory policy and warehouse procedure.

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1. Introduction

In this chapter, Rottink Zuigerverenfabriek is introduced (Section 1.1). Next, the problem context and problem identification are sketched (Section 1.2 & 1.3), followed by the norm and reality of the problem (Section 1.4). Section 1.5 provides the problem-solving approach and the research questions of this research. Section 1.6 describes the scope of the research. The scope is followed by the key constructs and the deliverables of this research (Section 1.6 & 1.7).

1.1 Company introduction

Rottink Zuigerverenfabriek is a highly specialized piston ring manufacturer. Piston rings are important components of any combustion engine. Piston rings seal the combustion chambers of an engine. They minimize the loss of gas, regulate oil levels and consumption, and improve the heat transfer from the piston to the cylinder wall. Without piston rings an efficient combustion engine is not possible. Rottink therefore plays a vital role in our modern-day society.

The company employs around 30 people of which most work in the factory. Rottink Zuigerverenfabriek was founded in 1946 by Bernhard Rottink. Rottink is a real example of a factory from the Twente region. They are located in a beautiful building at the new XL Businesspark in Almelo.

1.2 Problem context

Rottink Zuigerverenfabriek wants to reduce inventory management costs and the number of stockouts in tool inventory. The tools consist of various pieces of equipment used to produce piston rings. Nevertheless, chisel tips are the most important piece of equipment in the production process. They constitute almost 65% of the total tool purchasing costs, despite having a relatively cheap price per unit. Most of the tools, especially chisel tips, are not long lasting and therefore require regular replacement. The management of tool inventory is thus a vital element in Rottink's operation. Currently, no structured inventory policy is in place at Rottink. Tool inventory is managed ad hoc. The warehouse manager is responsible for tool inventory management. This individual possesses complete knowledge of the process. The inventory management process at Rottink is not documented. A considerable concern for company management is that the absence of the warehouse manager would significantly hinder inventory management.

The past year (2022) Rottink experienced a vast increase of over 35% in tool costs. Rottink attributes this increase to misfunctioning inventory management. Rottink recognizes the influence of external factors on the increase but attributes a significant role to inefficient inventory management. With the execution of this research, Rottink aims to reduce costs associated to tool inventory management.

Rottink also experiences stockouts in the tool inventory. According to the company these stockouts are caused by miscommunication in the warehouse procedure. A warehouse procedure structurally guides the warehouse workflow. The current warehouse procedure is operated based upon verbal agreements. Nevertheless, these agreements are not always adhered to as not all employees are attentive to them. This causes operational issues in the warehouse workflow and can eventually cause stockouts. The role of inventory management in the occurrence of stockouts is researched in Section 2.4.5.

Summarized, inventory management costs and the number of stockouts, are not at Rottink's desired level. Moreover, the number of separate orders as a result of ad hoc inventory management causes loads of associated administrative work.

1.3 Problem identification

The problems discussed in Section 1.2 all lead to higher costs for the company in general. Tool stockouts and administrative inefficiency ultimately contribute to the high inventory policy costs as well. Therefore, the overarching problem for Rottink is the high cost associated to their tool inventory. Specifically, the high inventory management costs. This leads to the following formulation of the **action problem:**

"High inventory policy costs."

Following the problems leading to the action problem, one will find the overarching source of all problems. Namely the ineffective and lacking tool inventory management. The **core problem** can therefore be formulated as follows:

"Non-existence of tool inventory policy."

The relation between the action- and core problem is portrayed in the problem cluster in Appendix A. The core problem is defined as the non-existence of a tool inventory policy. The non-existence of a warehouse procedure is not a separate core problem as the warehouse procedure is a complementary part of the inventory policy.

The measurability of the core problem is linked to the main problems experienced by Rottink (Section 1.2) and can be expressed in the following three variables:

Variable 1: *Tool inventory management costs per year (expressed in €)*
Variable 2: *Number of tool stockouts per year*
Variable 3: Number of separate orders per year

To address the problems Rottink faces in their tool inventory, Rottink aims to improve on all three variables. To achieve this, Rottink desires a coherent inventory policy and warehouse procedure.

1.4 Norm and reality

The problem presented by the company reflects upon the gap between norm and reality. The norm represents the desired situation whereas the reality represents the current situation. The desired situation for Rottink is to solve the core problem by designing a new inventory policy that improves tool inventory management. The norm that follows is to have an operational inventory policy in combination with a seamless warehouse procedure.

The reality shows a different picture. There is no worked-out inventory policy in place and inventory is managed ad hoc. Moreover, the verbally-agreed guidelines in the current warehouse procedure are not always adhered to, causing issues. Rottink faces a gap between the norm and reality. With the execution of this thesis, they aim to bridge this gap.

The gap between norm and reality can be expressed numerically using the three variables from Section 1.3. The reality, so the current performance of tool inventory management costs is €22.789,80 on average per year over the last five years. For the number of stockouts, the reality is not extractable from any recorded data. According to an estimate from the warehouse manager, a stockout occurs around once every two weeks. Multiplying this number gives a value of 26 chisel tip stockouts per year. The reality of the number of separate orders for or including chisel tips per year is around 87. To bridge the gap between norm and reality, Rottink aims to reduce the tool inventory management costs and the number of separate orders by a minimum of 15%. The number of stockout Rottink aims to reduce to almost zero. It is unknown whether this is a realistic goal, due to a lack of data.

1.5 Problem-solving approach and research questions

As mentioned in Section 1.4 there is a clear gap between norm and reality concerning tool inventory management at Rottink. To solve the core problem as defined in Section 1.3, the main research question and accompanying sub-questions are formulated. The main research question is as follows:

How to design a new inventory policy to optimize inventory management for Rottink BV's chisel tip inventory?

To answer the main research question a systematic problem-solving approach is needed. The sub-questions below are created to provide in this need.

1. *How is the current inventory policy performing?*

First, a detailed overview of how the current process performs is needed. The context in which Rottink's tool inventory is managed is an important starting point. Then, the functioning of the current inventory policy is documented. Before looking at the current inventory policy, chisel tip demand is analysed. The total tool costs are researched as well as to analyse the cause of the major increase in 2022.

Then, the operational performance of the current inventory policy is researched. Also the role of the inventory policy in the occurrence of stockouts is researched. Lastly, the current warehouse procedure is analysed. The objective of this sub-question is to conduct a quantitative analysis of the existing inventory policy to map the policy and identify areas of underperformance.

2. *What inventory models exist for managing tool inventory effectively?*

Now that the current policy is fully observed one can look at what inventory models exist that fit Rottink's tool inventory context. This sub-question is answered by a literature review. First, a comparison study selects the inventory models most suited. Then, that model is worked out in-depth.

Lastly, the format of the warehouse procedure is discussed to ensure seamless operation.

3. *What is a suitable inventory policy design for Rottink's tool inventory?*

Here, the inventory policy is designed. The inventory model presented in the previous sub-question is revised so that the mathematical model best represents the actual situation at Rottink. Moreover, it is given a place and function within the revised steps of the new inventory policy, which are discussed in this chapter as well.

Accordingly, the warehouse procedure is designed.

4. *How does the new inventory policy perform?*

It is time to test the new inventory policy and warehouse procedure. A sensitivity analysis is performed on the performance of the policy under different circumstances. Afterwards, an in-depth validation of the new inventory policy against the current inventory policy using the heuristic in optimal alignment is performed. Lastly, the performance of the new warehouse procedure is also analysed.

5. *How can the new inventory policy be effectively communicated and implemented across the organization?*

After the design completion, the implementation of the new inventory policy and complementary warehouse procedure are discussed. Now that the inventory policy is designed it is important to consider the best method of implementation. Based on the different stakeholders, a method is designed to safeguard successful implementation.

6. *Conclusions, recommendations & limitations*

In this final step of the problem-solving approach, the conclusion of the research is discussed. By summarizing the conclusions from the sub-questions, a walkthrough of the main observations and findings of this research is created. Following this, the recommendations for Rottink following the research are discussed. Lastly, the limitations regarding the execution of this research are discussed.

1.6 Scope

Due to time constraints for the execution of this thesis, it is important to elaborate on the scope. Firstly, the tool inventory of Rottink consists of 323 different SKUs. 265 of these have only been bought once or twice during the past five years indicating singular demand. This research will limit itself to the 96 chisel tip SKUs. Chisel tips do require regular replacement. Moreover, chisel tips are responsible for just short of 65% of the total tool costs, despite being relatively cheap per unit. The design of a new inventory policy is therefore especially important for those 96 chisel tip SKUs.

The warehouse procedure describing the workflow in the warehouse will only encompass a worked-out procedure for systematically managing the tool warehouse. This procedure is to be kept simple and for everyone interpretable. Therefore, this procedure is expressed in the form of a graphical model. A graphical model is straightforward and for everyone interpretable. Furthermore, the creation of a graphical model is less time consuming than alternative deliverables. The format of the graphical model is discussed in Section 3.3.

It is imperative that the process workflow for the new inventory policy and warehouse procedure remains manually workable, like the current system. While automatic inventory management by help of technology may be desirable in the future, it is not feasible in the limited timeframe of this thesis. Therefore, the new inventory policy is designed around manual inventory management.

Lastly, it is important that the new inventory policy does not impose significantly higher labour demands on employees compared to the current policy. There is little room to increase the allocation of human resources to tool inventory management.

Adhering to these limitations is important in order not to surpass the scope of the research.

1.7 Key constructs

The key construct of this research is ‘inventory policy’. An inventory policy refers to the set of guidelines and strategies employed by businesses to manage their inventory levels effectively. This includes determining the optimal quantity and timing of stock replenishment to minimize costs and meet demand. Balancing these competing goals is critical for ensuring efficient operations, reducing stockouts and overstock situations (Khan & Yu, 2019).

Another key construct is ‘warehouse procedure’. A warehouse procedure outlines a structured set of guidelines and processes that govern the workflow within a warehouse. It serves as a comprehensive framework that encompasses various tasks to manage the processes within a warehouse. The primary purpose of a warehouse procedure is to ensure seamless operation while minimizing errors.

1.8 Deliverables

The final outcome of this research is a new tool inventory policy and a complementary warehouse procedure. Together, they form the new system for tool inventory management at Rottink. This research has the following deliverables:

- Inventory policy
- Warehouse procedure (graphical model)

2. Current inventory policy performance

This chapter provides a quantitative analysis of the performance of the current tool inventory policy. This step of the problem-solving approach is addressed by answering the question "*how is the current inventory policy performing?"*. First, Section 2.1 provides the context of the inventory policy by shortly introducing some fixed distribution parameters. Then, Section 2.2 discusses the functioning of the current inventory policy. This section also provides information on chisel tip demand rates. Section 2.3 investigates the rising tool costs experienced by Rottink. Section 2.4 extensively discusses the operational performance of the current inventory policy. Lastly, Section 2.5 analyses the current warehouse procedure. The objective of this chapter is to map the policy and identify areas of underperformance.

2.1 Distribution parameters

Rottink sources its chisel tips from three suppliers: Slijptechniek Enter BV, OSG Nederland BV, and Duhra Tools BV. Delivery time is within 48 hours. When an order is initiated, it must be processed and placed at one of the three suppliers manually. Moreover, when the delivery arrives, it must also be placed in the tool warehouse. These two moments distinguish delivery time from lead time. However, even combined they rarely exceed one hour in duration. Therefore, the lead time for chisel tips in Rottink's tool inventory is almost equivalent to the 48-hour maximum delivery time.

Rottink's tool warehouse consists of a small room located at the back of their factory building, featuring around 5 cabinets. Only a few drawers are dedicated to storing chisel tips. Chisel tips are small and therefore occupy little room in the warehouse. Tools are organized based on tool type. The storage of chisel tips in the current setup is well-structured, with each type of chisel tip neatly divided into its own container. The current storage structure for chisel tips therefore meets all requirements from the company as no issues are experienced in the setup.

2.2 Current inventory policy

2.2.1 Functioning of current inventory policy

The current inventory policy is shortly introduced in Chapter 1. Due to the ad hoc inventory management of the current policy, it is counterintuitive to name it a policy in the first place. Decisions on tool inventory are made based on the subjective judgment of the warehouse manager. They are responsible for most of the inventory management. However, inventory management is not the main task of this employee. In inventory management, deciding on the timing of orders, the order quantity and how to control the system are the three major decisions to make (Slack et al., 2016).

Regarding the timing decision in the current inventory policy, orders are initiated when a production employee takes the last package of a certain type of chisel tip. Chisel tip boxes are packaged in batches of 10, occasionally in batches of 5, resulting in an inventory level of either 10 or 5 for the specific chisel tip SKU at the time of order initiation. Upon taking the last package of a particular type of chisel tip, it is the responsibility of production employee who takes it to notify the warehouse manager, indicating the need for replenishment of that chisel tip. Nevertheless, it does occur that a production employee forgets to do this. In this case, the need for a new order is not acted upon and the order initiation is delayed until this need is identified. This can result in a stockout of that type of chisel tip. Stockouts often do not cause large problems, but they have caused production complications in the past. These complications differ per time but most common is the need to relocate production employees from their intended working area to another one. Although less common, partial production stops can also occur when there is a stockout. Although the timing and costs associated with stockouts are unknown, Rottink aims to minimize the likelihood of chisel tip stockouts in their tool inventory. The role of the inventory policy in the occurrence of stockouts is investigated in Section 2.4.5.

The next step is to generate the order. In the current inventory policy this is again done by the warehouse manager. Coordinated multi-item replenishment is absent in the current inventory policy. Instead, the warehouse manager checks the tool inventory on other SKUs with low inventory and decides whether to include them in the order. Occasionally, this step is omitted, resulting in orders being generated solely for the SKU that initiated the order. No information exists on the number of times this occurs. When the decision is made on which SKUs to include in the order, the order quantity is decided upon per SKU. This decision is mainly influenced by the threshold for delivery costs (Section 2.4.3). Discounts are considered only for the SKUs where they are relevant and only when the order quantity is already close to the quantity threshold of the discount (Section 2.4.2).

2.2.2 Data availability

The only data available on the tool inventory are the history of tool order placements. These data are detailed, complete and accessible.

These data are systematically stored in the company's ERP system. Therefore, the data are easily accessible. The data on the history of all tool order placements are extracted from the company's ERP system into an Excel sheet from which a data-analysis can be performed. Before this is done, the data must be processed to be workable. After the extraction from the ERP system, the data are not loaded suitably into an Excel worksheet. By splitting cells into separate columns, removing blank rows, and loading the data into an Excel table, the data on the history of tool order placements are ready for analysis. Nevertheless, before analysis takes place, the data are filtered to correspond with the prescribed scope. Two datasets emerge from the history of tool order placements. Dataset A is the unfiltered dataset on the history of all tool order placements. Dataset A is used for analysis of chisel tips in Rottink's complete tool inventory. Dataset B is the filtered dataset on the history of only chisel tip order placements, corresponding to the prescribed scope. The data filtering process of Dataset B can be found in Appendix B.

Dataset A: *Dataset containing data on the history of all tool order placements (2018-2022)*
Dataset B: *Dataset containing data on the history of chisel tip order placements (2018-2022)*

For both datasets the timeframe has been limited to the past five years (2018-2022). In 2022, Rottink experienced a major increase in tool costs (Section 1.2). The four years before 2022 were stable in terms of total tool costs (Section 1.4). The four stable years before 2022 therefore provide enough background information to find out what changed in 2022. It has been considered to look only at data on the history of tool order placements from 2020 onwards, since Rottink moved to a new location in 2020. However, according to company management, the relocation of the company caused no significant production variations. Therefore, the bottom end of the timeframe is selected to be 2018. In this way the data includes the history of tool order placements before, during and after the Covid pandemic. This is important as the pandemic had a large effect on the industry in which Rottink operates (de Vet et al., 2021). 2022 is selected as the end of the timeframe. The history of tool order placements for 2023 is not complete. Consequently, annual comparisons are not possible and there is little room for conclusions to be drawn.

2.2.3 Chisel tip demand

The demand rates of chisel tips in Rottink's tool inventory are extracted from the data available on the history of tool order placements. These data are not equivalent to the exact chisel tip demand. Exact demand is not available as inventory is currently not monitored. Nevertheless, the history of tool order placements is closely related to tool demand at Rottink. According to company management, a new order is placed when the last package of a SKU is taken (Section 2.2.1). Therefore, at the moment of ordering, the inventory level of that SKU is 10 or 5, depending on the package quantity of that chisel tip SKU (Section 2.2.1). The next order for that SKU is placed when there is again one package left. Following this rule, one can therefore assume that if a quantity X is ordered at day Y and the subsequent order is placed at day Z, the demand between days Y and Z corresponds to X. This makes it workable to extract meaningful demand rates from the data available on the history of tool order placements. The quantity ordered at a particular time is similar to the demand from that time to the next order.

However, in some cases a chisel tip SKU is ordered before the last package is taken. When the inventory level of a chisel tip SKU is low, this SKU can be included in the order of another SKU that did reach the last package (Section 2.2.1). When this is the case, the above-mentioned method of calculating demand does not hold. The demand does not correspond to X in this scenario as the inventory level at days Y and Z are different. The calculated demand will thus differ from the actual demand. Nevertheless, a chisel tip SKU that is included in another order was included due to its already low inventory level. The difference in calculated demand and actual demand is therefore small. Due to the limited data available (Section 2.2.2), the above-mentioned calculation method is the best possible with limited data.

Annual demand for a chisel tip is on average 64 units. Nevertheless, with a median of 13 units and a mode of 4 units, a lot of chisel tip SKUs have a small yearly demand. An explanation is that almost half of the SKUs were ordered only once or twice throughout the timeframe (2018-2022) of Dataset B. Thus, a lot of chisel tip SKUs were ordered based on singular demand in production. Despite this, there is also a group of fast-moving chisel tips within Rottink's tool inventory. The average annual demand for chisel tip SKUs ordered more than two times throughout the timeframe is over 100 units, substantially more than the median and mode. With demand for a chisel tip maxing out at 460 units per year. 95% of all chisel tip demand comes from the SKUs with an annual demand higher than the median of 13 units. These fast-movers are the primary focus of the new inventory policy. There is thus a significant difference in chisel tips required on singular bases or on regular bases.

The standard deviation between tool demand rates over the years 2018 to 2022 is on average relatively small considering the annual demand rate. However, for chisel tips required on singular bases, this does not hold as their demand is based on unpredictable production circumstances. For the chisel tips needed on more regular bases, the standard deviation is 29,00, resulting in a coefficient of variation of 24,00%. For the 15 most fast-moving chisel tips, the standard deviation is 21,00, resulting in a coefficient of variation of 09,00%. These 15 SKUs constitute 60,00% of the chisel tips purchasing costs. This coefficient of variation indicates a small variability of chisel tip demand rates over the years. Demand rates over smaller time periods show an increased coefficient of variation, indicating that demand rates fluctuate more when compared over smaller time periods. The increase in variability over smaller time periods, like weeks, leads to moderate variability in the demand rates. Company management confirms this by stating that the demand for chisel tips is steady over time, with variations over smaller time periods.

Demand rates move around an average but are not constantly the same number. The variation from that average decreases the more a chisel tip is used in production, thus the higher the demand. Demand rates follow a clear pattern over larger time periods, like one year. Still, they do have a moderate variation. Time periods of a week or a few days show significantly different demand rates. Therefore, the nature of chisel tip demand for chisel tips needed on regular bases is dynamic and not static. However, demand rates are not to be considered probabilistic as moderate variation moves towards a pattern over large time periods. Here, the demand rates move around an average. Due to the variability around that average, the demand rates are considered deterministic. Silver et al. (2016) describe deterministic demand as time-varying demand with small to moderate variability, as is the case for chisel tips at Rottink. Therefore, following the observations in the demand rates and the input from company management, chisel tip demand rates at Rottink best fit the description of deterministic demand.

One important consideration with deterministic demand is the definition of the model. One can use the fixed EOQ-model. “This approach makes sense when the variability of the demand pattern is low; that is, the constant demand rate assumption of the fixed EOQ-model is not significantly violated” (Silver et al., 2016, p. 201). However, despite little demand variation with the most fast-moving chisel tips, other chisel tips still show moderate variability in demand. Moreover, this variability increases with smaller time periods, significantly violating the constant demand rate assumption of the fixed EOQ-model. Another model that can be used is the dynamic lot-sizing model. Dynamic lot sizing considers the effect of cumulative needs across time to determine the best order quantities (Schenker, 2020). The demand rate per period is given and may vary from one period to the next, but it is assumed as known (Silver et al., 2016). Chisel tip demand rates at Rottink vary from period to period. However, due to limited insights in demand, demand rates per period are difficult to predict, resulting in forecast variability. As time advances and new requirements are known, forecast variability for time periods closer to the initial time period decreases. For further time periods, the forecasts at Rottink will move towards the demand rate average as little information on requirements is yet known and demand insights are limited.

2.3 Total tool costs

The total purchasing costs for chisel tips throughout the timeframe 2018-2022 is €253.211,96. Chisel tips constitute almost 65% of the total tool purchasing costs despite their relative low price per unit of €9,80 on average. The price of different chisel tips does not differ much relatively.

In 2022 there is an increase in total tool purchasing costs following a dip in 2020 and 2021. The dip corresponds to the company’s turnover. Over 2020 and 2021 the total tool purchasing costs for all tools decreased by over 20%, while for chisel tips, the decrease was almost 22%. These declines align with a notable decrease in Rottink's turnover during the same period, with a 30% decrease in 2020 and a 33% decrease in 2021 compared to the previous year. This decline in turnover can be attributed to a decrease in production, which consequently led to a reduced demand for tools in production. The significant decrease in production during 2020 and 2021 can largely be attributed to the impact of the Covid pandemic, which caused disruptions across various sectors, especially in the production industry (de Vet et al., 2021).

In 2022, there was a significant increase of 36% in total tool purchasing costs and a 39% increase in chisel tip purchasing costs. Turnover rose by 12% in 2022 compared to 2021. Purchasing costs significantly exceeded this growth in turnover and production, something

Rottink did not experience before. Company management attributes the significant increase in tool costs to the malfunctioning current inventory policy (Section 1.2). The current inventory policy is held accountable for the increase in tool costs exceeding the increase in turnover by a factor 3. However, external factors provide a rational explanation for the increase in tool purchasing costs exceeding the increase in turnover. The average price of a chisel tip in 2022 was 26% higher compared to 2021. Moreover, 2022 saw exceptionally high inflation of 10% and increased raw material prices (CBS, 2023). These external factors rationally explain the higher increase in total tool costs compared to the company's turnover in 2022.

The current inventory policy is thus not the reason behind the increase in tool costs exceeding the increase in turnover. External factors and tool demand are the primary drivers of fluctuations in Rottink’s annual tool costs. External factors had an increased influence during the turbulent year of 2022.

2.4 Operational performance

2.4.1 Order frequency and quantity

On the timeframe of Dataset A, 432 orders were made for or included chisel tips. On average, there were 1,7 SKUs per order. Over 60% of the orders consisted of 1 SKU, yet there are orders with up to and including 10 SKUs.

Annually, on average 86 orders are placed for or include chisel tips. The average order quantity for chisel tips is 37, a relatively large quantity considering that average annual demand for a chisel tip is 64. Nevertheless, as mentioned in Section 2.2.3, 95% of all chisel tip demand comes from the SKUs with a demand higher than 13 units, the median of annual demand for chisel tips. These fast-moving chisel tips have an average order quantity of 40 units, enough to fulfil 9 months of demand on average. However, there are some fast-moving chisel tips for which one order fulfils around 2 months of demand, not much considering the regular and extensive use of these chisel tips. These are the 15 most fast-moving chisel tips. They have an average annual demand of 245 units and an average order quantity of 43 units, approximately the same as other fast-moving chisel tips with a much smaller demand. Chisel tips with a demand smaller than 13 have an average order quantity of 15. Based on the demand of these chisel tips, this is enough to fulfil demand for more than three years on average.

For most chisel tips, except for the most fast-moving chisel tips, the order quantity fulfils demand for a longer period, indicating a large order quantity. Consequently, a chisel tip SKU requires less than 2 orders per year on average. Nevertheless, there are still quite some orders performed annually that include chisel tips, confirming that the current inventory policy does not combine orders systematically (Section 2.2.1). Reducing the number of separate orders and increasing the number of chisel tip SKUs per order reduces order costs (Section 2.4.3) and improves administrative efficiency.

2.4.2 Purchasing discounts

Rottink receives two kinds of discounts on chisel tips, namely fixed discounts, and lot size-based discounts. Rottink receives its discounts through business-to-business (B2B) arrangements with the three chisel tip suppliers.

Regarding the fixed discount, at Slijptechniek Enter BV, Rottink receives a 40% discount on chisel tips from the brand Kennametal. At Duhra Tools BV, Rottink receives a 30% discount on chisel tips from the brand Sandvik. The exact number of chisel tip SKUs sourced from

Slijptechniek Enter BV that belong to the Kennametal brand is not tracible with the data available. However, chisel tips from Kennametal form the majority of chisel tips from Slijptechniek Enter BV. At Duhra Tools BV, all chisel tips are from the brand Sandvik. Additionally, at OSG Nederland, Rottink receives a 35% discount on all chisel tips. The three suppliers do not offer the same chisel tips, ordering one chisel tip SKU at two or more suppliers is not possible. The fixed discounts effectively result in a lower price for Rottink independent of the inventory policy, as the price remains unaffected by decisions made within the inventory policy. The fixed discounts cannot be optimized by the inventory policy and thus fall outside the scope of this research. Their financial savings are however substantial, and insights gained from this research allow Rottink to explore their expansion.

The lot size-based discounts on the other hand are influenced by the inventory policy. Rottink receives this discount at Duhra Tools BV. There, they receive a 2,86% discount on chisel tips from the brand Sandvik if the order quantity exceeds 100 units. This 100-unit threshold is per chisel tip SKU. Over the five-year timeframe of Dataset B (Section 2.2.2), this threshold was reached 9 times in all 202 orders for or including chisel tips placed at Duhra Tools BV. The lot size-based discount amounted to a saving just short of €180,00 over the five years. In the same years, over €125.000,00 was spent on chisel tips at Duhra Tools BV. Even if the 100-unit threshold was reached for all orders for or including chisel tips at Duhra Tools BV, the monetary savings would amount to just over €700,00 annually. However, it is highly unlikely a monetary saving close to this number is reachable considering that the average order quantity for chisel tips at Duhra Tools BV is 36. Moreover, only 11 of the 42 chisel tip SKUs ordered at Duhra Tools BV have an annual demand of 100 units or more. For the other SKUs, more than a year's worth of demand would have to be ordered in one order to profit from the lot size-based discount. A risky move considering additional holding costs. The monetary savings from the only available lot size-based discount therefore play almost no role in the finances of tool inventory management.

The 11 chisel tip SKUs from Duhra Tools BV with an annual demand of over 100 units belong to the category of really fast-moving chisel tips for which the order quantity does not fulfil demand for longer periods (Section 2.4.1). Using a higher order quantity for these SKUs would cover demand for a longer period than the current 3 months. With these higher order quantities, a maximum of €550,00 can be saved by the lot size-based discount per year. These savings would still play a minor role. Considering additional holding costs, the financial benefits are reduced and potentially outweighed.

2.4.3 Tool order costs

Order costs at Rottink are built-up of two components: delivery costs and human resource allocation costs. Delivery costs are not incurred for all orders. The three chisel tip suppliers all incur a delivery fee unless the order exceeds a certain order value. At all three suppliers, the threshold for order costs depends solely on the order value of the whole order, independent of what is in the order. Delivery costs at Slijptechniek Enter BV amount to €12.50, but if the order value exceeds €250, no delivery costs are incurred. At OSG Nederland BV, orders above €200 have no delivery costs, while orders below that value incur a delivery cost of €15. Duhra Tools BV charges no delivery costs for orders above €275, but orders below that value are charged a €9.80 delivery fee. The human resource allocation costs refer to the costs associated with the manual labour in the order process. As mentioned in Section 2.1, the human effort in the order process includes placing an order, receiving the order, and storing the order in the tool warehouse. Based on an estimate from company management, these three activities combined take around 10 minutes to execute. The associated labour costs are on average €10,00 per order. The exact costs differ from order to order.

As mentioned in Section 2.4.1, 432 orders for or including chisel tips were placed at the three chisel tip suppliers throughout 2018-2022. *Table 1* depicts the order costs per chisel tip supplier and for chisel tips in total throughout this timeframe. The total order costs are calculated by summing the human resource allocation costs and the delivery costs. Dividing the total order costs by the number of orders gives the average order costs per order. Following this, the average order costs per order are €12,24.

Supplier	Total number of orders	Number of orders below delivery cost threshold (percentage of total)	Total order costs	Average order costs per order
Slijptechniek Enter BV	112	32 (28,6%)	€1.520,00	€13,57
OSG Nederland BV	118	21 (17,8%)	€1.495,00	€12,67
Duhra Tools BV	202	26 (12,9%)	€2.274,80	€11,26
Total	432	79 (18,3%)	€5.289,80	€12,24

Table 1: Chisel tip order costs per supplier and in total (2018-2022)

Table 1 shows that the current inventory policy is not faultless in its optimization of order costs. 18,3% of all orders for or including chisel tips incurred delivery costs throughout the past five years. On average, that amounts to 16 out of 86 orders per year. The order costs add up to just over €1.000,00 per year. The threshold for delivery costs is not reached when chisel tips with small demand are ordered in an order with little other SKUs. Due to their small order quantity (Section 2.4.1), the total order value in these cases stays below the threshold for delivery costs. The average order value of orders for or including chisel tips is €586,00. The fast-moving chisel tips are ordered in quantities for which the order value exceeds the threshold for delivery costs. Nevertheless, there still is a considerable number of chisel tip SKUs with small demand (Section 2.2.3). Increasing the order value for orders including these SKUs would reduce the number of orders that incur delivery costs. For SKUs with small demand, the best option for increasing the order value is to increase the number of SKUs per order. Increasing order quantities for these SKUs creates other problems like high holding costs and overstock.

2.4.4 Tool holding costs

Rottink does not have specific costs associated with the storage of tools in inventory. Typically, holding costs are calculated by applying a predetermined percentage to the average inventory value. With the limited data available, it is difficult to calculate the average inventory value. However, based on the data from Section 2.2.2, one can calculate an estimate of the average inventory value for chisel tips. First, the average inventory level is calculated. The average inventory level is calculated by summing the opening and closing inventory value per replenishment cycle and dividing the outcome by two. Following the assumption from Section 2.2.3, that a new order is only initiated when the last package is taken, the difference between the opening and closing inventory level is the order quantity used at the opening of that replenishment cycle. The average order quantity for chisel tips is 37 units (Section 2.4.1). The average inventory level for a chisel tip is then 18,5 units, the half of 37. Multiplying the average inventory level for a chisel tip with the 96 chisel tip SKUs and their average price of €9,80, gives a rough image of the average inventory value for chisel tips.

This amounts to around €17.500,00. The predetermined percentages often move around the 20% per year, although it depends per situation and many factors what the exact percentage is. Using a percentage around the 20% per year means that the annual holding costs for chisel tips would be around €3.500,00. A significant amount considering just over €50.000 is spent on average on chisel tips each year. This calculation is not perfect but does provide a rough image on the situation. Decisions within the current inventory policy are not influenced by holding costs. The holding costs and average inventory value being substantial indicate drawbacks of the sizable order quantities.

2.4.5 Stockouts & warehouse procedure

One of the issues of the current inventory policy is the occurrence of stockouts. An estimate from the production manager is that a stockout occurs around once every two weeks, so around 26 times per year. As mentioned in Section 2.2.1, stockouts cause complications in production and therefore Rottink aims to minimize them. As mentioned in the same section, a new order is initiated when the last package of a chisel tip SKU is taken. The inventory level at that moment is at least 5 and often more. Chisel tips are delivered within 48 hours and their lead time is almost equivalent to the delivery time (Section 2.1). Even for the chisel tip SKU with the highest annual demand of 460, having at least 5 in inventory is enough to fulfil demand during the 48-hour lead time. This example has the smallest margin, other chisel tips have a smaller demand and are likely to be packaged in batches of 10 instead of 5. Thus, demand during the 48-hour lead time is covered by the last package. The inventory policy therefore plays no role in the occurrence of stockouts.

2.5 Current warehouse procedure

In the current warehouse procedure, orders are initiated when a production employee takes the last package of a particular type of chisel tip SKU. It is the responsibility of the production employee who takes the last package to notify the warehouse manager, indicating the need for replenishment of that specific chisel tip SKU. However, there are instances where production employees forget to notify them, leading to delayed order initiation. This is not uncommon, as it was one of the main issues identified by company management (Section 1.2). Therefore, the delayed order initiation is added in the documentation of the current warehouse procedure identifying a large bottleneck of the current warehouse procedure. A BPM model of the current warehouse procedure can be found in Appendix C

Another issue with the current warehouse procedure is that the activity of returning the package to the chisel tip warehouse is not always performed. According to company management, employees keep the package with the remaining chisel tips at their working area for various reasons, most often because they need it later. However, when the last package is not returned to the tool warehouse, there is no inventory in the warehouse left to fulfil lead time demand of other employees, resulting in a stockout. This is another severe bottleneck of the current warehouse procedure.

The documentation of the current warehouse procedure in Appendix C portrays the current warehouse workflow including the process when errors occur in the adherence of the warehouse procedure. This highlights the two main issues with the current warehouse procedure. Firstly, the warehouse manager is not always notified of the need for replenishment. Secondly, chisel tip packages are not always returned to the tool warehouse after usage.

2.6 Conclusion

To conclude, for most chisel tips, except for the most fast-moving chisel tips, the order quantity fulfils demand for a longer period, indicating a large order quantity. As a result, a chisel tip SKU is ordered less than 2 times per year on average. Still, the number of separate orders for or including chisel tips is large. In the current inventory policy, multi-item replenishment is uncoordinated resulting in an average of 1,7 SKUs per order and a lot of separate orders. The large number of separate orders cause for almost 20% of the orders to incur delivery costs and result in additional administrative work. Order costs amount to just over €1.000,00 annually.

The current holding costs are substantial and indicate drawbacks of the sizable order quantities. Rottink aims to avoid significant overstock situations to limit the holding costs but optimizing holding costs specifically is not an objective for the company.

Rottink requires an inventory model that fulfils demand and optimally balances costs. Lot size-based discounts are not to be included in this balance as the discount saved €180,00 over a five-year period, an insignificant amount overshadowed by other financial parameters, especially order and holding costs. Moreover, as Rottink seeks simplicity in the inventory policy the discount is omitted for research timeline adherence.

Considering the nature of chisel tip demand at Rottink, as described in Section 2.2.3, demand at Rottink is deterministic for chisel tips with regular demand. Due to the relative variation, the constant demand rate assumption of the fixed EOQ-model is significantly violated. Therefore, the dynamic lot-sizing model better fits the context. Moreover, the interdependence between different SKUs regarding order costs indicates the need for multi-item replenishment. Coordinated multi-item replenishment should reduce the number of separate orders and increase the number of SKUs per order, resulting in a reduction of order costs and the amount of administrative work in the tool procurement process.

Additionally, severe inflation, not the current inventory policy, were the reason behind the major increase in tool costs that Rottink experienced in 2022. Moreover, the inventory policy plays no role in the occurrence of stockouts. Rottink therefore requires a new warehouse procedure with seamless operation. Relying on a single individual for inventory management poses a risk to the control of the system, but implementing a well-documented policy usable to a wider range of employees mitigates this threat significantly.

3. Inventory models

In this chapter, inventory models are theoretically examined on pertinence for coordinated replenishment at Rottink. This step of the problem-solving approach is addressed by answering the question *"what inventory models exist for managing tool inventory effectively?"*. First, inventory models applicable for inventory management at Rottink are selected (Section 3.1). Elaborations on selected models follow. Section 3.2 examines the simple Chan and Chiu heuristic. Lastly, for the prevention of stockouts, Rottink requires a new warehouse procedure (Section 2.4.5). Section 3.3 evaluates the format of the warehouse procedure to ensure seamless operation.

3.1 Selection of inventory models

The objective of implementing a new inventory policy is well-defined through the norm and reality (Section 1.4), scope (Section 1.6) and conclusions of chapter 2 (Section 2.6). The objective for Rottink is to decrease the costs associated with the inventory policy and to reduce the number of stockouts in Rottink's tool inventory (Section 1.3). Chapter 2 analyses the current inventory policy. The conclusion from this chapter expresses the need for a deterministic inventory model that reduces the large number of separate orders by coordinated multi-item ordering. Currently, Rottink deals with a multi-item dynamic lot-sizing problem. To solve it, Rottink needs to redesign their inventory policy. Therefore, an inventory model for the multi-item deterministic dynamic lot-sizing problem is needed, on which coordinated replenishment is based.

Several methods exist for the solvation of multi-item deterministic dynamic lot-sizing problems. Rottink's tool inventory has no capacity constraints (Section 2.1), so only uncapacitated inventory models are relevant. Many dynamic programming solutions exist for this problem. However, they are computationally complex (Iyogun, 1991). Rottink desires an inventory policy that remains manually workable (Section 1.6). For this reason, the use of a dynamic programming algorithm surpasses the capabilities of tool inventory management at Rottink. Moreover, dynamic programming solutions are developed for single-item problems and cannot be directly extended to multi-item problems (Jans & Degraeve, 2007). The implementation of a dynamic programming algorithm in Rottink's tool inventory would require significant tailoring, adding complexity to the process. Furthermore, managers typically find it difficult to understand dynamic programming solutions (Iyogun, 1991).

Other methods are the meta-heuristics such as tabu search and simulated annealing. These explore the unexplored neighbours of a solution following a traditional heuristic (Robinson et al., 2009). However, according to Jans and Degraeve (2007), meta-heuristics are mistakenly assumed to be easy to understand. They argue that meta-heuristics are complex because of all the special adaptations that are needed to make them work better. Otherwise, little improvement will be seen from meta-heuristics over simpler traditional heuristics (Robinson et al., 2009). This complexity in the adaptation of meta-heuristics is a problem for inventory management at Rottink.

Solutions to the multi-item deterministic dynamic lot-sizing problem obtained from dynamic programming or meta-heuristics are from a high quality (Ullah & Parveen, 2010). However, all existing exact solution methods are of a complexity that grows exponentially with the number of periods or the number of items, and therefore may be used only for problems of small size (Federgruen & Tzur, 1994). Whereas 20-30 items are reasonable for exact solution methods (Federgruen & Tzur, 1994), the scope of this research are Rottink's 96 chisel tip

SKUs (Section 1.6). The recommended number of periods is 20-30, a small number for Rottink considering the number of annual orders (Section 2.4.1). Therefore, exact solution methods are not suitable due to their computational and functional complexity. This holds for meta-heuristics as well, despite not technically belonging to the category of exact solution methods.

Due to the computational complexity of optimal value solutions, efforts have shifted to the development of heuristic solutions (Iyogun, 1991). Therefore, traditional heuristics are a major topic in most literature on multi-item deterministic dynamic lot-sizing problems. Heuristics greatly simplify the computation of a solution to dynamic lot-sizing models that is optimal or near-optimal (Winston & Goldberg, 2004). Heuristics do not aim to calculate the optimum solution but find satisfactory solutions close to the optimum. The simplicity of these heuristics is what makes them suitable for Rottink's tool inventory. These heuristics generally depend on the Wagner-Whitin dynamic programming solution for the single-item dynamic lot-size problem (Iyogun, 1991). A disadvantage considering that managers typically find it difficult to understand dynamic programming solutions (Iyogun, 1991). However, in the same paper, Iyogun (1991) provides a heuristic that overcomes this problem by decomposition, which further simplifies the associated computations.

One of the most well-known heuristics for multi-item deterministic dynamic lot-sizing problems is the Atkins and Iyogun heuristic (Robinson et al., 2009). This heuristic is further improved by Iyogun (1991). This simple heuristic extends the well-known Silver-Meal heuristic for single-item problems to multi-item problems (Federgruen & Tzur, 1994). Despite the limited literature on multi-item deterministic dynamic lot-size problems (Iyogun, 1991), most literature sources consulted in this Chapter contained a positive reference to the Atkins and Iyogun Silver-Meal heuristic. While the Atkins and Iyogun heuristic provides effective solutions for many practical scenarios, it doesn't guarantee optimality in all cases. Nonetheless, it strikes a balance between computational efficiency and solution quality, making it a valuable tool in inventory management (Iyogun 1991).

Barringer and Fogarty proposed another well-known heuristic that produces high quality solutions under relatively high fixed cost ratios (the joint setup cost divided by the sum of the item setup costs), but solution quality suffers under low fixed cost ratios (Robinson et al., 2009). At Rottink, the setup costs consist of the order costs (Section 2.4.3). The fixed cost ratio at Rottink is quite small considering that joint ordering costs hardly exceed single ordering costs. This is complicated by the threshold for delivery costs. The context of Rottink's tool inventory is thus not well-suited for this heuristic.

Federgruen and Tzur (1994) present a partitioning heuristic that divides the complete horizon into smaller period intervals, in which each interval is solved using an optimal solution method, in this case the branch-and-bound method (Federgruen & Tzur, 1994). The small intervals allow quick solvation of the optimal solution method. However, despite little computational complexity, this heuristic is not easy to implement in practice (Chan & Chiu, 1997; Iyogun, 1991). Therefore, this heuristic does not fit Rottink, where the process is to remain manually workable and simple in its functioning (Section 1.6)

Chan and Chiu (1997) on the other hand present a heuristic for the multi-item deterministic dynamic lot-sizing problem that is designed around simple functioning. According to them, existing heuristic methods provide iterative solutions which are not easy to implement. They present an alternative heuristic that is extremely simple to use and can be done manually

(Chan & Chiu, 1997). Moreover, it has promising results with an inefficiency of about 10% of the optimum (Chan & Chiu, 1997). Also, "the heuristic performs well with less accurate demand forecasts" (Chan & Chiu, 1997, p. 977), which is very much the case at Rottink where the calculation of tool demand rates is not exceptionally precise (Section 2.2.3).

Heuristics provide the most suitable method of solving the multi-item deterministic dynamic lot-sizing problem at Rottink. From the heuristics studied in this Section, two heuristics might be suitable for Rottink, namely the Atkins and Iyogun heuristic (Section 3.2) and the Chan and Chiu heuristic (Section 3.3). Both heuristics use a similar iterative process. The Atkins and Iyogun heuristic performs well on a wide set of problems, generally within 5% of the optimum solution (Iyogun, 1991). The Chan and Chiu heuristic performs with an inefficiency within 10% of the optimum (Chan & Chiu, 1997). Given the precision in calculating chisel tip demand rates in Chapter 2, both heuristics exhibit satisfactory performance for the coordinated replenishment decision at Rottink as they both operate with a low inefficiency. The Chan and Chiu heuristic is even proven to perform well with less accurate demand forecasts.

For Rottink however, the simplicity factor is more important (Section 1.6). The Chan and Chiu heuristic is simplistic and uses straightforward comparisons between order and holding costs (Chan & Chiu, 1997). The logic behind the Atkins and Iyogun heuristic is an extension of the logic in the Silver-Meal heuristic for single item problems. Due to this, the understandability of the heuristic's calculative steps is lower than with the Chan and Chiu heuristic. Academically, both heuristics are considered simple and the difference is small. However, for employees of Rottink who have never dealt with such items before, the Atkins and Iyogun heuristic is not quickly graspable. As simplicity is a key factor in Rottink's tool inventory management, the Chan and Chiu heuristic is initially selected as most suited. The heuristic is elaborated in Section 3.2.

3.2 Chan & Chiu heuristic

The Chan and Chiu (1997) heuristic is a heuristic for the multi-item deterministic dynamic lot-sizing problem that is designed around simple functioning. The objective of this heuristic is to schedule the replenishment of N items over a planning horizon H such that total costs are minimized. The items are classified into groups where the order cost structure makes coordinated replenishment attractive. Products that share a common supplier or mode of transportation can be considered as a group.

The multi-item deterministic dynamic lot-sizing problem according to Chan and Chiu is formulated as follows: a fixed major order cost, referred to as A_0 is incurred at every order, independent of the number of items in the order. A minor order cost, referred to as A_i, is added if product i is included in the order. The demand of each item is known per period over a given planning horizon H. Chan and Chiu do not consider initial inventory in their heuristic. Linear holding costs are charged on the inventory on hand at the end of a period. Backlogging, the delay of demand fulfilment due to demand exceeding available inventory, is not permitted in the heuristic. The unit purchase cost for each product is constant throughout the planning horizon H. Lot size-based discounts are not considered by the heuristic. The problem is to determine a replenishment schedule for all items that minimizes the total order and holding costs over the horizon.

N represents the number of items. D_{it}, X_{it}, I_{it}, and h_i represent the demand, order quantity, end-of-period inventory, and holding cost respectively for item i in period t. The holding cost rate can be allowed to vary from period to period, but it is assumed to be constant for expository simplicity. The problem of minimizing the total order cost plus holding cost over the horizon can be stated as follows:

Equation (1)

$$Z = \min \sum_{T=1}^{H} \left\{ A_0 \delta \left[\sum_{i=1}^{N} X_{it} \right] + \sum_{i=1}^{N} [\mathrm{A}_i \delta(\mathrm{X}_{it}) + h_i \mathrm{I}_{it}] \right\},$$

Subject to $X_{it} + I_{it-1} - d_{it} - I_{it} = 0$, for all i and t = 1, 2, …, H,

$X_{it} \geq 0$, $I_{it} \geq 0$, $d_{it} \geq 0$,

Where $\delta(x) = \begin{cases} 1, & if\ x > 0 \\ 0, & if\ x = 0. \end{cases}$

H is the given time horizon and t is the period so that t ∈ H. Let T represent the last period an order was made for any product. Let $L_i \leq T$ be the last time item i was ordered. At any time t > T, two decisions need to be made, to have another order and/or to allow an item whose $L_i < T$ to join the reorder in period T.

The Chan and Chiu (1997) heuristic for multi-item deterministic dynamic lot-sizing problems works as follows:

To *initialize* the heuristic let T = t = 1 and let $L_i = 1$ for all items i ∈ {1, 2, …, N}. During *initiation* an order is always authorized.

Step 1:

- Set t = t + 1. Compute Δ_{it} for all i as follows:

Equation (2)

$$\Delta_{it} = max \left\{ \frac{1}{2}(t - \mathrm{L}_i)(t - \mathrm{L}_i + 1) h_i d_{it} - A_i, 0 \right\}.$$

Δ_{it} evaluates the holding costs with the minor order costs in a predefined proportion. If the holding costs exceed the minor order costs in this proportion, Δ_{it} will be greater than zero. Otherwise, Δ_{it} is zero. Basically, Δ_{it} depicts the costs of not ordering item *i* in time period *t* multiplied with a predefined factor.

Step 2:

- Compare $\sum_i \Delta_{it}$, the sum of the evaluations from *step 1* over all items *i*, with the major order cost A_0. If $\sum_i \Delta_{it} > A_0$, go to *step 3*. Otherwise, go to *step 4*.

  In other words, if the total costs of not ordering in time period *t* exceed the major order costs, an order is placed in time period *t*. otherwise no order is authorized.

Step 3:

- An order is authorized in time period t for those products i with $\Delta_{it} > 0$. These are the products where the costs of not ordering exceed the minor order costs. Set T = t,

$$L_i = \begin{cases} T & if\ \Delta_{it} > 0 \\ L_i & if\ \Delta_{it} = 0. \end{cases}$$

- If t = H, then STOP. Otherwise go to *step 1*.

Step 4:

- No order is authorized in time period t.
- For each i, perform the shifting test:

$$\text{If } h_i(T - L_i)(t - T + 1)d_{it}\Delta_{it} > A_i\Delta_{it}, \text{then reset } L_i = T.$$

The shifting test checks whether a product was better ordered at T rather than L_i.

- If t = H, then STOP. Otherwise go to *step 1*.

Chan and Chiu (1991) also contains a worked-out example of the heuristic's functioning.

3.3 Graphical model for warehouse procedure

Due to stockouts resulting from errors in the adherence to the warehouse procedure (Section 2.4.5), there is a pressing need to redesign and improve the warehouse procedure. A new warehouse procedure must prevent the mistakes that are causing the occurrence of stockouts. Stockouts occur when the inventory level at order initiation is too small to fulfil lead time demand (Section 2.4.5). This happens when there is delay in the order initiation due to errors in the adherence to the warehouse procedure. Currently, the warehouse is operated based on verbal agreements (Section 2.2.1). However, these verbally arranged regulations are not always adhered to as not everyone is attentive to them. To prevent errors in the adherence, a new warehouse procedure must contain clear regulations in an accessible and transparent format, so all employees are aware of them. The format of the warehouse procedure plays a crucial role in its operational effectiveness. To ensure seamless operation of the warehouse procedure, the procedure will be depicted as a graphical model. Utilizing a graphical model format rather than textual instructions offers advantages such as comprehensiveness, easy interpretation, and enhanced transparency. In contrast, a written-out procedure can be time-consuming for the user, compromising efficiency and usability. A graphical model is smaller than textual instructions and can be made accessible effortlessly. Thus reducing the risk of errors in the adherence to the warehouse procedure.

The warehouse procedure is depicted in the form of a business process model (BPM), a graphical model extensively utilized during the bachelor's program. A BPM is created using a standard notation known as business process model notation (BPMN). This notation is a standard notation created by the Object Management Group used for the graphical illustration of business processes. The notation contains clear items for the notation of most business process elements. A business process model is comprehensive, has little room for misinterpretation, and everyone can understand the process depicted (BPMN Specification - Business Process Model and Notation, date unknown). Moreover, business process models transparently communicate solutions to stakeholders (Increase efficiency and transparency, date unknown). Additionally, by mapping the business process in the current state and in the forthcoming state the identification of bottlenecks is enhanced (Increase efficiency and transparency, date unknown). Therefore, it fits the format requirements for a warehouse procedure at Rottink well.

In the context of business operations, Business Process Models (BPM) serve as a visual guide to understand how an organization executes its activities. Graphical symbols represent different elements of a business process. These elements are differentiated by four main categories of objects: flow objects, connecting objects, swimlanes and data.

Flow objects represent the workflow of the business process. Events, activities, and gateways are the main flow objects. Events are denoted as circles, indicating occurrences like the initiation or conclusion of an activity. Activities are depicted as rectangles and indicate a specific activity of the business process. Gateways represent decision points. They are diamond-shaped symbols and allow for multiple flow paths to exit the point. aligning with the choices of the decision point.

The flow sequence between different parts of a business process is depicted through connecting objects. There are three types of connection objects: sequence flow, message flow, and associations. They are represented by different types of arrows. Sequence flows depict the sequential progression of the workflow. Associations illustrate relationships between different data and objects. Lastly, message flows indicate communication between diverse participants within the workflow.

Swimlanes distribute tasks in diverse manners. They consist of pools and lanes. Pools represent various departments while lanes depict specific participants. A pool may consist of multiple lanes. In a BPM, pools and lanes are represented by rectangles in which the other objects lay out the business process workflow.

Lastly, data are represented by symbols illustrating a document. They indicate a certain type of data or information that is required for the activity at hand.

3.4 Conclusion

Throughout this chapter inventory models are theoretically examined on pertinence for the coordinated replenishment decision at Rottink. After a study between different models, the Chan and Chiu heuristic is analysed in detail throughout this Chapter. The Chan and Chiu heuristic performs well with less accurate demand forecasts as is the case at Rottink considering the calculation of demand rates in Chapter 2. Moreover, the heuristic has promising results with an inefficiency within 10% of the optimum. More importantly for Rottink, the heuristic is extremely simple in its functioning. As simplicity is a key factor in Rottink’s tool inventory management, the Chan and Chiu heuristic is initially regarded as most suited for chisel tip inventory management.

Stockouts caused by errors in the adherence to the warehouse procedure emphasise the need for a redesigned and improved warehouse procedure. Part of the solution involves transitioning from verbal agreements to transparent and accessible operational guidelines in the form of a graphical model depicted as a Business Process Model (BPM). Utilizing the Business Process Model Notation (BPMN), this graphical representation provides a comprehensive and easily understandable guide that enhances seamless operations in Rottink’s warehouse workflow.

4. Inventory policy design

This chapter outlines the procedure of the new inventory policy. This step of the problem-solving approach is addressed by answering the question "*what is a suitable inventory policy design for Rottink's tool inventory?". First, the functioning of the new inventory policy is discussed in Section 4.1, including the changes from the current policy. This concerns the timing of the order, the order decision, and the control of the system. The Chan and Chiu heuristic is utilized for the joint-replenishment decision in the new inventory policy. Its adaptation in Rottink's tool inventory is discusses in Section 4.2. Lastly, to ensure seamless operation of the new inventory policy, an integral part of the problem-solving approach in this chapter is the design of a new warehouse procedure to complement the new policy (Section 4.3).

4.1 Functioning of new inventory policy

Chapter 2 identified two main issues with the current inventory policy, namely the uncoordinated joint-replenishment and the occurrence of stockouts. This concerns the order decision and the control of the system. The occurrence of stockouts is solely caused by errors in the adherence to the warehouse procedure (Section 2.4.5) and is addressed in Section 4.3. The uncoordinated joint-replenishment is addressed with the utilization of the Chan and Chiu heuristic for the joint-replenishment decision and aims to reduce the number of separate orders. The timing of the order remains the same as in the current inventory policy (Section 2.2.1). An order is initiated when the last package of a certain type of chisel tip is taken. This method functions well when the warehouse procedure is adhered to (Section 2.4.5).

The new inventory policy works as follows:

1. *Order initiation:*
   a) 🖂 Incoming message from warehouse procedure: one of the chisel tip SKUs, x, has reached its last package in inventory.
   b) An order for SKU x is initiated.

2. *Joint-replenishment decision:*
   Based on elements from the Chan and Chiu heuristic, it is decided upon which chisel tip SKUs are included in the initiated order of SKU x and in which quantity. Section 4.2 depicts the Chan and Chiu heuristic adapted for the joint-replenishment decision at Rottink.

3. *Place order*

4. *STOP:* End of the process, continue at *order initiation* when new order is initiated.

Section 4.2 Chan & Chiu joint replenishment decision

The Chan and Chiu heuristic is used in the new inventory policy to define the order after it has been initiated by the warehouse procedure. This step of the new inventory policy is the joint-replenishment decision in which it is decided which chisel tip SKUs are included in the initiated order and in which quantity. In Chapter 3, the heuristic is described in detail. The consulted literature for this heuristic is the paper by Chan and Chiu from 1997.

When an order is initiated in the new inventory policy, the aim of utilizing the Chan and Chiu heuristic is to minimize total costs by optimal joint replenishment. When a SKU from a certain supplier initiates an order, the joint replenishment decision includes only SKUs from that supplier. Considering the inclusion of SKUs from other suppliers has no monetary influence on the initiated order, as its order costs are not influenced by SKUs from other suppliers (Section 2.4.3). Moreover, the number of separate orders is also not influenced if joint replenishment across suppliers is considered. The order placement is still separate per supplier and does not influence the administrative work. Reducing the allocation of work in the tool procurement process by reducing the number of separate orders is only influenced by the number of orders per supplier. Therefore, the joint-replenishment decision is limited to SKUs from the same supplier.

The heuristic as described in Chapter 3 does not consider initial inventory levels. When an order is initiated, SKU x has one package left. However, other SKUs have different inventory levels at that moment. These initial inventories can be implemented in the heuristic by changing the definition of d_{it} from demand for item *i* in period *t* to demand to fulfil for item *i* in period *t.* The demand to fulfil is the demand rate subtracted by the initial inventory. In this way, initial inventory levels are considered. If the initial inventory exceeds demand for the first time period, the difference is subtracted from the succeeding time periods. The inclusion of initial inventory makes for a new *problem definition* with every *order initiation*.

In Chapter 3, the major order cost is defined as a constant cost. The major order cost is incurred at every order, independent of the number of items in the order. At Rottink, the fixed cost per order consists of the delivery cost and the labour cost for processing an order of one SKU (Section 2.4.3). The delivery costs can differ based on the order value (Section 2.4.3). However, to make it a constant cost, the average order costs per order and per supplier throughout dataset B are used as fixed major order costs (Section 2.4.3). Differentiation per supplier works as joint-replenishment is only across one supplier.

The minor order cost is defined differently from Chapter 3. In Chapter 3, the minor order cost is different for each product i. At Rottink however, the minor order costs for chisel tips are almost equivalent for all SKUs. Therefore, the minor order cost for the joint-replenishment decision in the new inventory policy is assumed to be constant over all chisel tip SKUs. The minor order cost at Rottink refers to the additional labour cost incurred when including an extra chisel tip SKU in the order. This labour cost for an order with one SKU is €10,00 as the activities included take around 10 minutes to complete (Section 2.4.3). These activities: placing an order, receiving the order, and storing the order, are the same for all chisel tips. Therefore, performing these activities for an additional chisel tip does not require an additional 10 minutes as the activities are performed simultaneously with the initial SKU. For an additional SKU, these activities take approximately an additional 5 minutes, based on an estimate from company management. The minor order cost averages €5,00 per additional SKU. The difference between labour costs for the first SKU and additional SKUs is the reason why the major order costs include the labour costs for the first SKU, as every order has at least one SKU.

The same holds for the holding costs. In Chapter 3 these costs differ per product i. However, as chisel tips have relatively similar unit prices and storage requirements, this variable is assumed to be constant over all SKUs. The chisel tip holding cost per period is based on taking the average price of a chisel tip, €9,80 (Section 2.4.4), and multiplying it with the same predetermined percentage used in Section 2.4.4. This percentage equals 20% per year. This results in an annual holding cost of €1,96 for storing a chisel tip SKU. The per period chisel tip holding cost h can be computed when the length of the time periods is chosen.

Problem definition:

a) Let D = {1, 2, *i*, 42}, S = {1, 2, *i*, 32}, and O = {1, 2, *i*, 22}. These sets contain the 96 chisel tip SKUs divided per supplier at which they are sourced, respectively: Duhra Tools BV, Slijptechniek Enter BV, and OSG Nederland BV.
b) Let H, the planning horizon, be divided into time periods t = {1,…,H}.
c) Let d_{it} be the demand to fulfil of chisel tip *i* during time period t.
d) Let h be the per period chisel tip holding cost.
e) Let T be the last time period in which an order was placed over all SKUs from the same supplier.
f) Let L_i be the last time period item *i* was ordered.
g) Let A_0 be the major order cost. x is the SKU that initiated the order (Section 4.1):
   If $x \in D$, the $A_0 = €11,26$.
   If $x \in S$, then $A_0 = €13,57$.
   If $x \in O$, then $A_0 = €12,67$.
h) Let A_1 be the minor order cost. A_1 = €5,00.

Joint replenishment decision:

An order for SKU x is initiated according to the new warehouse procedure (Section 4.1). The *joint-replenishment decision* is performed based on elements from Chan and Chiu heuristic:

To *initialize* the heuristic let T = t = 1 and let L_i = 1 for all items i ∈ D, S, or O, dependent on the supplier of SKU x. At *initialization* an order is always authorized, this is the order that the *joint-replenishment decision* aims to define.

Calculate d_{it} for the first time periods by subtracting initial inventory from the per period demands until no longer possible, starting at the first time periods and working onwards. Per period demands are forecasted based on known requirements and insights. However, due to limited insights in demand, especially for further time periods, the demand rate average is often used as well (Section 2.2.3).

Then perform *step 1 to 4* from the Chan and Chiu heuristic from Section 3.2. Combine only across the relevant supplier D, S or O, and use the major order cost of that supplier. If t = H, then STOP

Define order: The order initiated by SKU x is defined based on the joint-replenishment decision. For all SKUs that have demand to fulfil in the planning horizon H, the order quantity is defined based on the amount of time periods for which is ordered at the initial order. The order quantity is rounded of so it represents full packages, as partial packages cannot be ordered. When the order has been defined, continue to step 3 of the inventory policy (Section 4.1).

The Chan and Chiu heuristic is used solely for the joint-replenishment decision in the new inventory policy. Therefore, the order is defined based on the amount of time periods for which is ordered at the initial order. However, the heuristic also schedules replenishments in later time periods to fulfil demand. Those scheduled replenishments are disregarded as towards that time the warehouse procedure will initiate a new order. The initiation of an order by the warehouse procedure is simple and already in place. As chisel tip demand is not completely constant, scheduling replenishments upfront based on the heuristic is a less attractive option. It is also more complicated than relying on the warehouse procedure. The role of the heuristic in the new inventory policy is optimal joint-replenishment in the order initiated by SKU x. To function properly, the heuristic still runs the entire iterative process. Another important consideration as the heuristic is used solely for the joint-replenishment decision in the new inventory policy is the appearance of SKUs that have zero demand to fulfil during the planning horizon. This occurs when a SKU has sufficient inventory when the order is initialized to meet demand during the planning horizon. However, Chan and Chiu (1997) tested cases with a high percentage of zero demands. This resulted in a very slight increase in the heuristic's efficiency between 3% and 5%. Therefore, even with the occurrence of zero demands, the heuristic performs well (Chan & Chiu, 1997).

Next, a simplified example is provided to illustrate the functioning of the *joint-replenishment decision*:

SKU	Initial inventory	Time period			
		1	2	3	4
1	0	12	2	6	8
2	0	42	24	27	34

Table 2: Demand table simplified example

There are 2 SKUs, 4 time periods. Demand and initial inventory are given in
Table 2. $A_0 = 20$, $h = 2$, and $A_1 = 5$. The new warehouse procedure *initiates* an order. As there is no initial inventory, d_{it} follows
Table 2. At time period t = 1, let T = t = 1 and let $L_i = 1$ for both SKUs.

At time period t = 2, $\Delta_{1,2} = max\left\{\frac{1}{2}(2-1)(2-1+1)2 \cdot 2 - 5, 0\right\} = 0$, $\Delta_{2,2} = 43$. $\sum_i \Delta_{i,2} = 43 > 20$. T = 2. $L_1 = 1$ ($\Delta_{1,2} = 0$) and $L_2 = 2$.

At time period t = 3, $\Delta_{1,3} = 31$, $\Delta_{2,3} = 49$. $\sum_i \Delta_{i,3} = 80 > 20$. T = 3. $L_1 = 3$ and $L_2 = 3$.

At time period t = 4, $\Delta_{1,4} = 11$, $\Delta_{2,4} = 63$. $\sum_i \Delta_{i,4} = 74 > 20$. T = 4. $L_1 = 4$ and $L_2 = 4$.

t = H, so STOP. The order is defined based on the amount of time periods for which is ordered at the initial order, as the Chan and Chiu heuristic is used solely for the joint-replenishment decision in the new inventory policy. Hence, the initial order in this example would consist of both SKUs. SKU 1 would be ordered up to time period 3, with order quantity 14. SKU 2 would be ordered up to time period 2, with order quantity 42.

4.3 Warehouse procedure

Section 2.4.5 identified the need for a new warehouse procedure as stockouts are caused by mistakes in the adherence to the current warehouse procedure (Section 2.4.5).

The current warehouse procedure is based upon verbal agreements. These agreements are not formally documented. Therefore, first the current warehouse procedure will be mapped as a graphical model. Then, a new warehouse procedure will be designed. The new warehouse procedure aims to fill the gaps from the current warehouse procedure. Part of the solution is the format of the warehouse procedure. The new warehouse procedure is depicted in the form of a business process model (BPM), using the standard BPMN notation. A business process model is comprehensive, has little room for misinterpretation, and everyone can understand the process depicted (Chapter 3). The other part of the solution is improving the workflow of

the current warehouse procedure. This is enhanced by firstly mapping the current warehouse procedure. Enabling superior identification of bottlenecks.
The new warehouse procedure is described in Section 4.3.2.

4.3.2 New warehouse procedure

The new warehouse procedure introduces minor adaptations to remove the bottlenecks of the current warehouse procedure. Firstly, instead of verbal agreements, the new warehouse procedure enforces better adherence. This is achieved by simplifying the process for the employees and communicating transparently through a well-accessible BPM, which can be found in Figure 1.

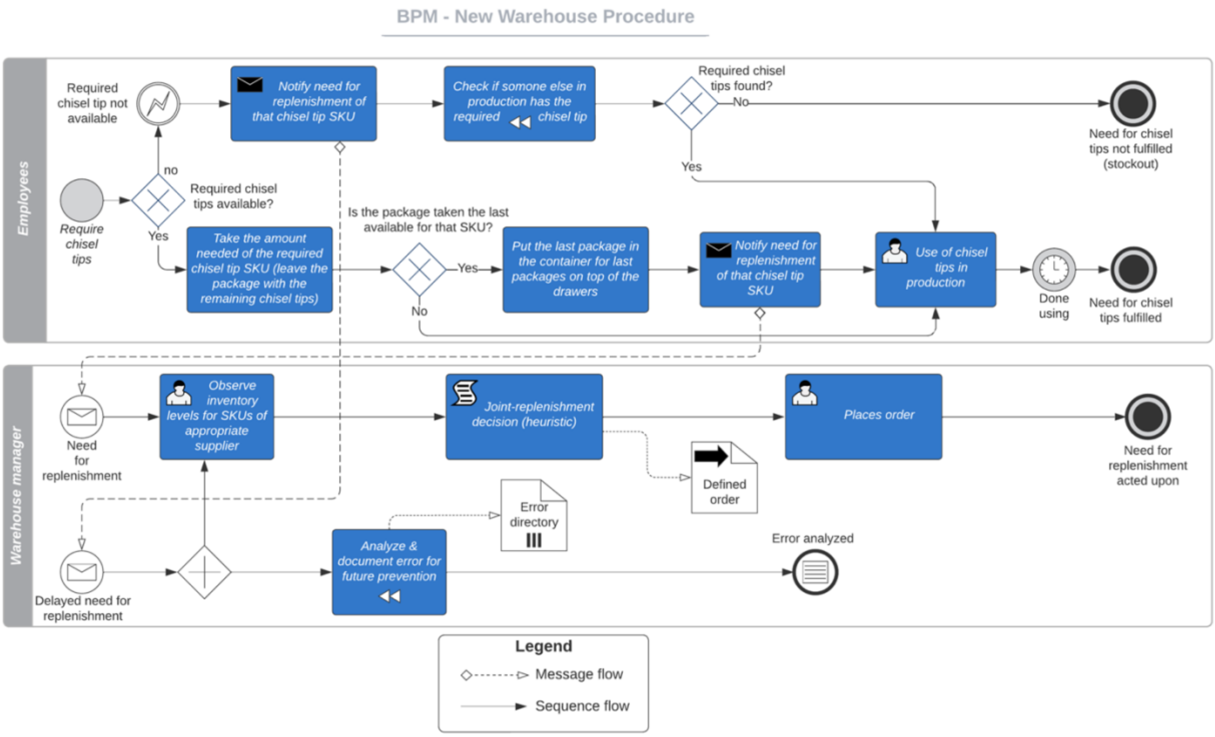

Figure 1: BPM model of new warehouse procedure BPM model of current warehouse procedure

To ensure chisel tip packages are returned to the tool warehouse after usage, the new warehouse procedure removes the need to take a whole package to the working area. Instead, in the new warehouse procedure, employees are supposed to take only the needed amount of the required chisel tip and leave the package with the remaining chisel tips. In this way, the activity of returning a package to the warehouse is removed from the procedure. With it, the error of an unreturned package.

Addressing the issue of notifying the warehouse manager of the need for replenishment, the new warehouse procedure adds one step. When an employee takes chisel tips from the last package in the new warehouse procedure, they are supposed to put that package in a container for last packages on top of the drawers. Afterwards, they still notify the need for replenishment to the warehouse manager. This extra step prevents errors by indirectly notifying the warehouse manager an additional time of the need for replenishment. An additional benefit is employees are only supposed to take the needed amount of the required chisel tip, making sure other employees will repeat the need for replenishment to the warehouse manager when requiring that chisel tip.

Nevertheless, errors can always occur. That is why the new warehouse procedure anticipates potential errors and tries to minimize their effect and occurrence in the future. When the required chisel tip is not available, the employee will notify the need for replenishment immediately and check at other production employees whether they do not have that chisel tip accidently stored at their working area. In this way, the warehouse procedure attempts to avoid possible complications in production. Moreover, when the warehouse manager gets a delayed notification of the need for replenishment, an analyzation and documentation of the error is performed. Identifying the cause of the error is crucial in prevention. In this way, the possibility of the same error happening again is decreased by the new warehouse procedure.

Lastly, the decision of whether to include SKUs in the order and in which quantity is not performed by the warehouse manager anymore. The joint-replenishment decision based on the Chan and Chiu heuristic will perform this task for the warehouse manager. The removal of these tasks is compensated by the required observation of inventory levels for SKUs from the supplier of the SKU that initiated the order.

4.4 Conclusion

Throughout this chapter the new inventory policy is constructed. In the new policy, the timing of the orders remains the same as it has proven to be simple and effective. When an order is initiated, it is decided upon which chisel tip SKUs are included in the initiated order of SKU x and in which quantity. This is done by the joint-replenishment decision based on the Chan and Chiu heuristic, which is adapted for utilization at Rottink. An important consideration remains the decision of the planning horizon and time periods. Luckily, conclusions from Chapter 2 give valuable information on what this could be, and it is further analysed in Chapter 5.

The new warehouse procedure complements the new inventory policy. The new procedure enforces better adherence through a well-accessible BPM. Employees are supposed to take only the needed amount of the required chisel tip and leave the package with the remaining chisel tips. The error of an unreturned package is no longer possible. A container for last packages aims to prevent the unacted upon need for replenishment. While aiming to minimize errors, the new warehouse anticipates upon their occurrence aiming to minimize their impact and prevent their occurrence in the future.

5. Inventory policy validation

In this chapter, the new inventory policy and warehouse procedure are validated. This step of the problem-solving approach is addressed by answering the question *"how does the new inventory policy perform?"*. First, Section 5.1 provides an in-depth validation of the new inventory policy against the current inventory policy. Then, a sensitivity analysis on the performance of the new inventory policy is performed (Section 5.2), specifically focusing on its financial performance and administrative efficiency, in Chapter 2 identified as the main goals to improve. In the sensitivity analysis, the performance of the heuristic under different circumstances is analysed. This includes the decision on the planning horizon, time periods, as well as the holding cost. Lastly, Section 5.3 assesses the performance of the new warehouse procedure.

5.1 In-depth analysis

In comparison with the current inventory policy (Chapter 2), the new inventory policy yields a 15% improvement in financial performance and a 9% improvement in administrative efficiency. This is in the base scenario when the heuristic is using a 24-month timeframe with time periods of 3 days.

The financial performance of the current and new inventory policy is depicted in Table 3. The administrative efficiency per chisel tip supplier of the current and new inventory policy is depicted in Table 4.

Financial performance	Current inventory policy	New inventory policy
Order costs	€5.289,80	€5.035,80
Holding costs (predetermined percentage: 20%)	€17.500,00	€14.236,10
Total costs	€22.789,80	€19.271,90

Table 3: Current and new inventory policy financial performance (2018-2022)

Administrative efficiency	Total number of orders current inventory policy	Total number of orders new inventory policy
Duhra Tools BV	112	101
OSG Nederland BV	118	121
Slijptechniek Enter BV	202	169
Total number of separate orders	432	391

Table 4: Current and new inventory policy administrative efficiency per supplier (2018-2022)

The introduction of multi-item replenishment improves the administrative efficiency. Whereas with the current inventory policy there were on average 1,7 SKUs per order, in the new inventory policy this is increased to 1,9 SKUs per order on average. There is one pattern in the calculations for the new inventory policy that explains this reduction in the number of separate orders. The new inventory policy has cases in which there are still some packages of a SKU in inventory and the heuristic still decides to include that SKU in the replenishment as it is cost beneficial. In the current inventory policy these SKUs are not even considered for inclusion in the order (Section 2.2.1). SKUs with more than four packages left in inventory are mostly the subjects, and especially the SKUs with relatively high demand. For these

SKUs, the introduction of coordinated joint-replenishment with the new inventory policy is most effective, especially at Slijptechniek Enter BV. The effect is such that even with smaller order quantities in general with the new inventory policy, there is still a reduction in the number of separate orders.

This coordinated joint-replenishment also enables a 5% reduction in order costs. This is caused by the same pattern. The reduction in order costs is remarkable considering order quantities decreased by 15,00% on average. This indicates well-functioning coordinated joint-replenishment from the new inventory policy as usually smaller order quantities mean more separate orders and thus higher order costs.

The reduction in order quantities within the new inventory policy is caused by the substantial role holding costs play in the decision-making process of the heuristic. Holding costs have decreased substantially in the new inventory policy in comparison with the current policy. A 19% reduction in holding costs is achieved by smaller order quantities, especially for the fast-moving chisel tips. This highlights the importance of selecting a holding cost rate which is in alignment with the context, as it significantly influences the heuristic’s behaviour.

5.2 Sensitivity analysis

The sensitivity analysis of the new inventory policy is done against key aspects of tool inventory management at Rottink. As identified in Chapter 2, these are the financial performance and administrative efficiency. The financial performance is based on total costs. The total costs refer to the order costs and holding costs combined. The administrative efficiency refers to the volume of orders. In the new inventory policy, the planning horizon and subsequent time periods for the Chan and Chiu heuristic are not defined. The sensitivity analysis aims to find the planning horizon and time periods for which the heuristic in the new inventory policy performs best at these key aspects (Section 5.2.1).

Moreover, the effect of different holding costs on the heuristic are examined (Section 5.2.2). The holding cost in the new inventory policy is based on the predetermined percentage of 20% per year, a commonly used percentage. Nevertheless, this percentage might not completely represent the context at Rottink (Section 2.4.4), therefore the heuristic’s behaviour under different percentages is analysed.

The sensitivity analysis is performed on the timeframe of Dataset B. The data from this 5-year timeframe are used to calculate the performance of the new inventory policy though this timeframe. This is achieved by implementing the new inventory policy in VBA. Chapter 2 extensively analyses the performance of the current inventory policy through this timeframe.

5.2.1 Planning horizon and time periods length

Most parameters for the heuristic within the new inventory policy are based on the context of inventory management at Rottink. However, the decision on the length of the heuristic's planning horizon and subsequent time periods is not directly extractable. These two parameters have significant effect on the performance of the new inventory policy. Therefore, following the findings from Section 2.4.1 and the analysis of demand rates in Section 2.2.3, planning horizons of 3 months, 6 months, 12 months, and 24 months will be tested. Subsequently, time periods of 1 day, 3 days, 1 week, 2 weeks, 4 weeks (1 month), 12 weeks (3 months), and 24 weeks (6 months) will be tested. depicts the financial performance in total costs and administrative efficiency in the number of orders for the different planning horizons and time periods with the new inventory policy. Red and green cells depict the worst and best performance per planning horizon and category. The yellow cells are the values in between.

Lengths of planning horizon	Lengths of time periods	Financial performance (total costs)	Administrative performance (total number of separate orders)
3 months	1 day	€21.277,80	572
	3 days	€21.586,70	505
	1 week	€22.774,00	468
	2 weeks	€23.243,70	423
	4 weeks	€25.282,40	375
	12 weeks	€37.645,00	351
	24 weeks		
6 months	1 day	€21.268,90	543
	3 days	€21.271,60	464
	1 week	€22.715,60	431
	2 weeks	€22.184,30	404
	4 weeks	€24.444,50	368
	12 weeks	€28.729,10	336
	24 weeks	€33.824,60	297
12 months	1 day	€18.986,30	529
	3 days	€19.313,00	412
	1 week	€19.664,30	394
	2 weeks	€19.913,60	379
	4 weeks	€22.497,50	350
	12 weeks	€23.160,50	301
	24 weeks	€26.406,80	230
24 months	1 day	€18.935,40	526
	3 days	€19.271,90	391
	1 week	€19.647,80	385
	2 weeks	€19.846,00	378
	4 weeks	€22.482,40	344
	12 weeks	€23.173,00	299
	24 weeks	€26.275,10	227

Table 5: New inventory policy financial performance and administrative efficiency for different lengths of planning horizons and time periods (2018-2022)

A few patterns are visible across Table 5. Firstly, no matter the length of the planning horizon, 1-day time periods perform the best financially. Regarding the administrative efficiency, 24-week time periods perform the best no matter the planning horizon. Diving into the VBA calculations, this pattern is following the logic behind the Chand & Chiu heuristic. As larger time periods mean less order opportunities, it would logically follow that there are more performed at the same period. Leading to a decrease in the total number of separate orders. Moreover, large time periods have little room for small order quantities as the minimum order quantity covers the length of one time period. Thus, for some SKUs, holding costs become significant. This holds mostly for the fast-moving SKUs. The increase in holding costs for these SKUs significantly outperforms the order cost savings. Through the testing of the different time periods this becomes evident as with smaller time periods order opportunities grow. If holding costs exceed the savings in order costs, orders are performed more frequently, leading to a higher number of separate orders while being financially more beneficial. This pattern is observable across all planning horizons. The fast-moving SKUs have the largest effect on this pattern. With larger time periods order quantities increase for these SKUs. Their holding costs quickly become substantial. SKUs with smaller demands have significant order quantities in the current inventory policy (Section 2.4.1). These order quantities decrease with the usage of time periods smaller than three months in the new inventory policy. The use of larger time periods does not always leave room for a decrease in the order quantity of these chisel tips. In those cases they are often ordered in quantities of the same magnitude as the current inventory policy. Holding costs play a major role in the heuristics decision-making process. Sections 2.4.4 analyses the behaviour of the new inventory policy under different holding cost percentages.

Another pattern observable from Table 5 is the effect of the planning horizon on the performance of the new inventory policy. The change from a one-year planning horizon to a two-year planning horizon has little effect on the performance. This is because little orders for more than a year worth of demand are performed by the new inventory policy. Holding costs simply become disproportional to the potential benefits from order cost savings. Only insignificant changes are visible. However, the shift from a one-year planning horizon to the 3 or 6-month planning horizons does bring changes in performance. Financially, the costs rise over the use of all time periods and administratively more separate orders are performed. The order quantity in the heuristic with 3 or 6-month time periods is bound by the timeframe. Making it impossible to order for more than the duration of the timeframe worth of demand, while this is cost beneficial with some SKUs. Moreover, the joint-replenishment under 3 or 6-month timeframes does not function optimally. Leading to more separate orders. This again adds to the total costs. Following this, the optimal timeframe for the heuristic within the new inventory policy is 24 months long.

The decision on the length of the time periods depends on which key aspect has priority, the financial performance, or the administrative efficiency. At Rottink, the aim is to reduce the costs associated with inventory management while reducing the number of separate orders (Section 1.2). Then, using time periods of 3 days seems the optimal decision. In comparison with the current inventory policy (Chapter 2), the new inventory policy with the use of a 24-month timeframe with time periods of 3 days yields a 15% improvement in financial performance and a 9% improvement in administrative efficiency. Financially, this is not the best improvement possible. However, the difference with using 1-day time periods is around €340,00, a small difference over five years. The use of 1-day time periods has a significantly worse administrative efficiency. Larger time periods allow for even better administrative efficiency. However, the priority lies with the total costs.

5.2.2 Holding cost rate

The selection of the percentage on which holding costs are calculated is based on a commonly used percentage of 20% per year. Nevertheless, this percentage might not completely represent the context at Rottink. Alterations in the holding cost rate percentage significantly impact the decision-making process of the heuristic. Therefore, the effect of different holding cost rates on the heuristic are examined.

Shifting to a holding cost rate of 10% per year, order quantities go up on average by 18%. The financial performance of the new inventory policy improves with it. However, this has little meaning as less holding costs are incurred in general. The number of separate orders is decreased by approximately the same magnitude as the increase in order quantities. Joint-replenishment is thus not enhanced by a smaller holding cost rate. There are still approximately the same number of SKUs per order on average as with a holding cost rate of 20% per year.

This same pattern turns the other way when increasing the holding cost rate to percentages above 30% per year. Order quantities go down, the number of separate orders goes up. However, the joint-replenishment still functions with approximately the same number of SKUs per order on average.

This research will stick to a holding cost rate of 20% as it is a commonly used percentage in practice. Rottink considers the holding costs for the chisel tips as financially negligible. In the future they therefore can decide to lower the holding cost rate. For Rottink, this means larger orders in general and therefore less separate orders.

5.3 Warehouse procedure performance

The performance of the new warehouse procedure can unfortunately not be analysed based on measured results due to lack of time in the strict research timeline. The validation of the proposed new warehouse procedure is dependent on opinions from the various stakeholders. In this case the production employees, warehouse manager and company management.

The employees are positive about having a general set of guidelines to follow. Also, the format of the warehouse procedure is considered understandable by everyone. The employees consider that awareness of the rules will increase due to the accessibility and clarity of the procedure. At first, the employees seemed sceptical about only taking the needed amount of the required chisel tip and leaving the package with the remaining chisel tips in the warehouse. However, when explained there is no need to return empty packages anymore and a large bottleneck in the current procedure is removed, the employees clearly understood the decision. They still noted however that it is to be expected that not everyone will take only the needed amount. Nevertheless, if at least the package is left behind the need for replenishment will not be missed due to unreturned packages. Additionally, the inclusion of the step to check at other production employees whether they do not have that chisel tip accidently stored at their working area when it is not available in the warehouse was a welcoming addition. Some employees were already doing this. Now it is formally included in the warehouse procedure. Another welcome addition is the introduction of a container for last packages. Some employees had proposed this already before. They consider it the simplest solution to the problem. The employees think this will prevent stockouts completely.

The warehouse manager considers the changes positive as the order decision is now performed by the heuristic. The warehouse manager does consider changes in the problem definition as a problem as they will have to change things in Excel themselves. Something they are unfamiliar with. Moreover, the warehouse manager is positive about the container for last packages and considers that with it no stockouts will occur as they will not miss the need for replenishment anymore. They do consider it will lead to less employees notifying the need for replenishment. However, more employees are expected to notify the need for replenishment with the new warehouse policy, partially compensating for it. Moreover, if the container is checked often, less frequent notifications by employees does not pose a threat to the operation of the warehouse procedure. The warehouse manager did express their doubts on the policy for employees to take only the amount needed. They predict employees will take more than needed. However, as long as whole packages are not taken it does not pose a threat to the operation of the warehouse procedure.

An important note from the warehouse manager and company management is whether all inventory levels of a supplier must be observed every time an order is initiated. Of course, this is the preferred option. However, considering the heuristic performs well with the occurrence of zero demands, not all SKUs need to be observed exactly. When the warehouse manager sees SKUs with a higher inventory level, they do not need to precisely extract the exact level. In this case, the demand to fulfil in the heuristic will be zero or close to zero, not leading to any substantial differences as it is not considered by the heuristic's algorithm.

5.4 Conclusion

Throughout this chapter the new inventory policy and warehouse procedure are validated. The implementation of coordinated joint-replenishment in the new inventory policy notably increases the average number of SKUs per order from 1,7 to 1,9, leading to a 5% reduction in order costs, while reducing the number of separate orders. This is remarkable considering the 15% reduction in average order quantities. A reduction in order quantities and order costs simultaneously indicates improved joint-replenishment with the new inventory policy. Holding costs are the underlying reason for the decrease in average order quantities as the holding cost rate has significant influence on the size of orders in the new inventory policy. However, joint-replenishment is merely influenced by a different holding cost rate.

From the sensitivity analysis follows that the optimal timeframe for the heuristic within the new inventory policy is 24 months long. The decision on the length of the time periods depends on which key aspect has priority, the financial performance, or the administrative efficiency. At Rottink, where the aim is to reduce the costs associated with inventory management while reducing the number of separate orders, using time periods of 3 days seems the optimal decision. This decision finds a balance between reduction in costs and administrative performance. Usage of 1 day time periods results in significantly worse administrative efficiency while time periods of more than 3 days bring higher costs.

Regarding the new warehouse procedure, the warehouse manager raises concerns about adapting Excel processes due to complexity. Prompting the focus on creating a user-friendly interface to simplify the Excel processes. The last package container is considered a significant improvement. Both the warehouse manager and company management question the necessity of observing all inventory levels. This is resolved as the heuristic performs well with zero demands, eliminating the need to extract exact inventory levels of SKUs with high inventory.

6. Inventory policy implementation

In this chapter, the implementation of the new inventory policy and its complementary warehouse procedure are discussed. This step of the problem-solving approach is addressed by answering the question "*How can the new inventory policy be effectively communicated and implemented across the organization?".* Section 6.1 discusses the implementation of the inventory policy.

6.1 Inventory policy implementation

The successful implementation of the new inventory policy and complementary warehouse procedure at Rottink necessitates a strategic approach that engages the various stakeholders in the process. To effectively introduce and integrate this policy shift, collaborative involvement from employees, the warehouse manager, and company management is imperative. Initial stages of implementation should prioritize familiarizing employees with the new policy framework. This can best be done through sessions in which the inventory policy and warehouse procedure are presented to production employees, for which the warehouse procedure will be most important. The message should emphasize the advantages of the policy changes while actively addressing any apprehensions or concerns raised by the workforce. Besides informative sessions, employees need to be remembered upon the new guidelines from the warehouse procedure to limit error in the adherence. Especially at the start, constant repeating of workflow guidelines is important. This is best achieved through the addition of certain workflow guidelines at the area where they hold. An example is putting a note at the chisel tip drawers that the last packages need to be put in a special container on top of the drawers. Additionally, establishing transparent communication channels to encourage continuous feedback will aid in incorporating valuable insights from stakeholders into the continuous improvement of the new inventory policy and warehouse procedure.

Moreover, close collaboration with the warehouse manager is crucial during this transition. Special attention should be given to assist the warehouse manager in understanding and adapting to altered procedures, particularly in relation to the joint-replenishment decision based on the Chan and Chiu heuristic. The calculative steps of the new inventory policy, including the calculation of order quantities are done by Excel processes. Moreover, the timing and execution of inventory monitoring is important. Here, it is important to explain the underlying logic so the warehouse manager can execute it swiftly yet effectively. It is important that the warehouse manager is guided until they can carry out the activities independently. By providing adequate support and guidance, potential challenges in adapting to the new processes can be effectively managed. The Excel sheet on which the joint-replenishment decision is run has been made as intuitive as possible for the warehouse manager.

However, the implementation process does carry inherent risks that need careful consideration and mitigation strategies. Foreseen risks include potential resistance from employees due to procedural changes, which can be mitigated through thorough explanation, training workshops, and consistent communication addressing concerns. Operational disruptions may also arise during the transition phase, warranting phased implementation to identify and resolve glitches before full-scale deployment. Additionally, the risk of non-compliance with the new procedures calls for rigorous monitoring mechanisms and periodic audits to ensure adherence and timely rectification of deviations. By adopting a proactive and inclusive approach that engages stakeholders, addresses concerns, and maintains close monitoring, Rottink can effectively mitigate risks and facilitate a seamless implementation of the new inventory policy and warehouse procedure.

6.2 Conclusion

Throughout this chapter the implementation of the new inventory policy and complementary warehouse procedure are discussed. The successful implementation of the new inventory policy and warehouse procedure at Rottink relies heavily on a collaborative and inclusive approach that engages various stakeholders. Prioritizing employee engagement through informative sessions aimed at presenting and familiarizing them with the policy changes is crucial. Remembering the employees on guidelines by inserting them in applicable areas assists the prevention of errors in adherence. Besides teaching them the underlying logic, guidance to the warehouse manager is important until able to carry out activities independently. By embracing a proactive and inclusive implementation strategy, Rottink can effectively mitigate risks and ensure a smooth integration of the new inventory policy and warehouse procedure.

7. Conclusion

In this chapter, the conclusion of the research on inventory policy design for chisel tips at Rottink is discussed. This step of the problem-solving approach elaborates on the main research question "*how to design a new inventory policy to optimize inventory management for Rottink BV's chisel tip inventory?".* Section 7.1 summarizes the conclusions from the sub-questions. Section 7.2 discusses the recommendations for Rottink following the research. Section 7.3 discusses the limitations regarding the execution of this research.

7.1 Sub-questions conclusion

Below, summaries of the conclusions for all five sub-questions defined in Section 1.5 are presented.

7.1.1 How is the current inventory policy performing?

The first step of the research is to create a full overview of the performance of the current inventory policy. The number of separate orders in the current policy is large, despite that chisel tips require less than 2 orders per SKU per year on average. This results in significant administrative work. Order quantities are large, except for the most fast-moving chisel tips, leading to significant holding costs of around €3.500,00 per year. With the uncoordinated multi-item replenishment, an order contains 1,7 SKUs on average. Nearly 20% of the orders incurs delivery costs, totalling over €1,000 annually. The consideration of the only available lot size-based discount is not included into a new inventory policy as it saved €180,00 over a five-year period, an insignificant amount. Considering the nature of chisel tip demand at Rottink, demand at Rottink is deterministic for chisel tips with regular demand. Due to the relative variation, the constant demand rate assumption of the fixed EOQ-model is significantly violated. Therefore, the dynamic lot-sizing model better fits the context. Coordinated multi-item replenishment in the new inventory policy should reduce the number of separate orders and thereby the administrative work associated with inventory management at Rottink. Additionally, the inventory policy plays no role in the occurrence of stockouts. Errors in adhering to warehouse guidelines are the cause. Rottink therefore requires a new warehouse procedure to prevent stockouts.

7.1.2 What inventory models exist for managing tool inventory effectively?

Throughout chapter 3 inventory models are theoretically examined on pertinence for the coordinated replenishment decision at Rottink. The Chan and Chiu heuristic is analysed in detail as it emerged as most suited in a comparison analysis with other inventory models. The Chan and Chiu heuristic performs well with less accurate demand forecasts as is the case at Rottink. The heuristic has promising results with an inefficiency within 10% of the optimum. More importantly for Rottink, the heuristic is extremely simple in its functioning. Therefore, it is initially regarded as most suited for the management of chisel tips at Rottink.

Regarding the new warehouse procedure aimed at preventing stockouts, part of the solution involves transitioning from verbal agreements to transparent and accessible guidelines in the form of a graphical model depicted as a Business Process Model (BPM). This graphical representation is comprehensive and easily understandable and enhances seamless operation, important elements in Rottink's warehouse workflow.

7.1.3 What is a suitable inventory policy design for Rottink's tool inventory?

Throughout chapter 4 the new inventory policy is constructed. The timing of the orders remains the same. When an order is initiated, the joint-replenishment decision based on the

Chan and Chiu heuristic decides which chisel tip SKUs are included in the initiated order of SKU x and in which quantity.

The new warehouse procedure complements the new inventory policy. In the new procedure employees are supposed to take only the needed amount of the required chisel tip and leave the package with the remaining chisel tips. The error of an unreturned package is thus no longer possible. A container for last packages is introduced, aimed to prevent unacted upon need for replenishment. Errors always occur. therefore the new warehouse aims to minimize their impact and prevent repetition in the future.

7.1.4 How does the new inventory policy perform?

In chapter 5 the new inventory policy and warehouse procedure are validated. A sensitivity analysis indicates that the optimal timeframe for the heuristic is 24 months long. The length of the time periods depends on which key aspect has priority, the financial performance, or the administrative efficiency. At Rottink, the aim is to reduce costs while reducing the number of separate orders. Then, using time periods of 3 days is the optimal decision.

Coordinated joint-replenishment in the new inventory policy notably increases the average number of SKUs per order to 1,9, leading to a 5% reduction in order costs, and reducing the number of separate orders. This is remarkable considering the 15% reduction in average order quantities. Which are reduced as the holding cost rate has significant influence on the order quantities in the new inventory policy. Nevertheless, joint-replenishment is merely influenced by the holding cost rate.

Regarding the new warehouse procedure, the warehouse manager raises concerns about implementing Excel processes due to complexity. Prompting the focus on creating a user-friendly interface to simplify the Excel processes. The last package container is considered a significant improvement. The necessity of observing all inventory levels is questioned. This is resolved as the heuristic performs well with zero demands, eliminating the need to extract exact inventory levels of SKUs with high inventory.

7.1.5 How can the new inventory policy be effectively communicated and implemented across the organization?

Throughout chapter 6 the implementation of the new inventory policy and complementary warehouse procedure are discussed. Successful implementation relies heavily on a collaborative and inclusive approach that engages all stakeholders. Prioritizing employee engagement through informative sessions aimed at familiarizing them with the policy changes and underlying logic is crucial. Remembering the employees on guidelines by inserting them in applicable areas assists the prevention of errors in adherence. Guidance to the warehouse manager is important until they are able to carry out all activities independently. By embracing a proactive and inclusive implementation strategy, Rottink can mitigate risks and ensure a smooth integration of the new inventory policy and warehouse procedure.

7.2 Recommendations

Following the answers to the research questions, the recommendations for Rottink are formulated. Firstly, it is recommended to implement all provided solutions to ensure optimal performance of the new inventory policy and complementary warehouse procedure. Regarding the implantation, it is recommended to execute the implementation in a stepwise approach to prevent errors. This is important as errors in implementation are difficult to repair.

Then, it is recommended to decide which key aspect has priority for optimization, the financial performance, or the administrative efficiency. The length of the time periods depends on which key aspect has priority, and this decision significantly influences the performance of the heuristic in financial performance and administrative efficiency.

Moreover, it is recommended that the warehouse manager engages in enhanced engagement with the production employees. This has advantages in both ways. The warehouse manager is able to remind employees on warehouse guidelines and the importance of them. Production employees can reach out more easily to the warehouse manager in case of doubt, preventing errors in adherence at their origin. In this way the warehouse manager is better aware of the warehouse procedure execution and is able to correct irregularities in an early stage.

It is also recommended that inventory levels of chisel tips are better monitored. Besides enabling better control and understanding of the system, the demand for chisel tips is better understood. As demand rates serve as input in the heuristic, better forecasting enables better performance. Currently, active monitoring is not present, and demand rates are extracted from historical data of tool order placements. Multiple assumptions make this possible. However, demand forecasting is more precise when active monitoring is performed. Therefore, it is recommended that Rottink engages in better monitoring of the inventory levels of chisel tips.

7.3 Limitations

Throughout the course of this research, various limitations have come to light. Firstly, as described in Section 2.2.3, the demand rate per period in dynamic lot sizing is given and is assumed as known. However, due to limited insights in demand, demand rates per period are difficult to predict, resulting in forecast variability. As time advances, inventory levels and new requirements are known, forecast variability for time periods closer to the initial time period decreases. For further time periods, the forecasts at Rottink will move towards the demand rate average as little information on requirements is yet known and demand insights are limited. This forecast variability reduces the preciseness of demand input in the heuristic and may lead to a loss of efficiency with the new inventory policy.

It is essential to note that the heuristic is specifically employed for the joint-replenishment decision within the new inventory policy. The influence of forecast variability is more evident for demand rates further from the initial time period, where information is less precise. Consequently, this limitation may have a relatively minor impact on the overall efficiency of the heuristic in the context of the new inventory policy.

Another limitation in the new inventory policy is the definition of major order costs in the Chan and Chiu heuristic. In Chapter 3, the major order cost is defined as a constant cost. The major order cost is incurred at every order, independent of the number of items in the order. At Rottink, the constant cost per order consists of the delivery cost and the labour cost for processing an order of one SKU. The delivery costs can differ based on the order value. However, to make it a constant cost, the average order costs per order and per supplier are used as a fixed major order cost in the new inventory policy. This oversimplification may impact the accuracy of optimizing order costs in the new inventory policy, particularly as it neglects the consideration of thresholds associated with delivery costs. Despite this limitation, it is crucial to highlight that the new inventory policy, even with the fixed major order costs, demonstrated cost savings and a reduction in the number of separate orders. These positive outcomes underscore the effectiveness of the new inventory policy.

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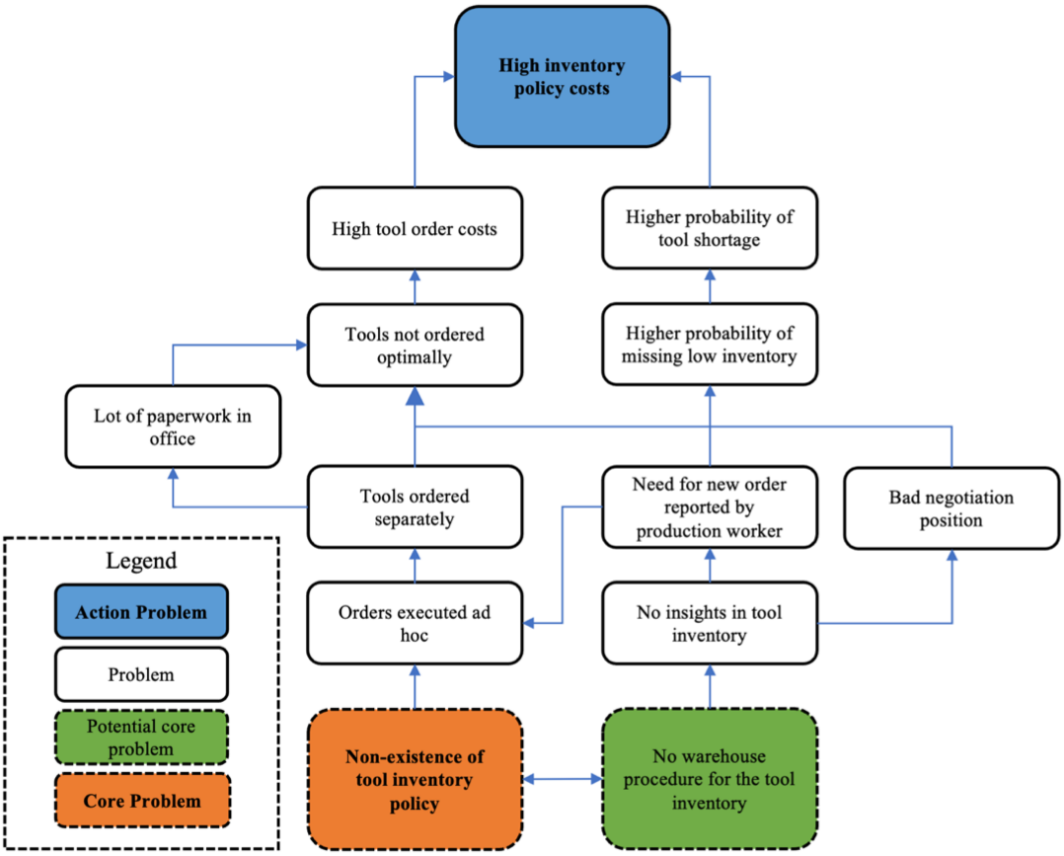
Appendices

Appendix A: Problem cluster



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Appendix B: Data filtering process of Dataset B

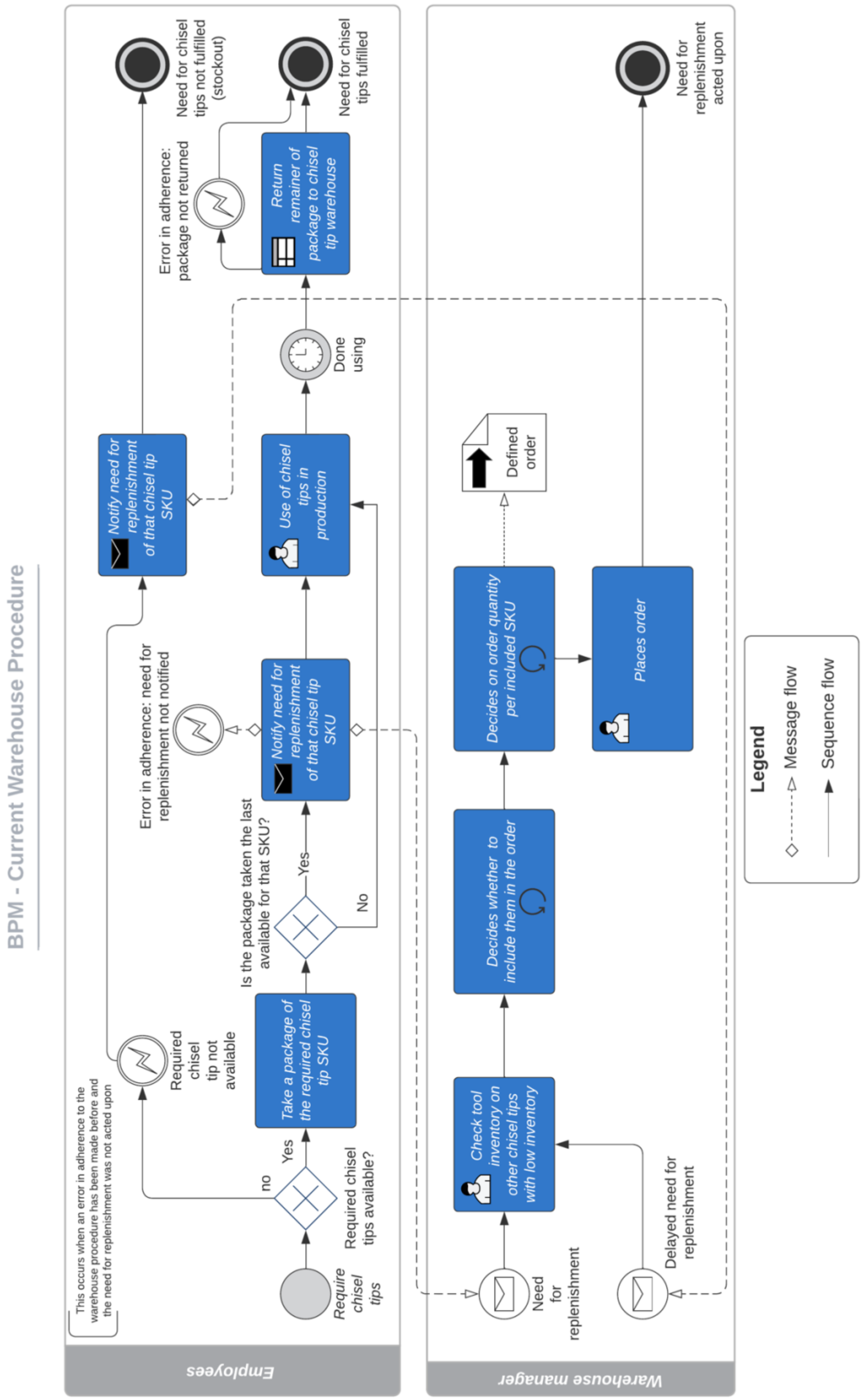
As described in Section 2.2.2, the data loaded from the companies' ERP system contain the history of all tool order placements. This contains all tools used in the production area. Nevertheless, the scope of this research as described in Section 1.6 focusses solely on chisel tips. Therefore, Dataset B should be filtered to only represent chisel tips.

Following the timeframe (2018-2022) selected for Dataset A and B in Section 2.2.2, Dataset B is filtered to depict the history of chisel tip order placements from 2018 to 2022. The data are sorted based on article numbers. These numbers typically include a prefix indicating the category or type of product, followed by a sequence of letters and numbers that identify the specific article. For example, in the article number "G00003 EG094I02U05GUN KCU10," the "G" prefix indicates that the article belongs to the tools category as the Dutch word for tools is "gereedschap". The remaining characters in the article number are used to identify the specific article. Following this, the first steps of filtering Dataset B is to remove all articles with number "G99999". This number is assigned to tools that are required on a one-time basis and are not regularly ordered. Chisel tips do not belong to this category.

Another indicator found in the data is the creditor number. The creditor number identifies the supplier of the tool. Rottink sources its chisel tips from three suppliers (Section 2.1): Slijptechniek Enter BV (100048), OSG Nederland BV (100146), and Duhra Tools BV (100496). The creditor number for the corresponding supplier is listed between brackets. Dataset B is filtered to solely depict these three creditor numbers. In this way, only order placements at suppliers of chisel tips are included in the data.

The final step in the filtering process of Dataset B is the removal of all non-chisel tip items that have been ordered from the three chisel tip suppliers. These items are manually removed by reviewing each article number and eliminating those that do not belong to the chisel tip category. Since many article numbers consist of complex codes that are difficult to untangle, this task often requires extensive Googling and consultation with company management. This step concludes the filtering process of Dataset B.

Appendix C: BPM model of current warehouse procedure



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