htm aerotec

2023

Ordering policy optimisation for forecast-driven orders within HTM-Aerotec

Author:
J.E.S. Roerink

Master:
Industrial Engineering & Management

Supervisor HTM-Aerotec:
Msc. A. Kasteel

Leading Supervisor University of Twente:
Dr. E. Topan

Second Supervisor University of Twente:
Dr. I. Seyran Topan

UNIVERSITY OF TWENTE.

UNIVERSITY OF TWENTE

FACULTY OF BEHAVIOURAL, MANAGEMENT AND SOCIAL SCIENCES

INDUSTRIAL ENGINEERING AND MANAGEMENT

Ordering policy optimisation for forecast-driven orders within HTM-Aerotec

Author:
J.E.S. ROERINK

Master:
INDUSTRIAL ENGINEERING & MANAGEMENT

Track:
PRODUCTION & LOGISTICS MANAGEMENT

Supervisor HTM-Aerotec:
MSc. A. KASTEEL

Leading Supervisor University of Twente:
DR. E. TOPAN

Second Supervisor University of Twente:
DR. I. SEYRAN TOPAN

MANAGEMENT SUMMARY

HTM-Aerotec is specialised in producing high precision complex products for the aerospace and defence industry as a tier-one supplier of leading high-tech OEM companies. In early 2020, HTM-Aerotec implemented a new ERP system (Glovia) which enables them to utilize point forecasts provided by three of its clients in its material requirements planning process. Since the introduction of Glovia HTM-Aerotec has developed and applied a relatively simple fixed lot-size ordering policy reinforced by empirical decision-making. In other words, in principle use is made of a fixed lot-size ordering policy, but based on the experience and personal judgment of the planner, purchaser, or management, the lot-size can be modified accordingly. Currently, HTM-Aerotec is not sure whether in case of these forecasted products this current ordering policy is still the optimal policy given the current company characteristics. Moreover, this method has not been analysed or evaluated on a financial or logistical level. The actual impact of increasing or decreasing the lot-size on the company performance is not clear. However, an analysis of sales revenue from the past two years reveals that approximately 70% of total revenues can be attributed to forecast-driven products. This highlights the significant potential impact of optimizing the ordering policy specifically for forecast-driven products.

The primary goal of this research is to optimise the ordering policy of the forecast driven products at HTM-Aerotec such that the sum of setup cost and inventory holding cost are minimised. However, in order to do so we first have to solve two additional forecast related observed problems (A and B) , solving these observed problems will ensure that the forecast data is reliable and ready to use for the main purpose of this research; the optimization of the ordering policy itself.

The first forecast related observed problem A "Transforming and transferring customer forecasts to Glovia is time consuming and exposed to human errors" occurs when the forecast data file is downloaded from the customer portal and transformed to a Glovia compatible layout and format. In order to transform and prepare this data for uploading to Glovia, there is currently made use of an Excel file where multiple manual sequential data transformation tasks have to be performed before the forecast demand data can be transferred to Glovia. These manual tasks are not only time consuming, but also induce the risk of incorrect faulty data to be transferred to the Glovia ERP system due to the fact that the transformation process is exposed to human errors. This faulty data can potentially harm and disrupt the purchasing of raw materials and production planning. To address this problem, we formulated the following research question:

> A: *"How can HTM-Aerotec reduce the time required for transforming and transferring forecast data to the Glovia ERP system, while also mitigating the risk of human error during this process?"*

In addition, the second forecast related problem denoted by B, which we define as "Forecast data is partly omitted by Glovia" occurs when the new updated forecast data is uploaded to Glovia. Before being uploaded, forecast data is converted into weekly buckets, with each bucket corresponding to a column. For reasons unknown, forecasts until a limited time in the future are visible in the ERP system. The remaining majority of data is inexplicably omitted by Glovia. Consequently, the ability of the planner and purchaser to accurately anticipate upcoming demand is severely restricted, which can lead to irreversible and unintended errors in decision-making related to raw material procurement and production scheduling. In order to address this problem we formulated the following research question:

> B: *"How can HTM-Aerotec minimise the quantity of forecast data that is omitted by the Glovia ERP system?*

The problem solving process started by analysing the current situation at HTM-Aerotec by a context analysis. Here we discovered after testing and consultation with the Glovia helpdesk, that during uploading of the CSV file to Glovia, it only considers the first 50 columns, causing the neglect of the remaining columns. As a consequence, the system experiences a significant data loss, with up to 75% of forecast data being inaccessible (reducing the available data from four years to just one year). This limitation directly impacts production scheduling and hampers the optimization of lot sizes.

To address both problem A and B, we developed a forecast conversion tool, enabling us to tackle both challenges simultaneously. This tool enables HTM-Aerotec to convert the point forecast data provided by their biggest customer to a layout and format compatible to the Glovia ERP system. Within this tool we incorporated a systematic approach to mitigate the impact of the 50 columns import limitation of Glovia. Therefore, we condense the point forecasts in weekly, 2-weekly, 4-weekly (Monthly) and 13-weekly (Quarterly) time buckets. By doing so, we are able to leverage the benefits of having precise demand data for the near future, while also retaining comprehensive demand data for the more distant future. As a results, the tool not only saves valuable time (1,5 hour every two weeks), resulting in cost savings for HTM-Aerotec, but it also provides the company with reliable forecast demand data. Which enables the planner, purchaser and management with a precise understanding of required demand for the immediate future, as well as a comprehensive overview of future demand trends. Furthermore, the newly developed live data infrastructure required for the automated processes included in this tool offers a multitude of possibilities beyond its primary application. This new infrastructure empowers HTM-Aerotec to make data-driven decisions and automate repetitive tasks.

As said, the main goal of this research is to research is to optimise the ordering policy of the forecast driven products at HTM-Aerotec such that the sum of setup cost and inventory holding cost are minimised. An important requirement for this cost minimisation is that the on-time delivery performance should not be negatively affected. The observed problem for this prominent research goal is defined as follows: "The currently used ordering policy for forecast driven orders is questioned", denoted as observed problem C .To solve this observed problem and achieve this research goal, the main research question of this research is formulated as follows:

C: "How can HTM-Aerotec _minimise the total relevant setup and inventory cost_ of the _forecast driven items_ by improving the ordering policy without compromising on on-time delivery performance?"

A literature review provides us with the following findings regarding research question C. The lot-size optimisation problem at HTM-Aerotec, often referred to as the Uncapacitated Lost-Sizing problem (UCLS) is NP-hard, indicating that it is computationally challenging to solve optimally for all instances. We can conclude that due to the complexity, various heuristics and approximation algorithms have been developed to find reasonably good solutions within a reasonable amount of time. However, in case of intermitted demand the options are limited, especially when taking in to account the ability to be seamlessly integrated into HTM-Aerotec's ERP system. We observe that an (s, Q) policy is a very common approach in literature for various lot-size optimisation problems, in particular when order size Q is determined using the Economic Order Quantity (EOQ) formula. In addition to the EOQ model, we are interested in the Least Unit Cost heuristic since it is very well capable of handling the intermitted demand characteristics present at HTM-Aerotec. Although these heuristics probably do not meet the requirement that they should be able to be implemented in the ERP system, they can serve as valuable benchmarking tools for evaluating lot-size optimization policies which do have the ability to be seamlessly integrated into HTM-Aerotec's ERP system. For the same reason we have also added the Lot For Lot policy.

To meet the requirement that the new optimised ordering policy is compatible with the Glovia ERP system we developed a new ordering policy based on the EOQ model. This ordering policy referred to as Dynamic EOQ leverages the easy of use of the Economic Order Quantity formula while capitalizing on the benefits of dynamic lot sizing. The Dynamic EOQ value [in weeks] is calculated by converting the (fixed order size) EOQ [in units] value into an equivalent value in weeks. In Glovia this parameter is referred to as the Order/Delivery Policy. The Dynamic EOQ ordering policy works as follows; in case upcoming demand for product A with a calculated Dynamic EOQ of 30 weeks cannot be delivered from stock, the upcoming demand for that period and consecutive 30 weeks is summed. In other words, the lot-size for this production run is set equal to the summed demand for the upcoming 30 weeks starting from the point in time the inventory level drops below zero.

We include four sub types, in the next paragraph we explain the differences:
- Dynamic EQO, Round Down, Upper Bound 104wk
- Dynamic EQO, Round Down, Upper Bound 84wk
- Dynamic EQO, Round Up, Upper Bound 104wk
- Dynamic EQO, Round Up, Upper Bound 84wk

We determined that an lower bound of 12 weeks for the Dynamic EOQ is sufficient since no products require al lower value than 12 weeks. Additionally, considering the First Article Inspection (FAI) restriction, which necessitates production runs no more than two years apart, we use an upper limit of 104 weeks (approximately two years). As Glovia utilizes a letter-based system to assign order/delivery policies to products, the maximum number of policies that can be assigned is limited to 26. Consequently, we adopt an incremental approach, assigning policies in four-week intervals ranging from 12 weeks to 104 weeks (12, 16, 20, ..., 104). This selection process yields a total of 24 letters, comfortably within the limitation of the Glovia ERP system. Furthermore, due to the fact that the Forecast conversion Tool transforms the forecast data to monthly time buckets up to 84 weeks (Appendix G) we also include an sub type with 84 weeks as upper bound. Using this upper bound of 84 weeks we exclude the 13 weekly (quarterly) time buckets ensuring proper functioning of the Dynamic EOQ policy when the rolling horizon progresses and time passes by. Beside the sub type with the 84 upper bound, we included an sub type in which we round the calculated order/deliver policy up towards the first option from the list (12, 16, 20, … 104) and a sub type in which we round down to the first option from the list.

We compare all the above mentioned ordering policies. This allows for evaluating the potential improvement of the performance indicators of the current situation of HTM-Aerotec with the newly developed "Dynamic EOQ" ordering policy. We use this information to determine whether the Dynamic EOQ ordering policy is able to deliver equivalent performance to the renowned and proven Least Unit Cost Heuristic. It is not possible to implement this least Unit Cost Heuristic in the Glovia ERP system, which is a strict requirement for this research. However, it only serves as means to compare the current and Dynamic EQO ordering policy with a proven lot-size optimisation technique. The performance of the policies are evaluated using the Ordering Poling Optimisation Tool, we use five key performance indicators; total relevant cost (TRC), the total setup cost, the number of deliveries from stock, the average inventory level and the average inventory value. The total relevant cost stands out as the most crucial performance indicator due to its ability to provide a comprehensive perspective on the overall costs. By considering all relevant cost components HTM-Aerotec can make informed decisions to minimize expenses by optimising their inventory policy accordingly.

Table 1 Results ordering policies (Annual data, at steady state)

Policy type	Current	L4L	EOQ	LUC	Dynamic EOQ			
					Round Down		Round Up	
Sub type	-	-	-	-	UB 104	UB 84 wk	UB 104	UB 84 wk
TRC								
Setup cost								
Holding cost								
Deliveries from stock								
Avg. inventory [items]								
Avg. inventory value								

Table 1 shows the performance for a one-year duration, specifically from May 2024 to May 2025. It's important to note that the preceding 12-month period prior to May 2024 has been excluded from the analysis as it is considered a warm-up period. The best-performing policy is visually highlighted in green for each performance indicator independently. Based on the results presented in Table 1 we can conclude that the newly developed Ordering Policy Optimization Tool enables HTM-Aerotec to increase the number of deliveries from stock by approximately xx% compared to the current ordering policy. Furthermore, this newly developed Dynamic EOQ policy resulted in an expected reduction of approximately xx% in total relevant cost and xx% in setup costs. Consequently, this outcome can be perceived as a win-win situation, offering both higher delivery reliability at lower costs simultaneously. As a result, HTM-Aerotec can benefit enhanced operational efficiency and improved customer satisfaction using the Dynamic EOQ ordering policy.

The research has identified several limitations. These limitations mainly stem from the assumptions made in the model and uncertainties in the data input and forecast accuracy. The setup cost data from the ERP system is assumed to be accurate, but variations in calculation methods over the years may introduce potential discrepancies and inaccuracies in the data. However, the sensitivity analysis suggests that the impact of holding costs on the outcomes is relatively minimal due to the robustness of the Economic Order Quantity (EOQ) model.

Another limitation is the failure to account for the inherent stochasticity of forecast demand over time, including timing and size. As a result, dynamic lot size policies might experience more negative consequences compared to fixed lot size policies. Incorporating safety stock could potentially address this issue, but the lack of sufficient raw forecast files hinders reliable forecast accuracy calculations, particularly for slow-moving products with small sample sizes.

In case of future research it is advised to implement the new Dynamic EOQ ordering policy in the ERP system. This implementation facilitates the evaluation of the policies functionality and impact, allowing for necessary adjustments to the model and policy Additionally, it presents an opportunity to assess the pros and cons of implementing a dynamic lot-size policy.

PREFACE

It is with great pleasure and a sense of accomplishment that I present this master's thesis, the culmination of my academic journey and research endeavours. Undertaking a master's degree has been a transformative experience, pushing the boundaries of my knowledge and providing me with the opportunity to delve deep into a specific area of study. This research project at HTM-Aerotec allowed me to apply theory to practice fostering a deeper understanding of lot-size optimisation and sharpening my critical thinking skills.

Throughout this journey, I have been fortunate to receive guidance and support from a multitude of individuals whom I would like to express my sincere gratitude to. My deepest appreciation goes to my company supervisor Arthur Kasteel, whose expertise and unwavering encouragement proved invaluable. His guidance played a crucial role in shaping the direction of this research and successful completion of this project.

I would also like to extend my thanks to Engin Topan and Ipek Seyran Topan (first and second supervisor) whose stimulating discussions and constructive criticism have played a vital role in shaping the ideas presented in this thesis. Their diverse perspectives and intellectual camaraderie have been instrumental in refining my research methodology and strengthening the overall quality of this work.. Their dedication to excellence has been a constant source of inspiration and has shaped my growth as a researcher.

Lastly, I am indebted to my girlfriend and family, whose unwavering support and understanding have been a source of strength during the arduous process of writing this thesis. Their encouragement and belief in my abilities have motivated me to persevere through challenges and reach this significant milestone.

In conclusion, this thesis represents the culmination of a rigorous intellectual pursuit, encapsulating countless hours of research, analysis, and contemplation. It is my sincerest hope that this work contributes to the existing body of knowledge and holds great value for HTM-Aerotec. I humbly present this thesis to the academic community and the reader, with the aspiration that it may stimulate curiosity, ignite discussions, and serve as a foundation for future research.

Jasper Roerink,

Enschede, July 2023

LIST OF ABBREVIATIONS

Abbreviation	Definition
SO	Sales Order
CPO	Computer Planned Order
WO	Work Order
PO	Purchase Order
PR	Purchase Requisition
OS	Outsourcing
MPS	Master Production Schedule
ERP	Enterprise Resource Planning
CTP	Capable To Promise
MRP	Material Resource Planning
CRM	Customer Relationship Management
BOM	Bill Of Materials
CTP	Capable To Promise
FAI	First Article Inspection
FAD	Fabriek Aansturende Documentatie (Factory controlling documentation)
LOI	Letter Of Intent
UoM	Unit of Measure
FP	Factory Planning
HMLV	High Mix Low Volume

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This research is carried out in the context of a graduation assignment for the Master Industrial Engineering & Management at the University of Twente with the aim to improve the ordering policy for forecast-driven orders within HTM-Aerotec (High Tech Machining).

This Chapter starts off by presenting general information about HTM-Aerotec in Section 1.1. Subsequently, the problem description including the problem cluster is explained in Section 1.2. Followed by the research question resulting from the problem cluster are shown in Section 1.3. Lastly, the scope of this research will be addressed in Section 1.4.

1.1. INTRODUCTION TO HTM-AEROTEC

HTM-Technologies is a subsidiary of the Precision Metals Group (abbreviated as PM Group), founded in 1966 (PM Group, 2022). The PM-Group is a world leader in the design, development and manufacturing of high-precision bearings, positioning systems, mechatronic systems, aerospace and military components and modules for both government use and civil industry. HTM-Technologies consists of five sister companies including HTM-Aerotec; HTM-Precision, HTM-Precision Sheet Metal and HTM-Industrial Partner, see Figure 1 for an overview. This research is carried out in Hengelo on behalf of HTM-Aerotec.

Figure 1 Geographical overview of HTM-Technologies

The HTM-Aerotec facility is specialised in producing high precision complex products for the aerospace and military industry (products for aircrafts, helicopters and rockets) as a tier-one supplier of leading high-tech OEM companies such as: Customer A, Customer B, Customer C and Customer D. The products are used in for example airplanes, helicopters, fighter jets or rockets. It employs approximately 45 people, of which fifteen situated in the office and thirty in the production department. The high precision products that HTM-Aerotec produces vary heavily due to specific requirements set by their clients. The products vary from large fuel tanks to small parts of a few millimetres, see Figure 2. Nearly every order therefore has a unique routing. Therefore, HTM-Aerotec uses both make to order (MTO) and engineer to order (ETO) production approaches. A typical routing for a product is

as follows: cut raw material to size, marking the parts, machining by turning and/or milling machine(s), first article inspection by coordinate measuring machine, manufacture the remainder of the batch, inspection by coordinate measuring machine of last and if required intermediate batch products, dispatch to surface treatment outsource partner, and lastly a final quality check before dispatch to client. An overview of the facility can be found in Appendix A.

Figure 2 Examples of parts manufactured at HTM-Technologies

The order size ranges from a few products to hundreds of products. Given the HMLV and MTO & ETO environment, HTM-Aerotec has organised the production department by process (Job shop facility layout). In addition, most of the product that HTM-Aerotec manufactures also have to meet the international aerospace regulations (AS9100) which requires for example first article inspection (FAI). Whilst operating in this very challenging industry, HTM Aerotec aims to achieve a 10% revenue growth annually. This requires HTM-Aerotec to keep the performance of their business process high to be able to meet both their clients' and HTM's targets.

1.2. PROBLEM DESCRIPTION

In early 2020, HTM-Aerotec implemented a new ERP system (Glovia G2) which enables them to utilize the point forecasts provided by three of its clients – Customer A, Customer B, and Customer C- in its material requirements planning process. Since the introduction HTM-Aerotec has developed and applied a relatively simple ordering policy reinforced by empirical decision-making. Currently HTM-Aerotec is not sure whether this current ordering policy in case of these forecasted products is still the optimal policy given the current company characteristics.

Within HTM-Aerotec 70% to 80% of demand is forecast driven (A. Kasteel, 2022). Based on the sales revenue analysis of the previous two years shown in Figure 3, the weighted average forecasted revenue accounts for 70% of total revenues. The available data is limited in this as there is no sales data available before the introduction of the new ERP system and 2020 has been omitted as this is considered a warm-up period. There may also be covid-related factors that influence the ratio between forecasted and not forecasted. Nevertheless, we can conclude that the forecasted orders account for approximately 70% of the total revenues, which shows that the potential impact of optimizing the ordering policy for forecast driven products is large.
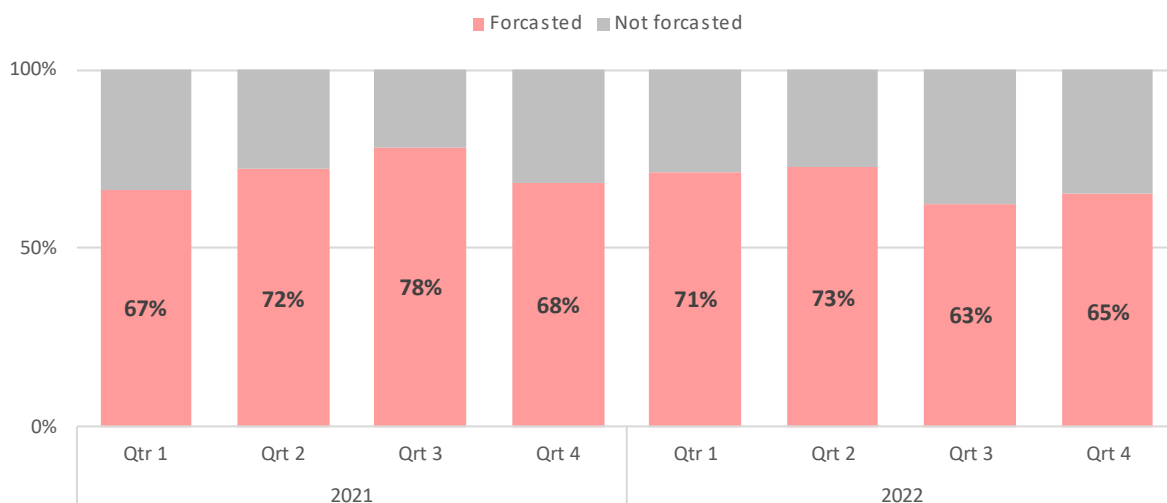
Figure 3 Forecasted revenues vs Not forecasted revenues

In case of forecasted products, the product specification, expected annual quantity and forecast conditions are recorded in Long Term Agreements. The forecasts itself are periodically updated and can be download from a dedicated customer portal. Since the introduction of Glovia (2020), HTM-Aerotec applies a relative simple ordering policy for the forecasted products in which they aim to simultaneously produce multiple point forecast in one larger batch (increased lot-size). As a result of which one or more consecutive deliveries are fulfilled from stock. The aim of this strategy is to increase the overall production efficiency and reducing total production cost. The batch size and timing on when to order is currently determined based on the following four factors:

1. **Minimum order size / Setup quantity:** The setup quantity is an important input parameter for calculating the listing price for an product. When the lot-size quantity used for the production is less than the lot-size used in the price calculation, the profit margin will be lower than desired. Therefore, in order to prevent this, the lot-size used for the price calculation is used by Glovia as a lower bound constraint when creating replenished orders.

2. **Order quantity multiple:** After the minimum order quantity is exceeded, planned order quantities round up to the nearest order quantity multiple for this item. For example, if the order quantity multiple is 5, then a demand for 31 would be rounded up to 35, the nearest order quantity multiple, during planning.

3. **Order/Deliver policy code:** For each forecasted product there is defined an Order and Deliver policy code in Glovia. Which functions as a review period in which all demand occurring in that period is consider to produce simultaneously in one batch. For example code 1 means a review period of 12 weeks and code 2 means 17 weeks ahead. By doing so, a single order is planned to replenish all demands that occur within the review period. The aim for using the Order/Deliver policy is twofold, preventing starting production of a new batch when the previous batch has not finished yet. And in particular, reducing the annual frequency of production setups, reducing the total amount of deliveries that need to be managed.

4. **Empirical driven finetuning:** Lastly, as long as the material planning still allows adjusting order quantities and therefore does not fall within the lead time of the raw material. Is it possible for the planner to adjust the lot-size based on experience given the latest demand forecasts. In this way, any errors can be detected and the planning can be optimized. In the ideal situation, this step is superfluous and Glovia is able to handle this on its own without the intervention of the planner.

Since the introduction of the new ERP system HTM-Aerotec uses the above described four factors/constraints to determine the lot-size. However, this method has not been analysed or evaluated on a financial or logistical level. The actual impact of increasing or decreasing the lot-size on the company performance is not clear. Optimizing the lot-size can thus potentially have a major impact on the company's performance. Since the frequency and timing on when to order are closely related to the lot-size, therefore this aspect should also be included in the research.

Given that HTM-Aerotec is not able to model or quantify the financial pro's and con's for different lot-sizes and evalute the ordering policy results accordingly using dedicated KPI's induces questionons being raised and doubts being expressed by employees about the extent to which the current lot-size and Ordering/Delivery policy settings used in Glovia are optimal given the current company charaterisctics. The first and most prominent observerd problem is therefore formulated as follows: "The currently used ordering policy for forecast driven orders is quesioned", as can be seen in Figure 4. This problem cluster depicts the relation between the observed problems and the underlying core problems. The observed problems exsits because HTM-Aerotec is not able to model and quantify the ordering policy. Up until now HTM-Aerotec has insufficient workforce capacity to obtain the required knowledge to built a model and building the model itself. Such as the knowledge regarding the Glovia extensive CPO planning related features and settings, denoted by core problem 3. In addition there does not exist an option to evaluate the Glovia Forecast consumtion features and settings (Core problem 6), causing even more uncertainty when incidental errors are discovered of which the rootcause is unclear.

In addition, three more core problems can be identified causing HTM-Aerotec not being able to model or quantify the financial pro's and con's for the lot-size and ordering policy; The lack of a clear overview of inventory holding cost (Core problem 2), and the lack of a ready to use overview of setup/order cost for each product specific (Core problem 4). Due to the fact that no useful overview regarding these aspects is aviable, makes creating a realistic ordering policy optimisation model difficult, if not impossible. Another aspect that plays a role in this research is the complexity of the products. Each order/product is unique, which causes a single ordering policy and lot-size for all parts being sub optimal, denoted by core problem 7.

In addition to the first most prominent observed problem related to forecasting, we observed another problem: "Transforming and transferring customer forecasts to Glovia is time consuming and sensitive to errors", shown as block A in the problem cluster. The forecast data is downloaded two weekly or monthly from the customer portal depending on the customer. The format and layout of these forecasts are not compatible to the layout and format of Glovia. In order to transform and prepare this data for uploading to Glovia, there is currently made use of an Excel file where multiple manual sequential data transformation tasks have to be performed before an CSV file can be transferred to Glovia (core problem 1). These manual tasks are not only time consuming, but also induce the risk of incorrect faulty data to be transferred to the Glovia ERP system due to the fact that the transformation process is exposed to human errors. This faulty data can potentially harm and disrupt the purchasing of raw materials and production planning.
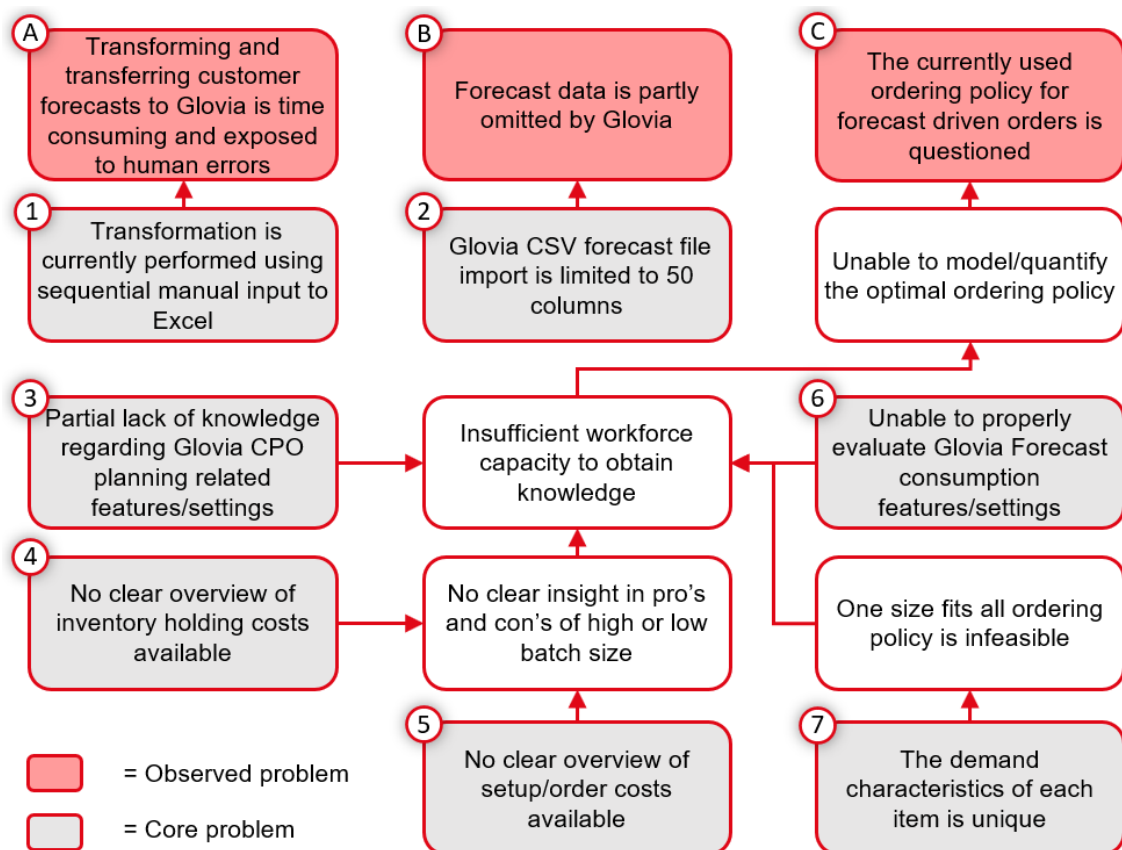
Figure 4 Problem cluster

Finally, we observed another forecast related problem. Shown as block B in the problem cluster: "Forecast data is partly omitted by Glovia". The problem occurs when the new updated forecast data is uploaded to Glovia. Before it is uploaded, the forecast data is converted to weekly buckets where each bucket correspond to a column. For reasons unknown, forecasts until a limited time in the future are visible is the ERP system. The remaining majority of data is somehow omitted by Glovia. Consequently, the planner and material requirement planner are also unable to access this information. This constraint restricts their ability to accurately anticipate to upcoming demand, potentially leading to irreversible and inadvertent mistakes in decision-making for the purchasing of raw material and production scheduling.

1.3. RESEARCH APPROACH

The primary goal of this research is to gain knowledge on what opportunities are available in order to minimise the total relevant setup and inventory holding cost for the forecast driven items at HTM-Aerotec by optimising the ordering policy.

However, in order to do so we first have to solve two other forecast related observed problems, shown as block A and B in the problem cluster. Solving these observed problems will ensure that the forecast data is reliable and ready to use for the main purpose of this research; the optimization of the ordering policy itself. Starting with observed problem A "Transforming and transferring customer forecasts to Glovia is time consuming and exposed to human errors". In order to address this problem we formulated the following research question:

"How can HTM-Aerotec <u>reduce the time required</u> for transforming and transferring forecast data to the Glovia ERP system, while also <u>mitigating the risk of human error</u> during this process?"

To support the process of answering main research question A, sub questions are defined:

1. *How are the customer forecasts currently transformed and transferred to Glovia?*

2. *How can the time required for transforming and transferring the forecast data to Glovia be reduced?*

3. *How can the risk of human error during transforming and transferring of the forecasts be reduced?*

In addition, for the second forecast related problem denoted by block B in the problem cluster, which we defined as "Forecast data is partly omitted by Glovia". We formulated the following research question:

"How can HTM-Aerotec <u>minimise the quantity of forecast data that is omitted</u> by the Glovia ERP system?

Sub-questions have been formulated to aid in addressing primary research question B:

4. *What causes Glovia to partly omit forecast data?*

5. *What measures can HTM-Aerotec adopt to enhance the quantity of accessible forecast data in Glovia?*

The main goal of this research is to gain knowledge on what opportunities are available for minimising the total relevant setup and inventory holding cost for the forecast driven items at HTM-Aerotec by optimising the ordering policy. An important constraint for this cost minimisation is that the on-time delivery performance should not be negatively affected. The causal underlying observed problem for this prominent research goal is defined in the problem cluster as: "The currently used ordering policy for forecast driven orders is questioned", denoted as block C in the problem cluster .To solve this observed problem and achieve this research goal, the following main research question of this research is formulated as follows:

"How can HTM-Aerotec <u>minimise the total relevant setup and inventory cost</u> of the <u>forecast driven items</u> by improving the ordering policy without compromising on on-time delivery performance?"

To support the process of answering the first main research question C, sub questions are defined:

6. *What is the current configuration of the business processes at HTM-Aerotec?*

7. *What is presented in literature regarding the ordering policy problem at HTM-Aerotec?*

8. *Which solution method suits best for solving the ordering policy optimisation problem at HTM-Aerotec?*

1.4. SCOPE OF RESEARCH

The research will be limited to the internal supply chain of the HTM Aerotec facility, part of the HTM Technologies group. In addition, only the forecast driven products will be taken into account, in particular the products from the most prominent customer which provides forecasts to HTM-Aerotec. In case the approach works well for this selection of products the approach can be applied to other customers which provide forecast as well.

Furthermore, the research will be limited to solution alternatives that can be useful for obtaining knowledge or new insights regarding the observed problems. In addition it is preferred that the proposed solutions must be compatible to the Glovia ERP system. Solutions that cannot be implemented have little to no value for the company and are therefore excluded from the research. The primary objective is to identify a practically feasible solution that can effectively address the problems.

Moreover, all proposed solutions must comply with several certifications: AS9100D QMS - Requirements for aerospace, space and defence organizations, ISO-9001:2015 - Requirements for quality management systems and AQAP 2110 - NATO quality assurance requirements.

2. CONTEXT ANALYSIS

*To address the first sub research question: **"What is the current configuration of the business processes at HTM-Aerotec?"** a context analysis is conducted. This chapter presents and discusses the findings of the context analysis. Each section consecutively discusses a department from the internal business processes of HTM-Aerotec. In case there exists a clear divergence in business process flows for new, recurring, and forecasted orders each will be described separately.*

*In particular section 2.3 will address the following two sub research questions: **"How are the customer forecasts currently transformed and transferred to Glovia?"** and **"What are the limitations which causes Glovia to omit forecast data?"**. A detailed understanding of the business processes pertaining to these two research questions would be immensely beneficial for the future progression of the research and would delineate the boundaries within which solutions must be pursued.*

In the context analysis chapter, we commence by detailing the sales quote and order acceptance phase in Section 2.1. Subsequently the production planning processes (Section 2.2) will be discussed. Followed by the production engineering phase (Section 2.4) including the manufacturing engineering and CAD/CAM department. The quality related business processes will be described in Section 2.5 and purchasing in Section 2.6. We will then expand on the layout and characteristics of the actual production process in Section 2.7. The supporting tasks of the HR and finance department are described in Section 2.8. Lastly, Section 2.9 finalises and summarises the chapter with conclusions and a swimlane diagram based on the discussed context analysis.

2.1. SALES

We start the context analysis with the sales department, which is an essential part of any business organization, responsible for generating revenue by selling products or services to customers. It plays a crucial role in driving business growth and achieving organizational goals by identifying potential customers, building relationships with them, and closing deals. The sales department comprises a team of sales representatives who are responsible for managing sales processes, communicating with customers, and negotiating deals. The success of a business often depends on the efficiency and effectiveness of its sales department, making it a vital function that requires careful planning, management, and execution (Lee & Yoo, 2016).

The sales department of HTM-Aerotec distinguishes between new, recurring and forecasted orders. There exists a clear distinction in process flows when creating sales quotes (SQ) for new, recurring or forecasted orders. The process flow of new orders is more complex, resulting in a larger workload compared to recurring and forecasted orders.

In case of a new order request the sales manager, production planner, manufacturing engineers, purchaser and quality manager, all contribute to the process of creating the sales quote. It is an interplay of several disciplines and is characterized as a team effort. The process starts with determining the routing by the manufacturing engineer based on the customer requirements and provided technical drawing. With routing we mean the sequence of production steps the part must go through to end up with a finished product. After the routing has been determined, the CAD/CAM engineers estimate the time required to create the production files and actual production of the parts such as machine run time. Parallel to the manufacturing engineers, the material requirements planner determines the expected lead time and costs of raw materials. If required, outsourcing and packaging costs will be defined by the material requirements planner as well. Based on this input data, the production planner calculates a feasible due date using the Capable To Promise (CTP) function of Factory Planning, which is an add-on of the ERP system Fujitsu Glovia G2. Lastly, the sales manager will create the sales quote based on the cost data from the ERP system and the calculated feasible due date.

In case of a recurring order, historical data such as lead time, production cost and material cost will be used to create a sales quote. However, this data can be obsolete and should therefore be checked. In order to do so, the manufacturing engineer will verify if the routing and documentation is still available and valid. Also, in case

materials and/or tooling are required, the purchaser needs to check the expected lead time and costs of the required materials. In case there are any changes, the information in the ERP system will be updated accordingly. Finally, the sales manager will create and send a sale quote based on the (updated) data from the ERP system.

In case of forecasted orders, the price, expected order quantities and deliveries conditions are recorded in a contract or letter of intent (LOI). Formulating and sending a quote is therefore superfluous. However, the client must confirm the forecasted order in due time by means of a purchase order (PO), from that point on the forecasted order will be designated a sales order status. Negotiating on price and delivery conditions is also superfluous in this case. Because these are already recorded in a contract.

On the other hand, both new and recurring order quotations may be rejected, or a counteroffer may be proposed. The sales manager will determine in consultation with the manufacturing engineers and production planner whether a better offer can be realized. If not, negotiations may result in lost sales.

2.2. PRODUCTION PLANNING

Production planning is an essential process in the manufacturing industry that involves the management of resources and activities to ensure that goods are produced efficiently, on time, and within budget. This process involves the coordination of various departments within a company, including engineering, production, materials management, and sales. Production planning involves determining the number of products to be manufactured, the materials and labour required and the time frame for production,. The goal of production planning is to optimize resources and minimize waste while meeting customer demand and maximizing profitability. In today's global market, where competition is fierce and customer expectations are high, production planning has become a critical function for manufacturing companies. Companies that can effectively plan and execute production processes are better equipped to succeed in the marketplace, deliver high-quality products, and satisfy customer demand (Vollmann T. E., Berry, Whybark, & Jacobs, 2017).

Whitin HTM-Aerotec the main task of the production planner is to schedule orders for production, but also anticipating and adapting to disruptions that may occur during production such as machine downtime, delayed outsourcing or quality issues. The goal is to monitor and preserve an optimal production schedule considering on-time delivery, machine utilization and WIP.

The production planner uses the data from their ERP system (Glovia G2). The sales order data such as, order quantity, routing, required outsourcing, machine labour setup and run times are provided by the sales manager, manufacturing engineers and CAD/CAM department. Based on this information and fixed information from the ERP system such as machine capacity constraints and internal transport time (Appendix B and C), the production planner can perform a CTP check (Capable to promise) using the Glovia G2 add-on called Factory Planning. This CTP check is used to calculate a promised delivery date. The actual delivery date that is communicated with the client by the sales manager is extended with one extra week as a safety margin.

In case the client accepts the sales quote, the SO (Sales order) is converted to a CPO (Computer planned order). As a result, the required machine/department capacities are reserved in the production schedule. A week before the production start date, the ERP system automatically changes a CPO to a WO (work order) unless the raw material is not delivered yet. Orders with a start date more than a week in the future are not converted to a work order with the aim of keeping WIP low. After the WO is released for production the production planner will inform the expedition department to ensure that the raw material arrives on time at the right machine. In addition, the tooling department is informed to prepare the required tooling for the machines.

Sales Order in ERP → Calculate CTP date → Promised date for client → Order accepted SO to CPO → Capacity reserved → Release WO → Start production
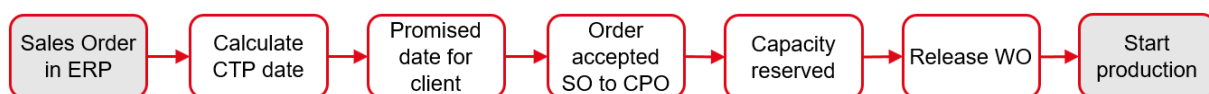
Figure 5 Production planning flowchart

The production planner has access to four different planning algorithms included in FP to create a production schedule; Very Short Forward (up to 14 days ahead), Short Forward (up to 30 days ahead), Long Forward (Up to

450 days ahead) and Long Backward (starting from 450 days up to 1000 days ahead), see Figure 6. Very Short Forward and Short Forward include the machine capacity and material availability status in the scheduling algorithm. Long Forward and Long Backward do not include this as constraints, in that case the machine capacity and material are set to infinite. Currently the production planner uses all four of the scheduling algorithms sequentially (Very Short Forward, Short Forward, Long Forward and Long Backward) in order to create/update the production schedule. Starting with the Very Short Forward which only schedules orders that are due within 14 days into the future. It schedules in forward direction and starts off by initializing all machines/departments. So, at the start the schedule is empty. Short Forward, the second scheduling algorithm schedules up to 30 days into the future using forward direction. The second algorithm takes previous results from the first algorithm into account when creating the schedule up to 30 days. The third algorithm schedules up to 450 days into the future and takes the previous results into account as well. The fourth and final Long Forward algorithm schedules the orders up to 1000 days into the future. Again, previous scheduling results are included.

Each of these algorithms uses priority rules in hierarchical order to determine which order to schedule next. For example, in case multiple orders have the same manual priority assigned to them, FP will consider the second priority rule to determine which order to schedule next. In the event there are still multiple orders which fulfil both priority rules the next rule will be considered and so on. FP has numerous priority rules, an overview below:

- "Manual priority" allows the user to manually assign priorities to orders
- "MRP End Date" prioritises orders given their MRP end date, first on top
- "MRP Status" uses information from the MRP to prioritize orders. The status of a work order (Closed, In Process, Released, Unreleased.) depends on availability of raw materials and if the order is released
- "In-Process first" prioritises orders in case their MRP status is set to In-Process
- "Slack Just-In-Time" schedules orders according to the smallest slack time
- "Order ident, Line etc." prioritises based on unique identifiers

An overview of the FP scheduling policies currently used by the HTM-Aerotec production planner can be seen in Figure 6. When running them sequentially, a production schedule up to 1000 days in the future can be created in a systematic manner.
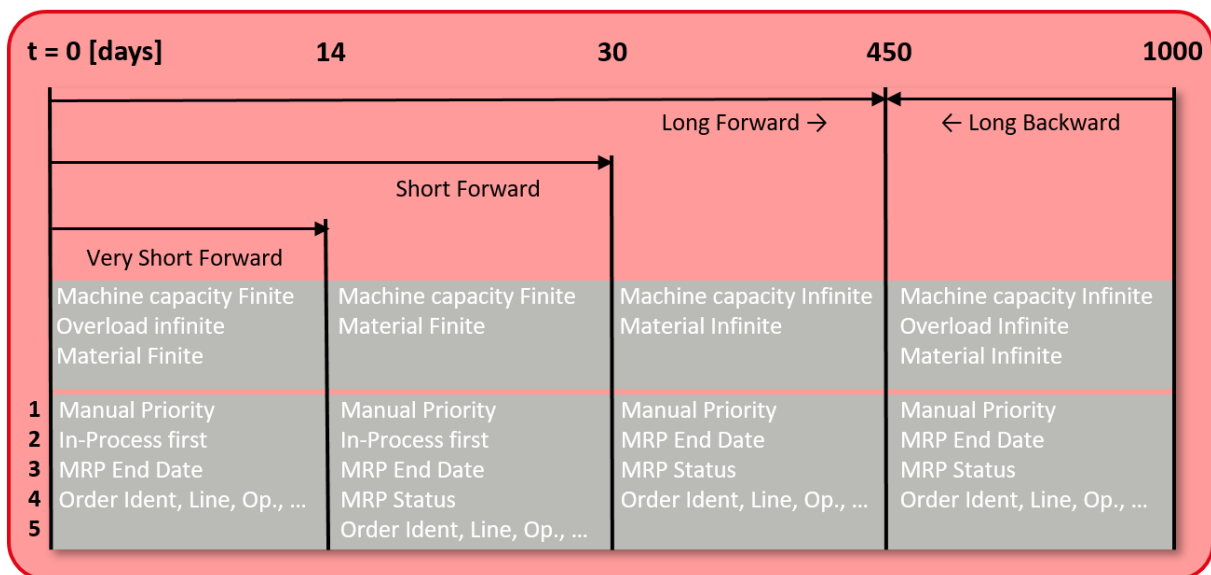
Figure 6 Overview of currently used Factory Planning scheduling policies

FP also allows users to define their own custom priority rules. However, up until now HTM-Aerotec only used standard priority rules. In addition, HTM-Aerotec does not include the workforce capacity as a constraint in the production schedule, the workforce capacity is considered infinite and therefore neglected by each of the algorithms. Nevertheless, holidays or absence of production employees are manually considered when scheduling orders and releasing work orders. The production employees are assigned to the machines and corresponding tasks

by the production manager. Because not every production employee can operate each machine given their skill set, it is important to consider the skill-matrix when creating the workforce schedule. However, in general production employees are assigned to one and the same machine. In the first place to simplify the workforce scheduling, but also in favour of the quality and consistency of the manufacturing process. Switching operators (production employees) can lead to an increased risk of rejected parts by the quality engineers due to minor differences in personal preferences when operating a machine.

Currently the Factory Planning scheduling add-on is used for indicative purposes only, before the schedule is proceeded to the Glovia G2 Master Production Schedule (MPS) it will be manually "fine-tuned" using Excel. The MPS is the leading schedule that states exactly when each operation should start and finish. The MPS is also used by the production manager to create the workforce schedule. Several attempts have been made to improve the FP scheduling policies in order to make fine-tuning using Excel superfluous. However, this has not yet led to the desired result. An example of the limitations of FP is that FP uses a due date including outsourcing, whereas the production planner actually wants to use the internal due date. Because FP does not offer this option, Excel is used for manually adjusting the production schedule based on the internal due date.

This production schedule outlines the production plan of a HTM-Aerotec. Once updated, this schedule is regularly transformed into "stuur lijsten" and proceeded to the production department. These "stuur lijsten" comprise a detailed individual schedule for each machine/workstation present in the production department. They contain essential information regarding the required quantity, materials, priority, and deadlines for each machine, and are updated regularly to ensure that all employees stay informed. By providing accurate and timely information, these "stuur lijsten" enable the production department to effectively manage the production process and ensure that all orders are completed on time and to the desired quality standard.

2.3. FORECASTED DEMAND

Forecasted demand refers to the projected amount of a particular product or service that customers will require in the future. Accurately forecasting demand is critical for businesses, as it allows them to optimize their production and distribution processes, effectively manage their inventory, and ultimately increase their profitability. In today's dynamic and ever-changing business environment, having a reliable demand forecasting system is essential for businesses to stay competitive and meet the needs of their customers.

This Section enables us to answer sub research question one; "*How are the customer forecasts currently transformed and transferred to Glovia*". In addition, the purpose and functionality of forecast consumption is explained (Section 2.3.2).

2.3.1. TRANSFORMING AND TRANSFERRING FORECAST DATA

Currently HTM-Aerotec is using the forecasted demand data of three customers accounting for approximately 70% to 80% of turnover. In case of Customer A, the use case for this thesis, there is an underlying long term contractual agreement (LTA) in which financial commitments, the forecasting procedure and delivery conditions are recorded. More details concerning the LTA cannot be shared in this public thesis as they are considered confidential.

The forecasts are periodically (monthly or 2 weekly) updated and can be retrieved from on online customer portal, in case of Customer A the forecast is updated 2 weekly. So, every two weeks Customer A Aerostructures provides HTM-Aerotec with a new updated forecast. The forecast consist of point forecasts for all included items for a period up to 48 months in the future. The file format that can be downloaded from the portal is a 2003-Excel file format (.xls). The format is organised as a typically database output format, a new unique line for each point forecast. The unique identifier is a combination of the item number data field and forecast due date data field. Only the non-zero demands are included in the file, all dates for which there is not included a forecast for a specific item for a specific period, corresponds with a zero-demand for that item in that period. It is worth noting that the forecasting procedure itself is performed by the customer, Customer A in this case, and not HTM-Aerotec. Finally, because Customer A is situated one level upstream compared to HTM-Aerotec and thus possesses more in-depth

internal knowledge about the production planning of different projects. With this additional information, Customer A Aerostructures has an advantage and will consequently be more capable of producing accurate forecasts.

To be able to make use of the forecast data provided by the customers it has to be to transferred to the ERP system (Glovia). Before the data can be upload it first must be transformed such that it will be compatible with the Glovia database layout. To do so, there has to be performed multiple manual transformations such as, connecting the customer product number to the internal product number, transposing the typical row database layout to column layout and changing the due date to be in line with the sales orders scheduling procedure while taking into account the safety lead time of approximately one week (6 to 12 days) and the weekly transport shuttle every Wednesday. In order to account for this, the point forecast due dates have been changed to the date of the Wednesday one week prior. Currently the data transformation is performed using an relative simple Excel workbook by manual input by the sales employee. By doing so, the data transformation is time consuming (Up to one and a half hour) due to the fact that new up to date data exports have to be download manually from the ERP to be able to connect the customer item number with the internal product number. It is important to have this data up to date because when a new item is added or the revisions of an product has changed the customer product number must be connected to the new revision letter. Otherwise incorrect information will be uploaded to the ERP system, which may lead to errors in the production planning or materials requirement planning. For example, it can happen that the forecast appears twice as a result of incorrect conversion. One product with the correct up to date revision number with only sales orders connected to it. And an old revision that has only forecasts connected to it. This can cause the forecast consumption to malfunction, causing demand to be overestimated by the production planner and/purchaser. On the other hand it can cause underestimating of demand in case the production planner and/or purchaser only take the upcoming demand of one of the revisions into account when planning or sending purchase orders.

Once the compatible grid is completed, with adjusted due dates, it will be saved as a CSV file. Subsequently, this file will be uploaded to Glovia. The observed problem when uploading this CSV file to Glovia is that Glovia only takes the first 50 columns into account, the remaining columns are neglected, where the first 5 are used for general purposes. Due to this only 45 columns can be used as forecast due dates each corresponding to one week. In case of weekly time buckets and a 4 year forecast horizon this would result in losing about ¾ of forecast data. This loss of information results in limitations when it comes to scheduling and determining the optimal lot size.

To ensure that the updated forecast data is reflected in the ERP system, the PLANNING UPDATE function needs to be executed. This function applies the forecast consumption rule to the updated data, as explained in the following paragraphs.

2.3.2 FORECAST CONSUMPTION

Forecast consumption is the process that replaces forecast demand with sales order demand. Each time there is placed a sales order, there is created actual demand. If there is created actual demand, it is required to reduce the forecasted demand by the sales order quantity to avoid overstating demand. The forecast consumption process deducts sales orders (actual demand) from the gross forecast, after spreading and rounding, to come up with a net forecast (GLOVIA G2, 2023).

Figure 7 Consumption calendar

Glovia provides the flexibility to select from a variety of five forecast consumption rules. The first two rules A and B allow only for backward consumption and/or consumption in the same period. Rule C and D allow for forecast consumption in the future or in in the same period. For each consumption rule, the number of period must be specified. If left blank, forecasts are consumed only by demands occurring in the same period. If 1, then forecasts are consumed by demands occurring in the same period, plus 1 additional period, in the direction, forwards or backwards set by the rule. This progression can continue up to a maximum of 53 periods. These period

are defined by the forecast consumption calendar, an example of calendar year 2023 is shown in Figure 7. The last rule type option, type S, is only valid for S type demand streams (Customer specific - applies to SCP forecasts in Supply Chain Planning) which are used with Supply Chain Planning (SCP) forecasts to schedule orders using event handling. This is similar to Rule C except that the forecast consumption calculations are done in real-time instead of batch mode. In case of HTM-Aerotec all demand streams are designated type G (Generic), therefor rule type S is rendered unsuitable for HTM-Aerotec.

Forecast consumption rule A consumes forecast demand from the customer order schedule date backward for the number of periods specified. In the forecast consumption rule type A example of below, customer order demands consume forecasts defined anywhere from the date of the customer order to the start of the previous forecast period. The number of periods entered is 1 meaning forecasts are consumed by demands occurring 1 additional period beyond the customer order period.
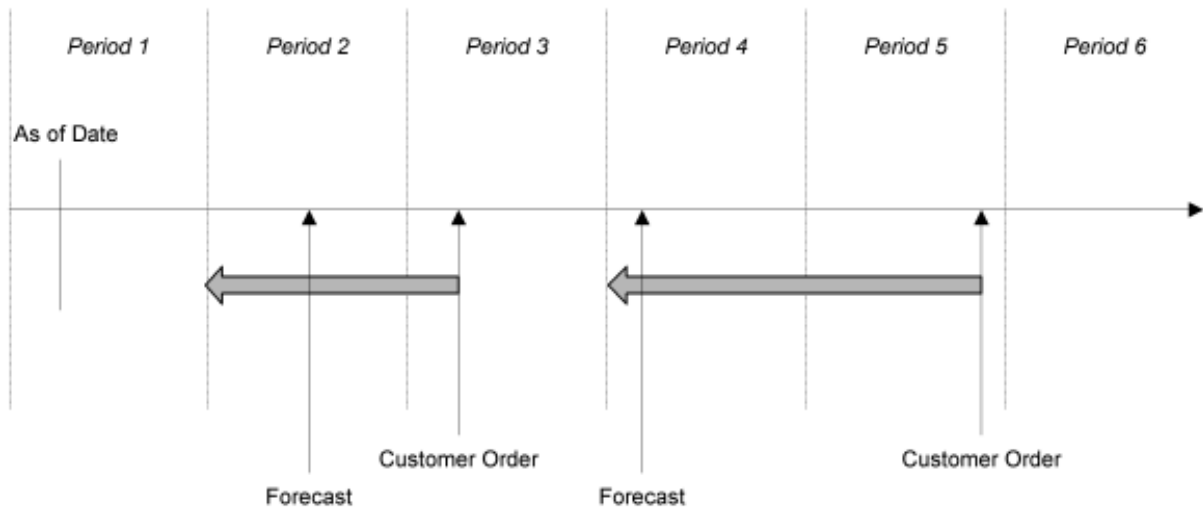
Figure 8 Forecast consumption rule A

Forecast consumption rule B consumes forecast demand from the end of the period of the customer order schedule date, backward for the number of periods specified. In the forecast consumption rule B example below, customer order demands consume forecasts defined anywhere from the end of the forecast consumption period to the start of the previous forecast period. The number of periods entered is one, meaning forecasts are consumed by demands occurring one additional period beyond the customer order period for a total of two periods.
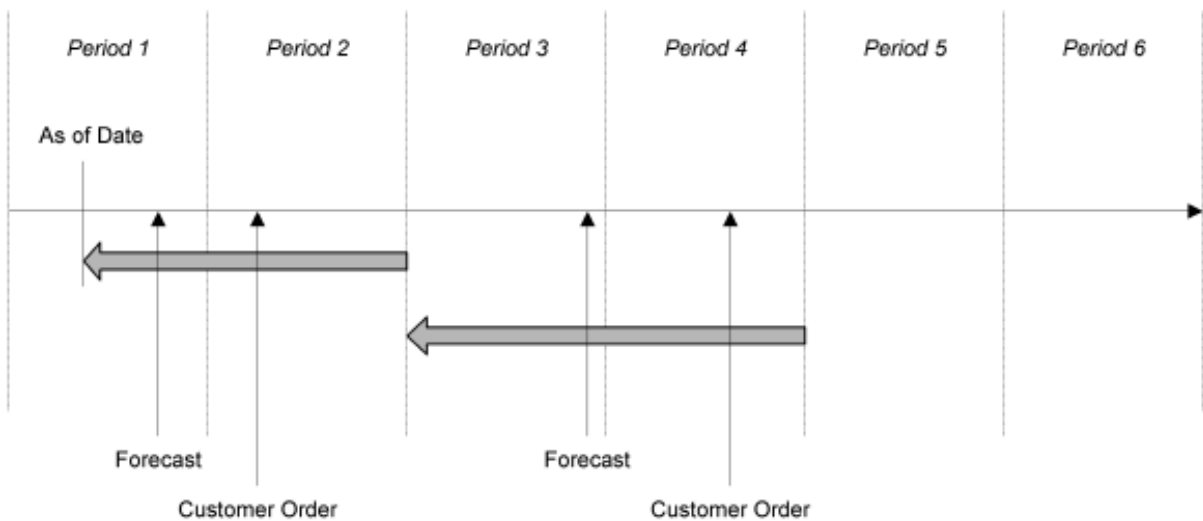
Figure 9 Forecast consumption rule B

Forecast consumption rule C consumes forecast demand from the beginning of the period of the customer order schedule date forward for the number of periods specified. In the forecast consumption rule C example below, customer order demands consume forecasts defined anywhere from the start of the forecast consumption period to the end of two additional forecast periods. The number of periods entered is two, meaning forecasts are consumed by demands occurring two additional periods beyond the customer order period for a total of three periods.
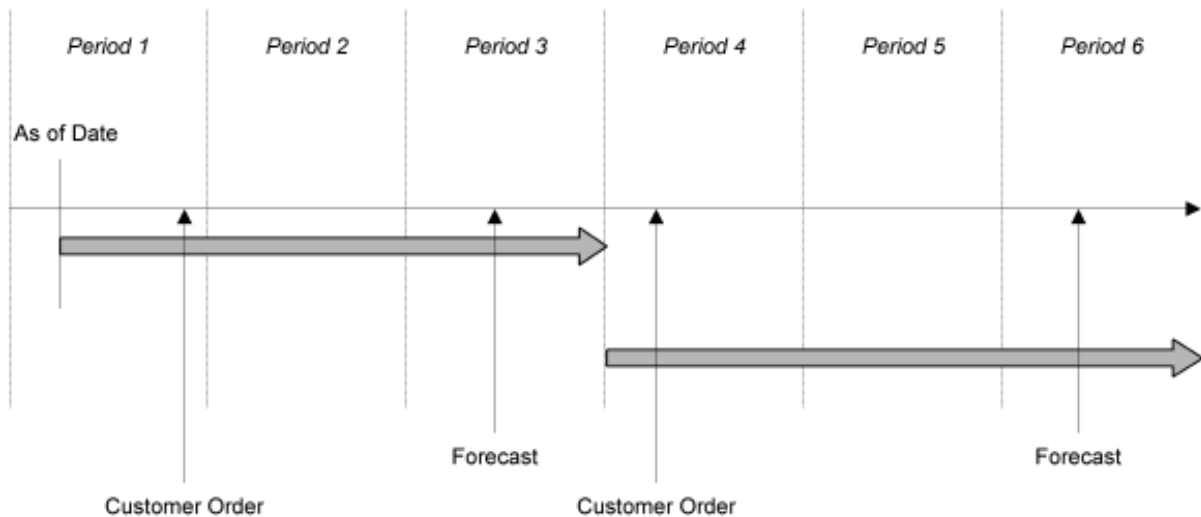
Figure 10 Forecast consumption rule C

Forecast consumption rule D consumes forecast demand from the customer order schedule date forward for the number of periods specified. In the example below customer order demands consume forecasts defined anywhere from the customer order date to the end of the next forecast period. The number of periods entered is one, meaning forecasts are consumed by demands occurring one additional period beyond the customer order period for a total of two periods.
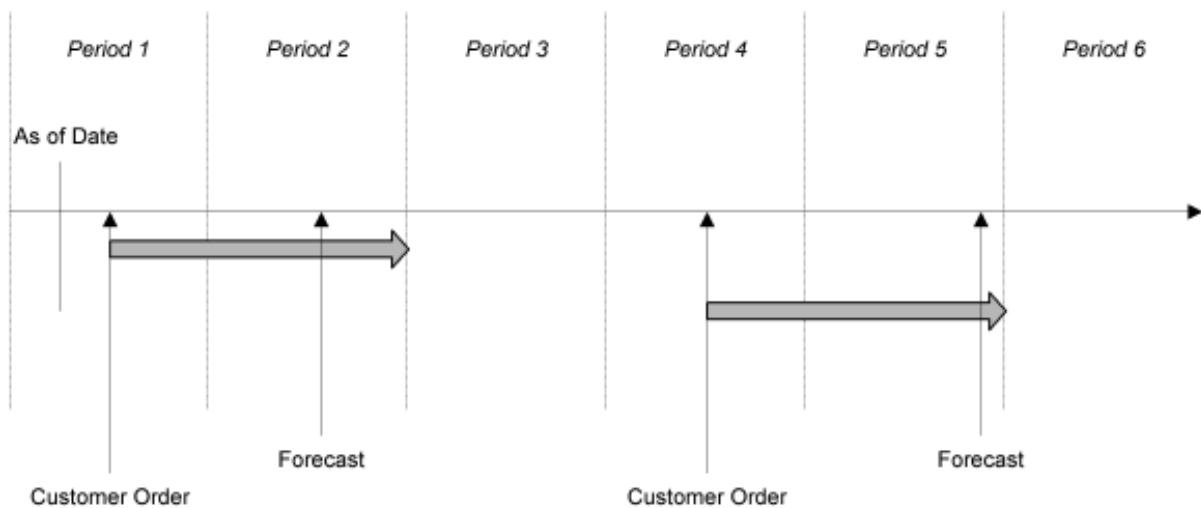
Figure 11 Forecast consumption rule D

In the past, different rules were used, which sometimes resulted in over or under estimating demand. Because of this, HTM-Aerotec is still not sure which consumption rule suits their needs best given the current company and system characteristics. The challenge lies in synchronizing the sales order due dates and the forecast due dates to ensure correct forecast consumption, taking into account the timing of sales order entry and forecast updates. As the forecasts are updated every two weeks while sales orders are continuously added, discrepancies can occur. It is crucial to replace the forecasted demand removed from the start of the forecast period with actual demand (sales orders) before uploading the next forecast to the system.

After the forecast consumption has been applied and the PLANNING UPDATE function has been executed, the ERP system will Generated CPO's using the ordering policy parameters set for each product individually. This information is essential for the material requirements planner to be able to obtain the raw materials delivered on time. Each CPO specifies the product number, quantity and due date.

2.3.3 CONCLUSION

To conclude, using forecasted demand in the ERP system requires a complex interplay between periodically updating the forecast data, entering the sales orders and applying the forecast consumption rule. Especially the timing of these business processes and modification of due dates play a crucial role in ensuring proper functioning of the system. An overview of the main forecast related business processes are summarized using a flowchart shown in Figure 12.
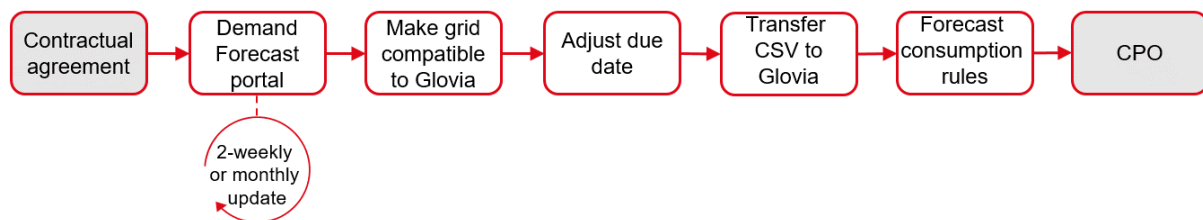
Figure 12 Business processes related to Forecasted demand

2.4. PRODUCTION ENGINEERING

For every new order, the production engineering department of HTM-Aerotec has to obtain the routing of the part, the production files and FAI certification. The production engineering phase starts with engineering the routing of a part (Section 2.4.1). Subsequently the CAD/CAM department will create the production files which will be elaborated on in Section 2.4.2.

2.4.1. MANUFACTURING ENGINEERING

Manufacturing Engineering is a field of engineering that focuses on the design, development, and implementation of processes and systems used in the manufacturing of products. This field combines principles of engineering, materials science, and management to create efficient, cost-effective, and high-quality manufacturing processes. Manufacturing engineering encompasses a broad range of industries, including aerospace, automotive, consumer goods, and electronics. The goal of manufacturing engineering is to optimize the production process, from the design and development of products to the delivery of finished goods, while minimizing waste and maximizing efficiency. This requires expertise in areas such as manufacturing processes, automation, quality control, and supply chain management. As manufacturing continues to evolve, the role of manufacturing engineers is becoming increasingly critical in ensuring the success and competitiveness of modern manufacturing companies (Groover, Fundamentals of modern manufacturing: Materials, processes, and systems (5th ed.), 2016).

Whitin HTM-Aerotec the main task of the manufacturing engineers is to determine an efficient and robust routing, considering cost and quality. Because every part has different characteristics and requirements set by the client, which induces that the routing of almost every part is unique. Combined with the fact that HTM-Aerotec has several dozen machines (See, Appendix A) that can be used multiple times in one single part routing results in countless variations of part routing. An example of the routing of a part can be seen in Figure 13. The numbers between brackets e.g. (582) correspond to the machine/function numbers as shown in Appendix A. In case of the example the production process starts with cutting the raw material roughly to size. Then, the parts are marked using labels to be able to easily identify the parts in proceeding production steps and by the client during assembly. After marking has finished, the parts are machined by a five-axis automated milling machine and inspected during production. In case the parts are approved, they are transported to a outsource partner which will apply a surface

treatment to the parts and transports them back to HTM-Aerotec. Followed by a final visual inspection and lastly prepared for dispatch to the client.
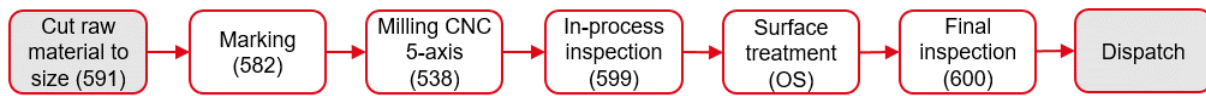
Figure 13 Example of item routing

In case of a new order, the manufacturing engineer determines the routing based on the shape, requirements, and order quantity of the part. The main driver for the development of the part routing is the experience of the production engineer. The process therefore relies mostly upon the empirical ability of the production engineer. There is no clear systematic approach used here due to the high variability in part characteristics.

In case of a recurring order the production engineer has to check if the previously used routing is still feasible and optimal. He asks him/herself questions like: Are the previously used machines still present? Or can the routing be improved using a different production approach/(new) machine? Altering the routing or production approach requires close contact and co-operation with the quality manager due to FAI certification restrictions. More on FAI in Section 2.5.1.

In case of forecasted orders, the manufacturing engineers can decide to alter the routing for quality related optimization and/or lead time reduction purposes. However, this optimisation opportunity is often not used due to FAI restrictions or limited time.

2.4.2. CAD/CAM

Computer Aided Design (CAD) and Computer Aided Machining (CAM) are two indispensable technologies that have revolutionized the way products are designed and manufactured in modern times. CAD involves the use of computer software to create 2D or 3D digital models of products or components. These models can be manipulated, analysed, and modified easily and quickly, saving time and reducing errors in the design process. CAM, on the other hand, involves the use of computer software to control and automate manufacturing processes such as cutting, drilling, and milling. This technology allows for precise and efficient manufacturing, resulting in higher quality products and reduced costs. Together, CAD and CAM have transformed the manufacturing industry, enabling businesses to produce complex products at a faster rate and with greater precision than ever before (Smith, 2021).
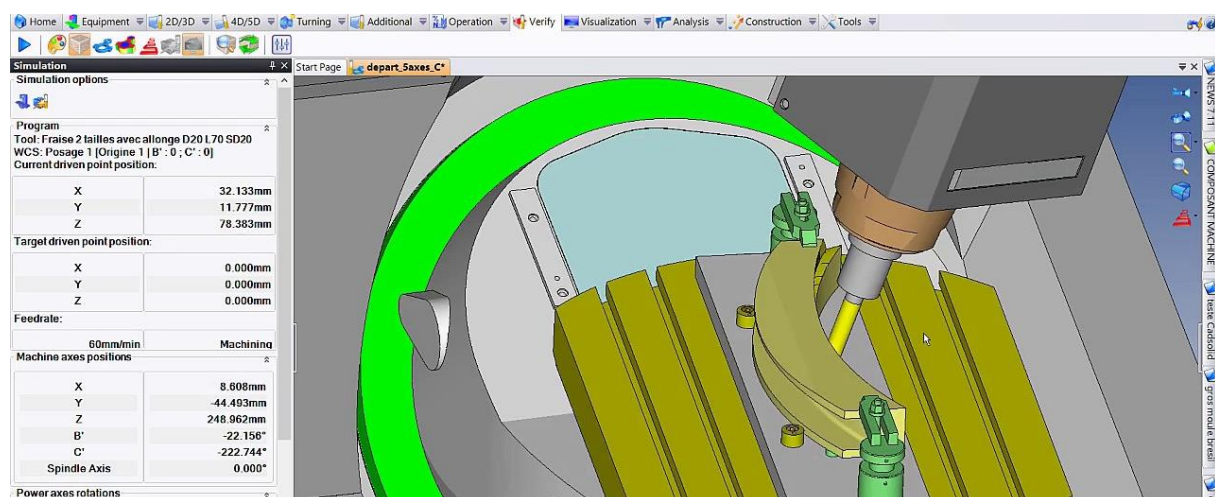
Figure 14 TopSolid example of interface

Whitin HTM-Aerotec the main task of the CAD/CAM department is creating the CAM files often referred to as CNC (Computer Numerical Control) program which are vital to produce the parts by the machines at HTM-Aerotec. The CNC file contains information for the machine how to remove material form the raw material in

order to end up at the desired result, such as the tools selection, cooling jets, feed rate, and rpm's required for the material removal. Material removal production processes by means of a cutter are often referred to as machining. The CNC files are created based on the CAD (Most often provided by the client in STEP file format), often referred to as the 3D model. The CAD file and corresponding technical drawing will be provided by the client.

In addition of creating CAM files for the actual customer parts, the CAD/CAM department can decide to design clamping jig(s) in which multiple parts can be clamped simultaneously in order to reduced setup time and make as efficiently as possible use of the autonomous milling machines at night-time.

Besides creating CAM files, the CAD/CAM department has to create documentation (FAD files) for the production department. This FAD, which is an Dutch abbreviation of: "Fabriek Aansturend Document" contains information and detailed instructions for the production employees on how to position the raw material into the machine and which CNC program to use. As well as information for the tooling department such as which clamp(s), jigs and milling cutters are required for production.

2.5.   QUALITY

All business processes of HTM-Aerotec must adhere to the AS9100 certification. Therefore, all quality-related tasks within HTM-Aerotec are organised according to the requirements described in this document. Part of the AS9100 certification is the FAI (First Article Inspection) which is mandatory in the Aerospace industry, more on FAI in Section 2.5.1. The quality department within HTM-Aerotec can be divided into two sub sections; the quality manager (Section 2.5.2) and the metrology room (Section 2.5.3) which is currently operated by two quality engineers.

2.5.1. FAI

First Article Inspection (FAI) is a critical process in the aerospace industry that aims to ensure that the first manufactured part or assembly meets all the required design specifications and regulatory requirements. The aerospace industry is highly regulated, and safety is a top priority. The FAI process is essential in ensuring that the first manufactured item or assemblies comply with all the necessary standards before proceeding with production of the remaining items. It involves a comprehensive and documented inspection process that includes verifying the design and specifications, measuring and testing of the parts or assemblies, and confirming that all the regulatory requirements have been met. The FAI process is critical in the aerospace industry as it helps to prevent quality issues, reduce production costs, and ensure compliance with industry regulations (Davies, 2017).

In order to manufacture parts in accordance with the SAE AS9102D requirement set by SAE International (2019), HTM-Aerotec has incorporated internal processes such as the First Article Inspection (FAI). This AS9102 Standard is a document created by SAE that establishes the baseline requirements for conducting and documenting a First Article Inspection for the aerospace industry. There are two types of FAI, Standard FAI and Delta FAI. HTM-Aerotec has added an extra type for internal use only called PreFAI.

In case of a new part which must comply with the AS9102 standard, there is required a standard FAI, often referred to as a Full FAI. A FAI Report (FAIR) consist of three forms: Form 1, Form 2 and Form 3. Form one contains general information about the definition and function of the part, partly provided by the client. Form two contains information about used materials and manufacturing processes. If applicable, outsourcing such as surface treatment and functional (pressure) tests are also described here. Form three is used to summarize actual specific design characteristics such as dimension, tolerances, drawing notes and the measurement results of the first article inspection. These three forms, which is often referred to the First Article Inspection Report (FAIR) is the documentation that will be provided to the client as evidence of the FAI. By means of this report, it is contractually concluded that the batch meets the requirements set by the customer. The report serves as proof and guarantee to the client.

A Delta FAI/Partial FAI is required in case there is a change in the manufacturing process such as a mutation in design, manufacturing routing, machine location, tooling, material, inspection method or CNC program. The Delta FAI is a simplified version of the standard FAI certification process. As mentioned before a FAI certification is

valid for two years after the production of the part. In the event that a recurring order has been produced more than two years ago, a Delta FAI is sufficient to be granted with a certification again.

The PreFAI is introduced by HTM-Aerotec due to complete batches that were rejected because the required tolerances were not met. This problem occurred because the FAI was performed retrospectively. By introducing the PreFAI, unexpected flaws in the production process will be noticed earlier. By doing so, rejections based on quality are minimized. In addition, it facilitates the FAI certification procedure. The PreFAI summarises al requirements related to the design characteristics and materials used. The format is similar to that of a checklist. The quality manager is responsible for creating this PreFAI document that will be uploaded to a dedicated database called Teamcenter. If a FAI is required, the first routing step will be the PreFAI referred to as "Documentation".
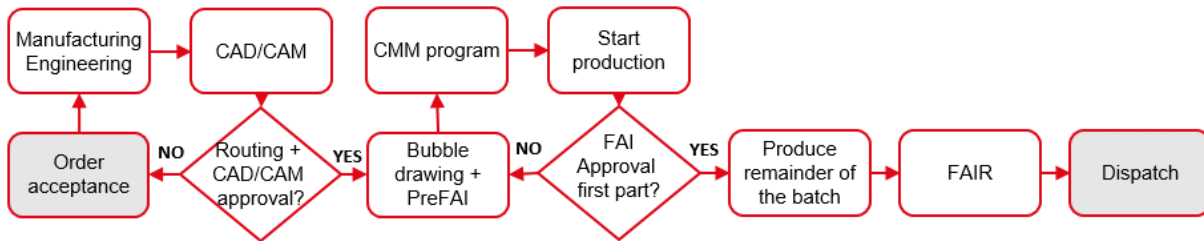
Figure 15 FAI certification process

After order acceptance the manufacturing engineer and CAD/CAM engineer ask for approval on their chosen manufacturing process by the quality manager (see Figure 15). In addition, the quality manager will convert the technical drawing provided by the client to a bubble technical drawing which will be used in the metrology room by the quality engineers later on. In case the technical drawing is not provided, the quality manager will create one based on the CAD model. This bubble technical drawing and PreFAI information is used by the quality engineer to create a program for the CMM parallel to the production of the first part. After machining the first part is finished, the quality engineer will verify if the part meets the crucial requirements specified in the balloon drawing and fills out the results in Form 3. If the part is approved by the quality engineer, the remainder of the batch parts can be machined as well and the quality manager finalises the FAIR. If the first part is rejected, based on the identified defects, a multidisciplinary consultation takes place by relevant employees and managers on how to tackle the flaws.

In case of a recurring order of which the previously granted FAI is still valid (last production took place less than two years ago and the part is produced exactly the same), only Form 3 needs to be filled out by the quality engineer. This is therefore a significantly simpler process and requires much less time and effort. However, a few checks of the existing FAI documents must be carried out to ensure that the FAI certificate is again valid.

2.5.2. QUALITY MANAGEMENT

Quality management is a critical aspect of manufacturing operations that ensures customer satisfaction, reduces costs, and enhances competitiveness. In the manufacturing environment, quality management involves the systematic control of various elements, including design, production, and delivery, to ensure that the final product meets the required quality standards. Manufacturing companies that excel in quality management can achieve significant benefits, including improved product quality, increased customer satisfaction, reduced costs, and increased operational efficiency (Defeo & Juran, 2016).

Whitin HTM-Aerotec the main task of the quality manager is to monitor and guarantee quality of the produced parts. In addition, the quality manager is responsible for creating the PreFAI before production starts, FAI documentation and the FAIR for the client. In addition, the quality manager plays a key role in solving quality issues. The quality manager is therefore the first point of contact in case quality related issues occur.

In case of new orders, the quality manager must convert the technical drawing provided by the client to a balloon drawing. The balloon drawing can be used by the quality engineers to create a coordinate measuring program for the CMM. Based on the tolerances and shape requirements defined in the balloon drawing the quality engineers

are able to verify if the parts meet the requirements set by the client using the CMM. Before production of a new part can start, the quality manager needs to create and fill out the PreFAI document.

In case a quality related issue occurs during production, the quality manager arranges a multidisciplinary consultation with the aim to identify the root cause of the quality issue. Based on the outcome of the consultation the production approach will be adjusted such that the issue will no longer occur. Or at least is significantly less likely to occur.

2.5.3. METROLOGY ROOM

A metrology room, also known as a measurement laboratory or inspection room, is a specialized facility within a manufacturing environment that is dedicated to measuring, testing, and verifying the accuracy of manufactured components and finished products. The metrology room contains sophisticated measurement tools and equipment that are used to assess the quality and performance of products to ensure that they meet the required standards and specifications. The metrology room plays a critical role in the quality control process, as it helps businesses detect and correct any defects or issues before the products are shipped to customers (Klaassen & Van der Veen, 2017).

Whitin HTM-Aerotec the main task of the quality engineers operating within the metrology room is to perform FAI inspections, in-process inspections, and visual inspection. In case of a FAI inspection and in-process inspection of a new part, the quality engineers need to create a measuring program for the CMM of their choice to be able to perform the inspection. Comparing the required tolerances specified by the balloon drawing and the results of the CMM, the quality engineers are able to determine if a part is approved or rejected.

A FAI inspection is performed after the first part has finished production or first machining step; the first article is checked whether it is in accordance with customer requirements before the production of the remainder of the batch can proceed. If required by the client or desired by HTM-Aerotec due to previous quality issues, in-process inspection will be added to the routing of the part. This can be in between clamping fixtures of one machine or in between different production steps/machines. In case of visual inspection, all pats are checked for scratches, damage and sharp edges. When all parts look neat and meet the requirements set by the client, the quality engineer gives approval for the next production step or dispatch to the client.

Currently the metrology room uses a FIFO order handling strategy but deviate from this strategy by manual assigning priorities to certain orders. The priorities are assigned by the production planner in favour of a constant production flow or with the aim to force on time delivery.

2.6. PURCHASING

A Purchaser, or MRP Planner, is a professional who specializes in the implementation and management of Material Requirements Planning (MRP) systems in a manufacturing environment. An Purchaser is responsible for ensuring that the right materials are available at the right time to support the production of goods. They work closely with various stakeholders within the organization, such as planners and (production) managers, to determine production schedules, and monitor inventory levels. Purchasers use ERP software systems to analyse data and generate reports that help businesses optimize their production processes, reduce costs, and increase efficiency (Karmarkar & Thomas, 2017) and (Vollmann T. , Berry, Whybark, & Jacobs, 2017).

Whitin HTM-Aerotec the material requirements planner is responsible for the availability of the required materials. The goal is to ensure that the materials are available on time before production starts, but not too early to avoid high inventory costs. The decision when to order is a personal, experience-driven decision backed by empirical information about lead times. This information about expected lead time and the variance of the lead time may be important information for this decision. Therefore, the material requirements planner must remain in close contact with all material suppliers.

HTM-Aerotec strives for Just-In-Time delivery of their raw materials. Nevertheless, are they using a safety margin of one week, the goal is therefore to ensure that the material is available one week before production starts. The material requirements planner is also responsible for purchasing tooling and workshop supplies as well as

outsourcing such as surface treatment or heat treatment. Especially in case of outsourcing, timing is very important. Seamlessly fitting the outsourcing into the intended production routing is vital for both a smooth production flow as well as on-time delivery.

The material requirements planner sends out purchase orders (PO) to suppliers based on accepted sales orders (SO) and forecasts provided by their clients. As soon as a SO is converted into a CPO in the ERP system, the required materials appear on the purchase list of the material requirements planner. This list is based on customer requirements and routing. In addition, occasionally clients obligate HTM-Aerotec to purchase the materials from one specific supplier due to mutual agreements or FAI-related requirements. In some cases, the clients purchase and ship the raw materials themselves to HTM-Aerotec.

The parts produced by HTM-Aerotec vary greatly on size, shape, and function. Which leads to high variation in raw materials as well. Numerous specific aluminium, stainless steel, titanium, and steel alloys are used. This characteristic of high variability, combined with the highly competitive nature of the aerospace industry, it can be difficult to obtain certain rare types of materials. This is exacerbated by the fact that there are only a few suppliers for some rare materials and outsourcing processes, let alone close to HTM-Aerotec.

As far as material requirements planning is concerned there is no difference for new, recurring or forecasted orders. In all cases the material could be unavailable or delayed. However, there is usually more time is available for obtaining materials for forecasted orders. Moreover, in case of forecasted orders potentially more favourable agreements with suppliers can be made by bundling multiple purchase orders.

In addition, external factors such as a change in economic and political landscape are also causes of delay, unavailability, and price increases of materials, as for instance closed borders, import duties, covid and war.

2.7. PRODUCTION

Manufacturing processes are the methods and procedures used to create goods in a manufacturing environment. These processes can range from simple manual operations to highly automated and computer-controlled systems, depending on the type of product being manufactured and the scale of production. The goal of manufacturing production processes is to efficiently and effectively transform raw materials into finished products that meet the desired specifications, while minimizing waste and maximizing productivity. Production processes are evolving rapidly, making it essential for businesses to continually adapt and optimize their operations to remain competitive (Groover, Fundamentals of modern manufacturing: Materials, processes, and systems (5th ed.)., 2016).

The manufacturing processes at HTM-Aerotec are characterized by high variability and so are the machines available. HTM-Aerotec has a total of 25 production machines to produce the requested parts by their clients. In addition, they have easy access to even more machines at other subsidiaries of the HTM group or the PM group. Based on the HMLV and the MTO & ETO environment, HTM-Aerotec has organised the production department by process (Job shop facility layout) as can be seen in Appendix A. The groups are Milling 3-axis, Milling 4-axis, Milling 5-axis, Conventional milling & honing, Manual Deburring and finishing, Lathes, Metrology, Assembly, and Part marking. The metrology room is situated in the centre of the facility.

The machines available to HTM-Aerotec are very capital-intensive machines. HTM-Aerotec therefore is aiming to use the machines as effectively and efficiently as possible. The goal is to maintain an optimal production schedule considering on time delivery, machine utilization, and WIP. To give an idea of internal part routing, an example is described in the following paragraph.

After arrival of the raw material and release of the WO, the material is cut roughly to size unless this has already been done by the supplier. In that case it is sufficient to compile the materials from the warehouse. Subsequently the parts are moved to the first machining step. After machining of the first part has finished, it will be measured in the metrology room to verify the part fulfils all critical dimension and shape requirements set by the client. If satisfactory then the remainder of the batch will be machined and if required, the last and/or intermediate parts will be checked by the quality engineers as well. After all material removal processes have been completed, the parts are prepared for dispatch to an outsource partner for surface treatment. Once the surface finish has been

applied to the parts and are transported back to HTM-Aerotec, the parts are marked for identification using stickers, labels or stamps. At last, the quality engineers will perform a final inspection before the parts are prepared for dispatch to the client. See Figure 16 for a summary flow chart corresponding to this part routing example. The numbers between brackets e.g. (517) correspond to the machine/function numbers as shown in Appendix A.
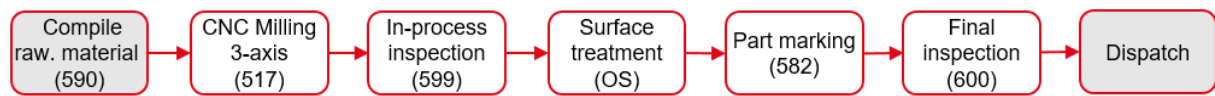
Figure 16 Example of part routing

In some cases, the routing is more extensive and requires multiple fixture positions per machine or even multiple milling and/or lathes in order to manufacture the part. In general, this results in additional in-process measurements being required. In addition, numerous routing variations are possible because different types and/or additional production steps are required for the production of the products.

At the time the WO is released there is sequentially a physical work order folder created. Which contains all relevant information to produce the parts, including information about required raw materials, routing, FAD documents, FAI and tooling. This work order folder is created by the production planner and is handed over to the tooling department unless the raw materials are not roughly cut to size by the supplier. In that case the folder is first handed over to the expedition department employees which also have the task of cutting the raw materials to rough size. Subsequently, the folder is handed over to the tooling department. Here the tooling and raw materials are collected in preparation of production. As soon as a production step is completed, this is recorded in the work order folder by ticking corresponding boxes and stamping relevant documents. Subsequently, the work order folder is again handed over to the tooling department in preparation of the next production step in case tooling is required for the subsequent step. In between production steps the parts are stored in a dedicated semi-finished storage location.

In addition to the information recorded in the work order folder, each production employee records the production time used for a production step using a start and stop button available in the ERP production department interface. This information is filled out using computers which are situated almost next to the machines. The total production time must be divided manually into Machine Setup, Labour Setup, Machine Run and Labour Run by the production employee. This allows the production planner to precisely monitor every order in production and to anticipate if necessary.

The workforce schedule for the production department is created by the production manager and not the production planner. The skill matrix is a limiting factor here as most production processes require specific knowledge. Therefore, in most cases production employees are assigned to one specific machine/task. As a result, most employees are specialized in one specific machine/task, inducing the risk of reduced scheduling flexibility and robustness.

2.8. HUMAN RESOURCE AND FINANCE

Human resource and finance are two critical functions within any organization, as they are responsible for managing the workforce and financial resources of the business. The human resource department is responsible for recruiting, training, and managing employees, ensuring that they have the skills and support they need to perform their jobs effectively. The finance department, on the other hand, is responsible for managing the financial resources of the organization, including budgeting, forecasting, and financial analysis. The success of any business depends on the effective management of these two functions, as they impact every aspect of the organization's operations (Dessler, 2021).

Within HTM-Aerotec the HR employees are responsible for several supporting business processes such as recruiting new employees, payroll administration, maintaining employee records, and enforcing disciplinary agreements. But also facilitating educational and personal development of employees. Nevertheless, these supporting tasks are essential for keeping the core business processes up and running. Since the human resource

related tasks are not directly part of the order handling process, they are not included in swimlane diagram (Figure 17).

The finance manager maintains close contact with the HR employees and the managing directors of the corresponding HTM-Technologies facilities. The range of duties consists of monitoring and controlling the financial flow and preparing annual statements. In addition, the finance employees will create several financial reports for performance evaluation purposes. Not all finance tasks can be related to the order handling processes of HTM-Aerotec, therefore they are not included in the summary swimlane diagram, in contrast to billing which is included as shown in Figure 17.

2.9. CONCLUSION

This chapter provides insight in the current configuration of the business processes at HTM-Aerotec and answers sub research question six: *"What is the current configuration of the business processes at HTM-Aerotec?"*. It elaborates on the main tasks and responsibilities of each of the departments independently, including the corresponding approach used. As discussed in chapter two, HTM-Aerotec distinguishes between new, recurring, and forecasted order handling. Which is indicated in the swimlane diagram by colour coding. In case of a new order, additional process steps are required, resulting to a larger workload and longer lead time. In case of forecasted and recurring orders the total sequence of business processes is shorter and more compact because the FAI certification, optional clamping jig(s) and production files are already available. In addition, historical data such as lead time and costs data are already known. The most prominent business processes described in Chapter 2 are summarised using a swimlane diagram (Figure 17), in which the business processes are grouped by department. The diagram summarizes all business processes from order request up to billing. The interconnected characteristics of the departments can be clearly identified using this swimlane diagram. Obtaining this thorough context overview is immensely valuable to the further course of the research. By revealing crucial interdepartmental connections and relationships, it will enable us to gain a more nuanced understanding of our research topic and guide us in conducting further research on potential solutions.

Section 2.3 in particular provides an answer to sub research question one: *"How are the customer forecasts currently transformed and transferred to Glovia?"* based on the new findings obtained by this context analysis we can conclude that in order to make use of the forecast data provided by the customers, it is essential to transfer the data to the ERP system (Glovia) in a correct and fool proof manner. Furthermore, before the data can be uploaded, it must be transformed to be compatible with the Glovia database layout. Currently, this requires multiple manual sequential transformations, which is time-consuming and prone to human errors. As a result, incorrect information may be uploaded to the ERP system, which may lead to errors in the production planning or materials requirement planning. In addition, it increases the risk of the malfunctioning of the forecast consumption.

Lastly we gained knowledge required to answer sub research question 7: *"What causes Glovia to partly omit forecast data?"*. After testing and consultation with Glovia helpdesk personnel, it turns out that when uploading the CSV file to Glovia, it only considers the first 50 columns, causing the neglect of the remaining columns. This leads to a loss of up to 75% of forecast data, resulting in limitations for scheduling and lot-size optimisation. Therefore, it is imperative to address this issue and find a viable solution that enables the improved utilization of forecast data.
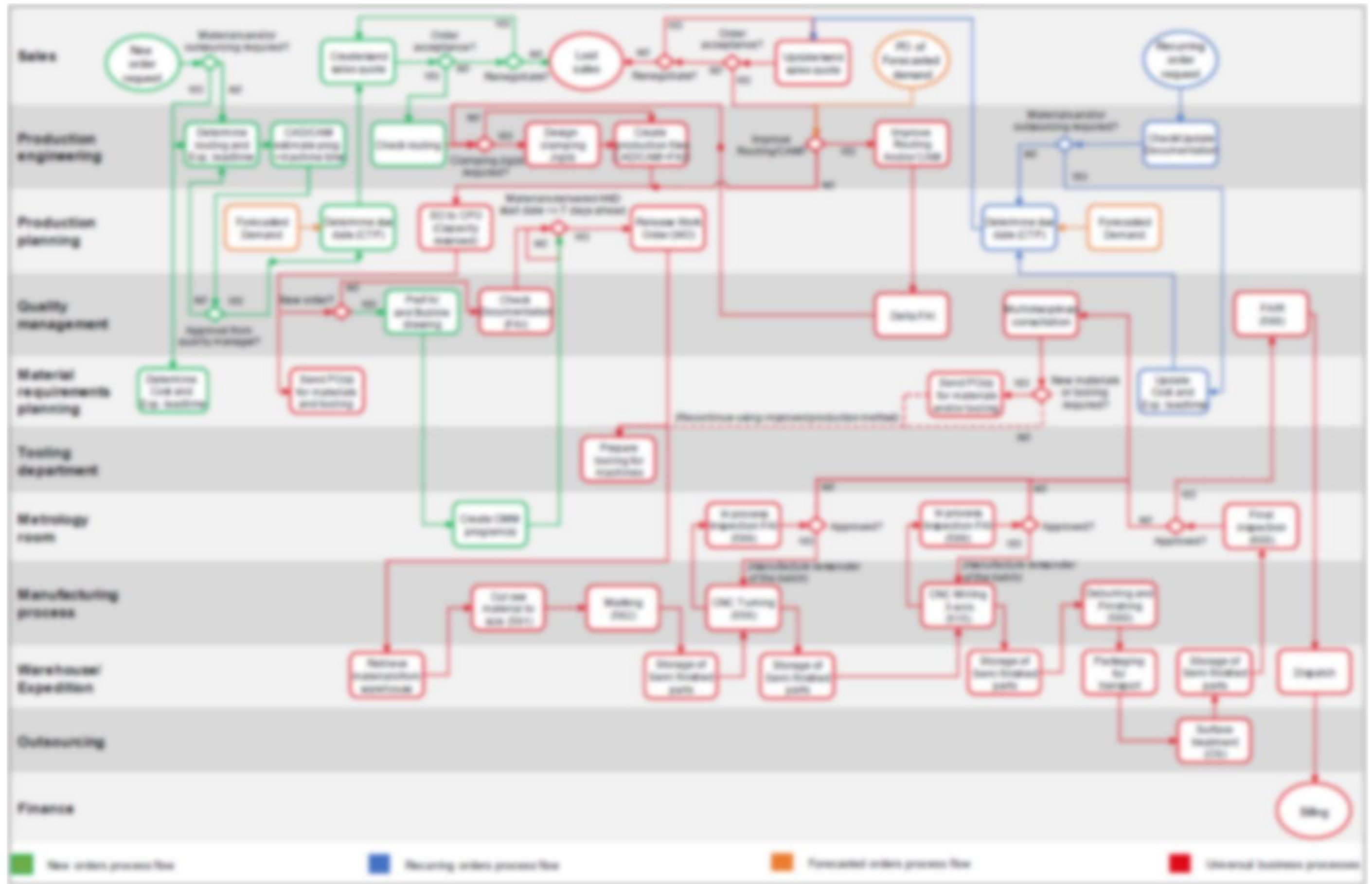
Figure 17 Swimlane diagram of business processes HTM-Aerotec including an example of part routing

3. LITERATURE REVIEW

*This chapter elaborates on the literature review that provides an answer to sub research question seven; **"What is presented in literature regarding the ordering policy problem at HTM-Aerotec?"**. First, Section 3.1 presents ordering policies using fixed lot sizing techniques. Followed by Section 3.2, where dynamic lot sizing techniques and its extensions are discussed. Lastly, Section 3.3 concludes this chapter.*

3.1.   FIXED LOT SIZING TECHNIQUES

In this first section on fixed lot sizing techniques we will elaborate on two important aspects of inventory management. Starting with the fixed order quantity inventory policy including safety stock calculations, followed by the second lot size optimisation technique, the economic order quantity (EOQ).

3.1.1. CONTINUOUS REVIEW, FIXED ORDER QUANTITY (S, Q)

The (s, Q) inventory management policy is a commonly used method for controlling inventory levels. The (s, Q) policy is designed to maintain a minimum level of inventory while minimizing holding and ordering costs. The reorder point ensures that inventory is ordered before it reaches a critical level, while the order quantity ensures that inventory is not ordered too frequently or in excessive amounts. It involves setting two parameters: the reorder point (s) and the order quantity (Q). The reorder point (s) represents the inventory level at which an order is placed. When the inventory level reaches the reorder point, a new order is placed for a quantity equal to the order quantity (Q). The order quantity (Q) represents the amount of inventory that is ordered when an order is placed. This quantity is typically chosen to balance the cost of ordering setup costs with the cost of holding inventory using the EOQ formula, see section 3.1.2 (Chopra & Meindl, 2016).
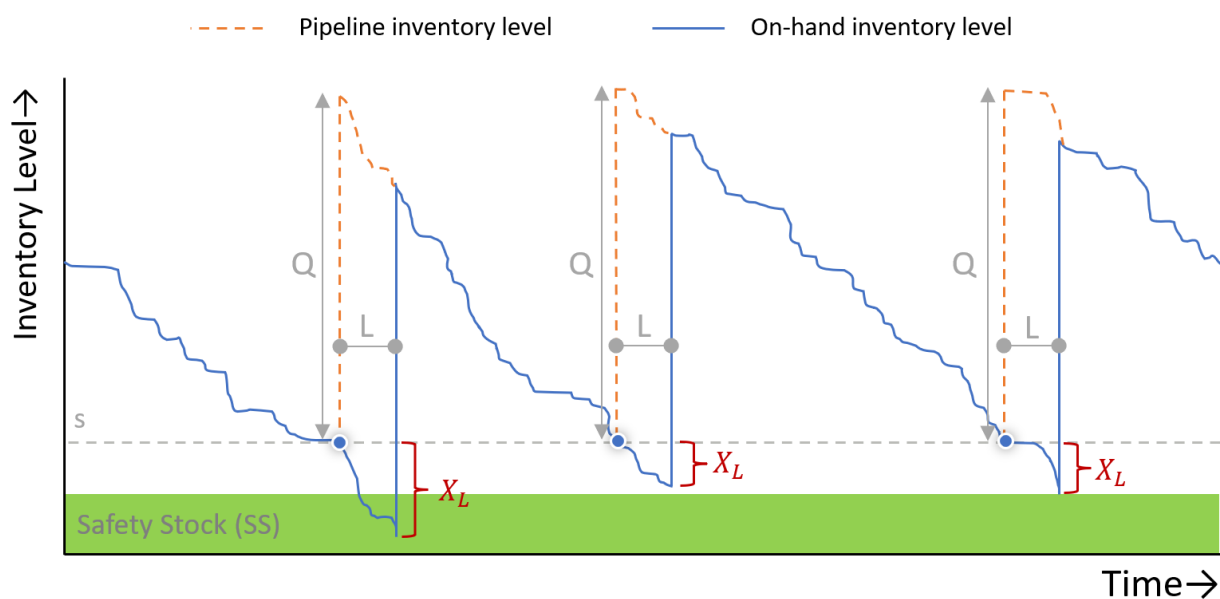
Figure 18 Continuous review Fixed order quantity (s, Q) with safety stock

In the case of fixed lot size methods such as Fixed Order Quantity, the supply planner needs to determine the timing of the order placement. To do so, the planner examines the projected available inventory and determines when it is expected to fall below the predefined safety stock level (SS). Based on the total lead time (L) for materials to arrive on time and prevent the risk of stock-out, the planner must then place the order a certain number of periods in advance. In larger companies this material requirements planning is facilitated by an ERP system.

The (s, Q) inventory model is formulated as follows:

$$Q = fixed\ order\ size\ [Units]$$

$$L = order\ lead\ time\ [Days, weeks, months \dots]$$

$$Safety\ stock\ (SS) = k * \sigma_L =$$
$$safety\ factor * standard\ deviation\ of\ lead\ time\ demand$$

$$Reorder\ point\ (s) = \hat{X}_L + k * \sigma_L =$$
$$Expected\ demand\ during\ lead\ time + Safety\ stock$$

The safety factor (k) used in the safety stock calculations is calculated using the normal loss function. For example a fill rate of 95% corresponds to a safety factor of 1,65. The safety stock should cover in demand uncertainty during lead time. But could also be useful in mitigating the risk of supply variation and/or preventing chaos and disruption of manufacturing processes.

In this model multiple assumptions are made (Silver, Pyke, & Peterson, Inventory management and production planning and scheduling, 1998):

- Lead time is assumed to be known and constant
- Demand during lead time is assumed to be normal distributed $\sim N(\hat{X}_L, \sigma_L)$
- The review period is equal to zero → Continuous review
- There are no quantity discounts
- The costs associated with shortages or backorders are not considered

It is essential to keep in mind that these assumptions are simplifications of the real world and may not hold in practice.

3.1.2. ECONOMIC ORDER QUANTITY (EOQ)

The Harris Wilson Model (1934), better known as the Economic Order Quantity (EOQ) is a formula used in inventory management to determine the optimal quantity of goods to minimize total relevant cost. The EOQ formula takes into account the costs associated with ordering and holding inventory, and seeks to find the most cost-effective balance between these two costs (Silver, Pyke, & Peterson, Inventory management and production planning and scheduling, 1998).

The formula for calculating EOQ is formulated as follows:

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

Where:

$$D = annual\ demand\ for\ the\ item\ [units\ per\ year]$$
$$A = setup\ or\ ordering\ cost\ [euro's\ per\ order]$$
$$v = value\ of\ item\ [euro's\ per\ item]$$
$$r = holding\ cost\ rate\ [percentage]$$
$$vr = annual\ holding\ or\ carrying\ cost\ [euro's\ per\ year]$$

The result of the formula gives the optimal order quantity that minimizes the total cost of inventory, taking into account both the costs of ordering and holding inventory. This helps businesses to optimize their inventory levels and reduce costs associated with excess inventory or stockouts.

The EOQ formula is a robust solution as it allows adjusting the lot size up or down without affecting the total cost all too much. A typical characteristic of the EOQ model is that increasing the lot size results in a slower rise in total cost compared to decreasing it. It is therefore obvious in the case of, for example, an order quantity multiple to round the lot size up to the nearest order quantity multiple as this will result in a lower total cost than rounding down. An illustrative example is shown in Figure 19.
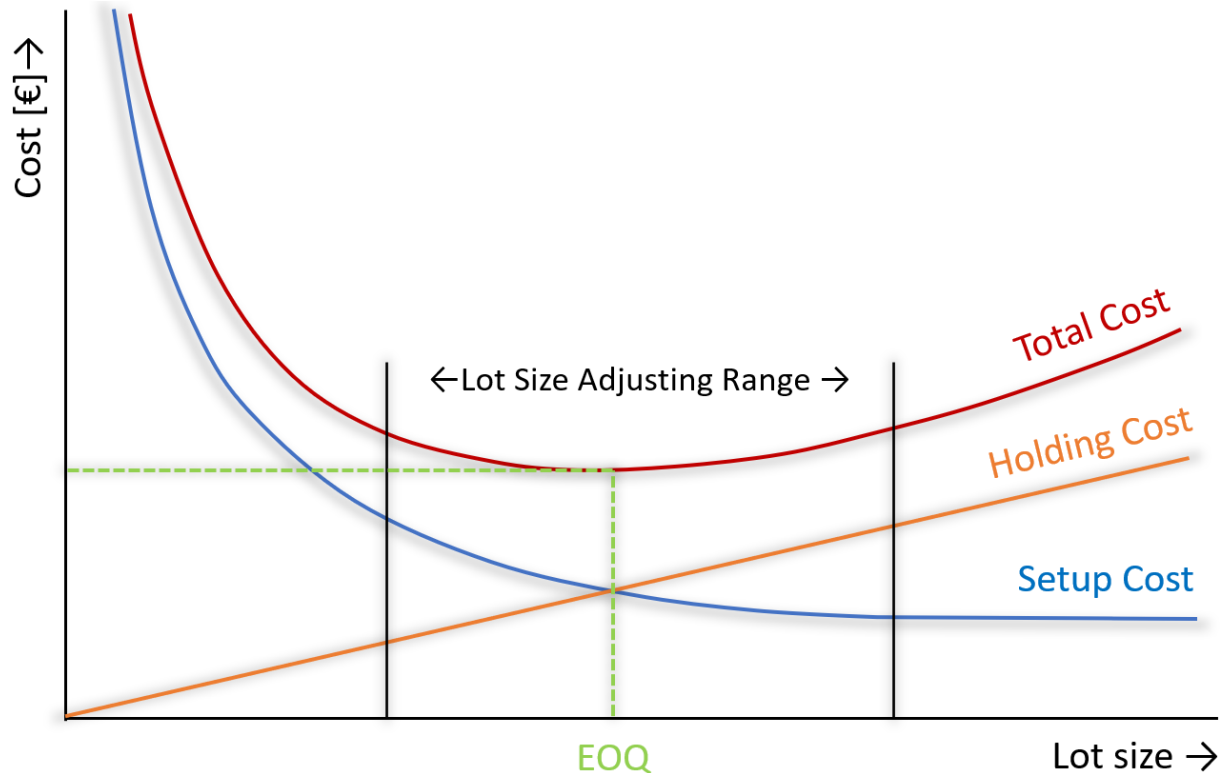
Figure 19 Illustrative graph of the Economic Order Quantity relations

The holding cost rate, usually between 15% to 30% of cost price annually (Chopra S. &., 2021), also known as carrying cost, refers to the expenses associated with storing and maintaining inventory or other assets over a certain period of time. These costs are typically incurred by businesses that need to keep a certain level of inventory or stock on hand to meet customer demand. Some examples of holding costs include, storage and handling, rent, utilities, insurance, taxes, depreciation, and the cost of capital tied up in the inventory (WACC). The total annual holding costs (given the lot-size Q) for an individual item can be calculated using the following formula:

$$Total\ annual\ holding\ cost = \frac{Q}{2} * vr$$

Setup cost on the other hand refers to the expenses incurred when preparing a production line or machine to manufacture a new product or switch to a different product. This cost includes the time and resources required to reconfigure the equipment, change the necessary tooling and preparing paper work. The total annual setup costs (given the Lot-size Q) for an individual item can be calculated using the following formula:

$$Total\ annual\ setup\ cost = \frac{D}{Q} * A$$

The Economic Order Quantity (EOQ) model is based on several assumptions, including:

- Constant demand: The EOQ model assumes that demand for the product is constant and known in advance. This means that the demand for the product does not vary over time and can be accurately predicted.

- Instantaneous delivery: The model assumes that the ordered items are delivered instantly, so there is no delay between ordering and receiving the goods.
- Fixed ordering costs: The model assumes that the ordering cost remains constant for each order placed, regardless of the order quantity.
- Fixed holding costs: The model assumes that the holding cost per unit remains constant and does not vary with the order quantity or the length of time the item is held in inventory.
- No quantity discounts: The EOQ model assumes that there are no quantity discounts available. This means that the unit cost of the product does not change based on the order quantity.
- Infinite planning horizon: The model assumes that there are no constraints on the length of the planning horizon. This means that the model assumes that the inventory system will continue indefinitely.

It is important to note that while these assumptions may not always hold true in real-world situations, the EOQ model remains a useful tool for managing inventory levels and optimizing inventory costs (Monks, 2005).

3.2. Dynamic Lot Sizing Techniques

In this section we elaborate on two well known dynamic lot-size optimisation techniques.

3.2.1. Silver Meal Heuristic

Determining the optimal lot-sizes for a set of items over a given planning horizon, while minimizing certain costs or objectives is often referred to as the Uncapacitated Lost-Sizing problem (UCLS) which is a is known to be NP-hard (computational complex). This means that there is no known polynomial-time algorithm that can solve the combinatorial optimization problem for all instances in a guaranteed manner. Due to the complexity of the problem, various heuristic and approximation algorithms have been developed to find reasonably good solutions within a reasonable amount of time. However, these algorithms do not guarantee optimality. One of them is the Silver-Meal Heuristic (SMH).

The Silver-Meal heuristic, developed by Edward A. Silver and H.C. Meal in 1973, is a production planning technique used in manufacturing to determine optimal lot-sizes at minimum cost to meet the requirement of operations at minimum total cost. The heuristic is a forward method that involves determining the average cost per period as a function of the number of periods the current order is to span. The heuristic is halted when this function first increases. It is an approximate heuristic for the dynamic lot-size model, which is often adjudged as computationally too complex (Silver & Meal, A heuristic for selecting the order quantity in a multi-item inventory system, 1968). The mathematical formulation of the Silver-Meal heuristic is shown below:

$K = setup\ costs$
$h = holding\ cost\ per\ unit\ per\ period$
$C(T) = the\ average\ cost\ per\ period\ if\ the\ current\ order\ size\ spans\ the\ next\ T\ periods$

$Where\ (d1, d2, d3, \ldots\ldots, dn)\ are\ the\ requirements\ over\ the\ n - period\ horizon.$

The heuristic starts by initialising, the initial cost value and production quantity is set by the total cost for satisfying demand for only period one. Which is equal to the setup costs for one production run.

$C(1) = K$

Subsequently, the average total setup and holding costs for producing for period one and two will be evaluated. The average total cost is equal to the setup cost plus the inventory holding cost of the lot required in period two divided by two periods to obtain the average.

$$C(2) = \frac{K + h * d_2}{2}$$

In case C(2) is smaller than or equal to C(1) it will continue calculating the C(T) value for C(3). Calculating the average total costs satisfying demand for period one, two and three. Bundling lot one, two and three in one setup give us an average cost of:

$$C(3) = \frac{K + h * d_2 + 2 * h * d_3}{3}$$

The average total cost is equal to the setup cost plus the inventory holding cost of the lot required in period two plus the inventory holding cost of the lot required in period three divided by three periods to obtain the average.

The general formulation is as follows:

$$C(j) = \frac{K + h * d_2 + 2 * h * d_3 + \cdots + (j - 1)h * d_j}{j} \qquad where\ j\ is\ the\ number\ of\ periods\ included$$

The heuristic stops evaluating when $C(T) > C(T - 1)$. It will than return the production quantity required to satisfy demand until period $C(T)$. And start the optimisation process again starting from period j. Until the end of the optimisation horizon.

An important characteristic of the Silver-Meal heuristic is that it performs poorly when demand is decreasing or when faced with frequent intervals of zero demand (Bookbinder & Tan, 1985). In case of intermittent demand and an infinite horizon. There are available other well known heuristics that are better capable of handling zero demands compared to the Silver-meal heuristic such as Least unit Cost.

3.2.2. LEAST UNIT COST

The objective of lot sizing is to balance the costs associated with holding inventory (holding costs) and the costs associated with ordering or producing (setup costs). The Least Unit Cost (LUC) lot sizing heuristic is a widely used method that aims to minimize the total costs by finding the lot size that results in the lowest average cost per unit (Baker, 2009). The mathematical formulation of the Least Unit Cost heuristic is similar to the Silver-Meal heuristic. It distinguishes itself by using a different denominator and stopping rule

$K = setup\ costs$
$h = holding\ cost\ per\ unit\ per\ period$
$D = total\ demand\ [Unit]\ if\ the\ current\ order\ size\ spans\ the\ next\ T\ periods$
$C(T) = the\ cost\ per\ unit\ if\ the\ current\ order\ size\ spans\ the\ next\ T\ periods$

$Where\ (d1, d2, d3, \ldots\ldots, dn)\ are\ the\ requirements\ over\ the\ n - period\ horizon.$

The heuristic starts by initialising, the initial cost value and production quantity is set by the total cost for satisfying demand for only period one. Which is equal to the setup costs for one production run.

$$C(1) = \frac{K}{D}$$

Subsequently, the average cost per unit for producing for period one and two will be evaluated. Periods with zero demand are neglected. The cost per unit is equal to the setup cost plus the inventory holding cost of the lot required in period two divided by the sum of demand for period one and two.

$$C(2) = \frac{K + h * d_2}{D}$$

In case there exits another demand requirements on the planning horizon it will continue calculating the C(T) value for C(3). Calculating the average unit costs satisfying demand for period one, two and three. Bundling lot one, two and three in one setup give us an average unit cost of:

$$C(3) = \frac{K + h * d_2 + 2 * h * d_3}{D}$$

The average unit cost is equal to the setup cost plus the inventory holding cost of the lot required in period two plus the inventory holding cost of the lot required in period three divided by the sum of demand for periods one, two and three.

The general formulation is as follows:

$$C(j) = \frac{K + h * d_2 + 2 * h * d_3 + \cdots + (j - 1)h * d_j}{D} \quad where\ j\ is\ the\ number\ of\ periods\ included$$

The heuristic stops evaluating until the end op the horizon. It will than return the production quantity required to satisfy demand until period $C(T)$ resulting in lowest average unit cost and start the optimisation process again starting from period j. Until the end of the optimisation horizon is reached. By doing so, the LUC heuristic provides a practical approach to making lot sizing decisions. An important property of the LUC heuristic is that it performs well in case of intermittent demand because it uses total demand in the denominator instead of the number of periods included which the Silver/Meal heuristic does.

3.3.   CONCLUSION

The lot-size optimisation problem at HTM-Aerotec, often referred to as the Uncapacitated Lost-Sizing problem (UCLS) is NP-hard, indicating that it is computationally challenging to solve optimally for all instances. When considering sub research question seven; **"What is presented in literature regarding the ordering policy problem at HTM-Aerotec?".** We can conclude that due to the complexity of the lot-size optimisation problem, various heuristics and approximation algorithms have been developed to find reasonably good solutions within a reasonable amount of time. However, in case of intermitted demand the options are limited, especially when taking in to account the ability to be seamlessly integrated into HTM-Aerotec's ERP system.

It is hard to say what the best lot-size optimisation approach is for HTM-Aerotec. We observe that an (s, Q) policy is a very common approach in literature for various lot-size optimisation problems, in particular when order size Q is determined using the EOQ formula. We expect that the EOQ functionality is capable of improving the lot-size at HTM-Aerotec. In addition to the EOQ functionality, we are interested in the Least Unit Cost heuristic since it is very well capable of handling the intermitted demand characteristics present at HTM-Aerotec. Although these heuristics probably do not meet the requirement that they should be able to be implemented in the ERP system, they can serve as valuable benchmarking tools for evaluating lot-size optimization policies which do have the ability to be seamlessly integrated into HTM-Aerotec's ERP system.

4. SOLUTION DESIGN

This chapter presents the solution design for the core problems at HTM-Aerotec which are developed using the findings from the context analysis and literature review. First, in Section 4.1 the conceptual model of the forecast data conversion tool will be explained. In addition, Section 4.2 4.2elaborates on the model requirements and model description of the forecast data conversion tool.

Subsequently, in Section 4.3 the conceptual model of the ordering policy optimisation tool will be presented, followed by the model requirements and model description in Section 4.4.

4.1. CONCEPTUAL MODEL OF THE FORECAST DATA CONVERSION TOOL

Section 4.1 and 4.2 present the conceptual model and design to solve the core problems related to main research question A: **"How can HTM-Aerotec reduce the time required for transforming and transferring forecast data to Glovia, while also mitigating the risk of human error during this process?"** including sub research question two: **"How can the time required for transforming and transferring the forecast data to Glovia be reduced"** and three: **"How can the risk of human error during transforming and transferring of the forecasts be reduced"**. In addition to main research question A will this Section present an answer and solution to main research question B: **"How can HTM-Aerotec minimise the quantity of forecast data that is omitted by Glovia"** including sub research question five: **"What measures can HTM-Aerotec adopt to enhance the quantity of accessible forecast data in Glovia?"**.

The conceptual model of the forecast data conversion tool includes three main modules: data input, a conversion model and the output to the ERP system (Glovia). The data input consist of two parts; the customer forecast file and the ERP data to facilitate the conversion. The forecast file is formatted as an Excel 2003 file format where each new line contains a new point forecast. The ERP (Item) data is required to link the customer item number to the internal item number. The attributes customer name, project name and default revision come in handy when filtering the data query. It also facilitates the ability to export a specific selection of items.
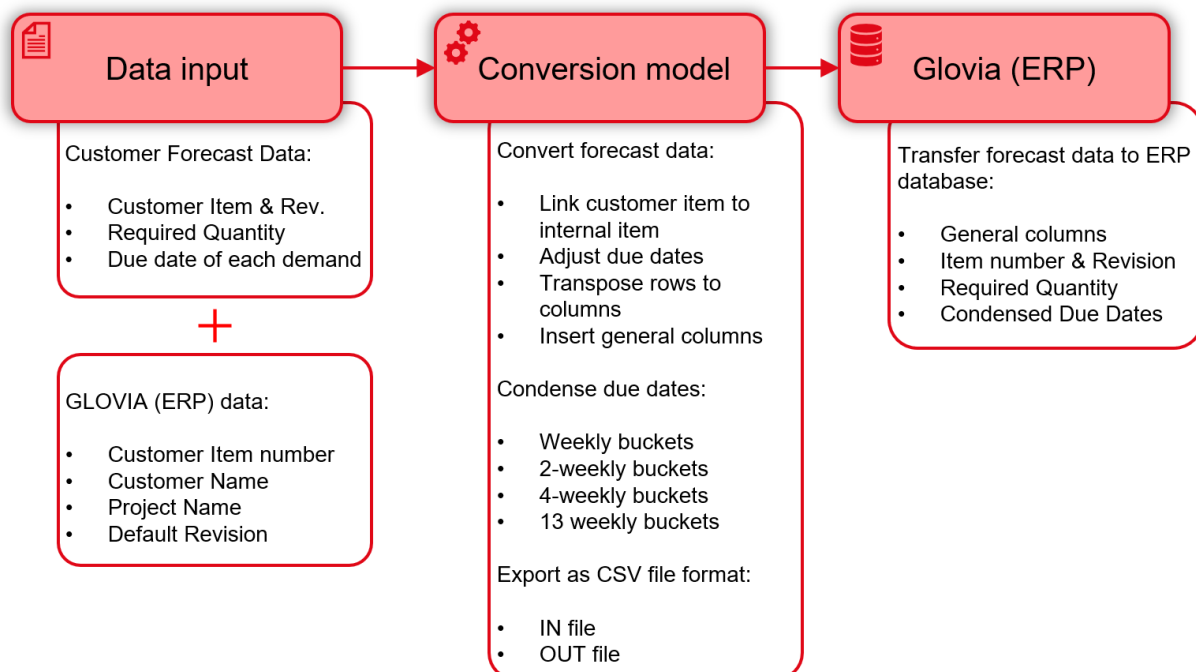
Figure 20 Conceptual model of the Forecast Data Conversion Tool

The conversion model uses the data input to convert the customer forecast data to a format compatible to the Glovia query. The first data mutation consists of linking and replacing the customer item by the internal item

number and default revision letter. Followed by adjusting the due dates to be in line with the sales orders scheduled due dates, this assures the forecast consumption to be performed correctly as well. After adjusting the due dates, the date column has to be transposed to a header row using a matrix conversion. Glovia requires three additional general data columns to make sure the forecast data is compatible to the upload format. A column to indicate the master location, a column to indicate demand stream type and a column for the facility ID.

As explained in Section 2.3 the maximum number of columns available for uploading the forecast to Glovia is limited by 50. The three general columns including the internal item number column and a column for the revision number add up to a total of five columns already used. The remaining 45 columns can therefore be designated to due date columns. The forecast horizon is finite up to four years ahead which induces approximately $(4 * 52) = 208$ weeks. Due to the limitation of Glovia of a maximum of 50 columns and the five columns that are already used, we need to fit 208 weeks/columns of data in 45 weeks/columns. Therefore, we condense the due dates in weekly, 2-weekly, 4-weekly (Monthly) and 13-weekly (Quarterly) time buckets. By doing so, we are able to leverage the benefits of having precise demand data for the near future, while also retaining comprehensive demand data for the more distant future. This results in a precise understanding of required demand for the immediate future, as well as a comprehensive picture of future demand trends. The proposed solution answers sub research question 8: "What measures can HTM-Aerotec adopt to enhance the quantity of accessible forecast data in Glovia?". An illustrative graph of the concept is shown in Appendix G.

After the conversion is performed, an IN and OUT (CSV) file must be exported and transferred to Glovia using a dedicated "Upload Forecast Quantity From .CSV File" module. The OUT file is used to remove the forecast data of the previous upload from the database. Followed by the IN file to provide the database with new updated forecast data. The OUT file is therefore always kept for two weeks (in case of Customer A) to reset the forecast data for the next update. It is therefore not an incremental update but a full update of the entire query.

4.2. DESIGN OF THE FORECAST DATA CONVERSION TOOL

In this section, we will explore the key considerations in the "Forecast Data Conversion Tool" model development, including the requirements (Section 4.2.1) that must be met for the model to be effective and a comprehensive model description (Section 4.2.2).

4.2.1. MODEL REQUIREMENTS

In this section, we will clearly define the requirements of the model that will serve as the foundation for addressing the core problems related to research question A and B. Our goal is to build an effective tool that can fulfil all requirements to solve these problems.

One important requirement for the model is the ability to work with live data. This means that the model must be able to retrieve data in real-time from the Glovia ERP database which contains the most recent up to data information available. To achieve this, the model needs to be connected to The Glovia ERP database source that constantly updates its information. This will reduce the time required for transforming and transferring the forecast data to Glovia (sub research question two) and will reduce the risk of human error during transforming and transferring of the forecasts (sub research question three). Because the data currently is retrieved using a manual export function which is time consuming and the risk of incorrect copying and pasting of the data cannot be ruled out. Like accidentally using an old export that was still in the downloads folder. Or accidentally incorrectly selecting too few rows and/or columns. It cannot even be ruled out that re-exporting up-to-date data is omitted due to time constraints. That potential can result in incorrect item numbers, erroneous revision letters and, even worse, omitting forecast demand data.

Another important requirement is the ability to adjust due dates accordingly. This means that the model should be able to adjust each of the point forecast due dates to the tuesday the week before, see Figure 21. This is particularly important for the forecast consumption to be performed correctly and to be in line with the process of entering sales orders in the ERP system where they set the scheduled due date using the exact same procedure. It is also required to set the due date always to Tuesday because there is a shuttle delivery service every Wednesday and the forecast consumption is chosen to be performed backwards using the context analysis in Section 2.3. So in case

when the rolling horizon proceeds and the forecasts are replaced by sales orders and the backward consumption rule type A is applied, the forecast consumption will be correctly performed. In case the due date of the most recent forecast and the sales order differ a mismatch can still occur, therefore it is required to reduce this risk using a predefined updating procedure. This complex interplay between periodically updating the forecast data, entering the sales orders in the ERP system, applying the forecast consumption rule, modification of due dates and timing of these independent business processes play a crucial role in ensuring proper functioning of the system, more on this in Section 4.2.2.
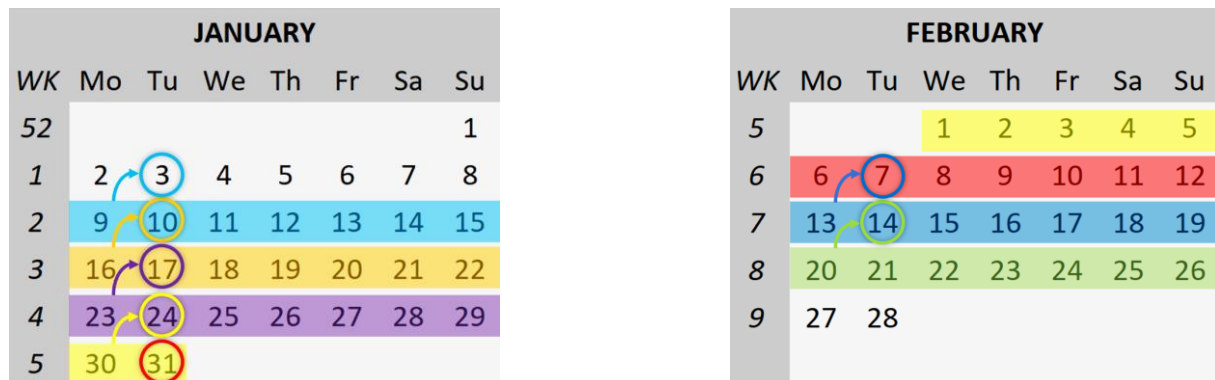
Figure 21 Illustrative example of the Forecast Due date Modification

In addition to the due date adjustment, the model should also be able to condense the due dates in weekly, 2-weekly, 4-weekly (Monthly) and 13-weekly (Quarterly) time buckets to reduce the quantity of forecast data omitted. By doing so, we are able to leverage the benefits of having precise demand data for the near future, while also retaining comprehensive demand data for the more distant future. This means that the model should be able to group demand data to specific due dates.

The first adjusted due date present in the customer forecast file should be assigned the first weekly column, this usually is approximately eight weeks ahead, for the period in between the forecast are already replaced with sales orders already. By doing so we save eight columns. This first column now concerns the start of the forecast horizon. An illustrative example of Table 2 is shown in Appendix G.

Table 2 Allocation template of columns to time buckets

Bucket type	Allocated Columns	% Of columns	Weeks included	% Timespan
Weekly	15	33%	15	7%
2-Weekly	8	18%	16	8%
Monthly (4 weekly)	12	27%	48	23%
Quaterly (13 weekly)	10	22%	130	62%
	45	**100%**	**209**	**100%**

It also is required that the model should be fool proof, meaning that it should be able to handle errors, exceptions, and unexpected inputs gracefully. This could involve implementing error-handling mechanisms or providing clear and concise error messages to users to help them troubleshoot issues. However, the prevention of possible errors always takes precedence over the error-handling mechanisms. In doing so, it should always first be evaluated if the risk-forming manual data mutations can be replaced by an automated error free process.

Finally, the model should be user-friendly and easy to use. This means that the interface should be intuitive and easy to navigate, and the model should provide clear and concise instructions to help users get the most out of it. Additionally, the model should be customizable to meet the specific needs and preferences of different users, such as sorting data tables and generating an output preview. It is also required that users are informed about the status when using the tool such as, feedback messages or checks marks. Furthermore, it is desirable to use software that most people are familiar with and have access to.

4.2.2. MODEL DESCRIPTION

This section presents the Forecast Data Conversion Model description including the backend infrastructure. The solutions to fulfil the requirements described in the previous section will be elaborated successively.

Based on the requirement to build the application on a simple and widely used software platform, it was decided after consultation to build the model using a combination of Excel, Power Query and Visual Basic for Applications (VBA). As a result, the ease of use and the continuity of the model have already been covered for the most part.

The first and most important aspect of the model is the introduction of the ability to work with live data. This means that the model is able to retrieve data in real-time from the Glovia ERP database which contains the most recent up to data information available. To achieve this, the model is connected to the Glovia ERP database source that constantly updates its information. This will reduce the time required for transforming and transferring the forecast data to Glovia (sub research question two) and will reduce the risk of human error during transforming and transferring of the forecasts (sub research question three).

In order to connect the model to the real-time ERP data there are required multiple intermediate processes facilitated by software add-ins, both locally and externally. In case of external there have to be set up a "Custom View", a custom view is an abstract name for a query. A custom view can be a predefined view that is already be used in the ERP software by itself or a combination of multiple queries. In that case, data from multiple queries are merged to a new query. A custom view can also contain just a selection or subset of attributes of a custom view. An illustrative example of a custom view is shown in Appendix D. In case of this model we only need one custom view that we give the anonymised name "ITEM_DATA" which contains five attributes: Customer Item number; Internal Item Number, Default Revision, Project Name and Customer Name. The Customer Item number field will only be filled if it is the default revision and all other conditional data requirements are satisfied. In all other cases the field will be empty.

Figure 22 Live data retrieval flow chart

A unintended side affect of the intruduction of this infrastructure lies in the fact that numerous customized views have already been established for this and in particular for the Ordering Policy Optimisation Tool (Section 4.4), which are now accessible to the entire company, which in turn can have a positive impact on several other business processes.

To ensure that the tool is fool proof, several security elements have been added. The first one is that the tool is split in five clearly numbered sequential steps. The first one is selecting the Customer forecast file "Browse raw forecast file path", this function saves the file path of the selected file to the sheet and loads the data into a query called "INPUT Forecast". To make sure the user selected the correct file a message box will appear asking the user to confirm that the selected file contains the correct "Active set date". When confirmed the forecast date and week number will be saved to the interface and the check mark will turn from grey to green to notify the user the step is performed correctly. Then the user proceeds to step two to exclude projects from the exports if required. Thereafter the user clicks the button "Built CSV files" to perform all modifications to the data. If finished the tool will write the end dates of each individual grouped bucket type to the sheet. This information is important for understanding how the dates are grouped according to the procedure showed in Appendix G, the awareness of this phenomenon is important. When finished, the step 3 check mark turns from grey to green. In case an error is detected a message box with a warning will appeared notifying the user with the observed error. The check mark will turn red in this case. An example of an error that can appear is that there is an typo or empty field in the database present required for the conversion to be performed correctly. In that case an Message box will appear with a list of items that contain a database error. This will allow the user to solve the problem by checking and updating/correcting the required data field(s) for the listed item(s). To be able to export the CSV IN and OUT files, a folder should be selected using the step four button. A windows browse window opens which allows the user to select the preferred folder. Again the corresponding check mark will turn green if performed correctly. Lastly, the CSV IN and OUT file can be exported using the step five button. When finished the output folder will automatically open using windows explorer. The file name is determined using a predefined procedure. In case the file names already exists, the user will be asked to overwrite the files or to cancel the procedure.

In addition to the data validity checks after each of the five steps, a number of checks take place during the opening of the file and when a mutation takes place anywhere in the sheet. In this way, the validity of the data export can be guaranteed even better. An overview of the main interface of the Forecast Conversion Tool can be seen in Appendix H. For more details about the structure of the tool an example of the VBA coding used to program the main functionalities of the tool can be seen in Appendix F. After the conversion is performed, the OUT file of the previous export (two weeks ago) is used to reset the forecast data. Subsequently the IN CSV) file must is transferred to Glovia using the same dedicated "Upload Forecast Quantity From .CSV File" module. That procedure finalised the updating procedure. The most up to data forecast data is now present in the ERP system. Which allows generating new updated CPO's given the new information using the PLANNING UPDATE function. This will then also affect the raw material requirements planning.

Figure 23 Query Dependencies of the Forecast Data Conversion Tool

4.3. CONCEPTUAL MODEL OF THE ORDERING POLICY OPTIMISATION

Section 4.3 and 4.4 present the conceptual model and design to solve the core problems related to main research question C: **"How can HTM-Aerotec minimise the total relevant setup and inventory cost of the forecast driven items by improving the ordering policy without compromising on on-time delivery performance?"** including sub research question eight: **"Which solution method suits best for solving the ordering policy optimisation problem at HTM-Aerotec?".**

The conceptual model of the Ordering Policy Optimisation Tool includes three main modules: data input, the optimisation model and the output to the ERP system (Glovia). The data input consist of two parts; the customer forecast file and the ERP data required for the optimisation. The forecast file is formatted as an Excel 2003 file format where each new line contains a new point forecast. The ERP data provides the model with the current planning status using the Work Orders and Sales Orders as well as the currently planned production orders and on hand inventory of each individual item. In addition, the attributes such as the setup quantity, cost price, setup cost, lead time, setup quantity, minimum order quantity and order quantity multiple are retrieved from the database. For this, the new live data infrastructure developed for the Forecast Conversion Tool (Section 4.1) is also used for the Ordering Policy Optimisation Tool.
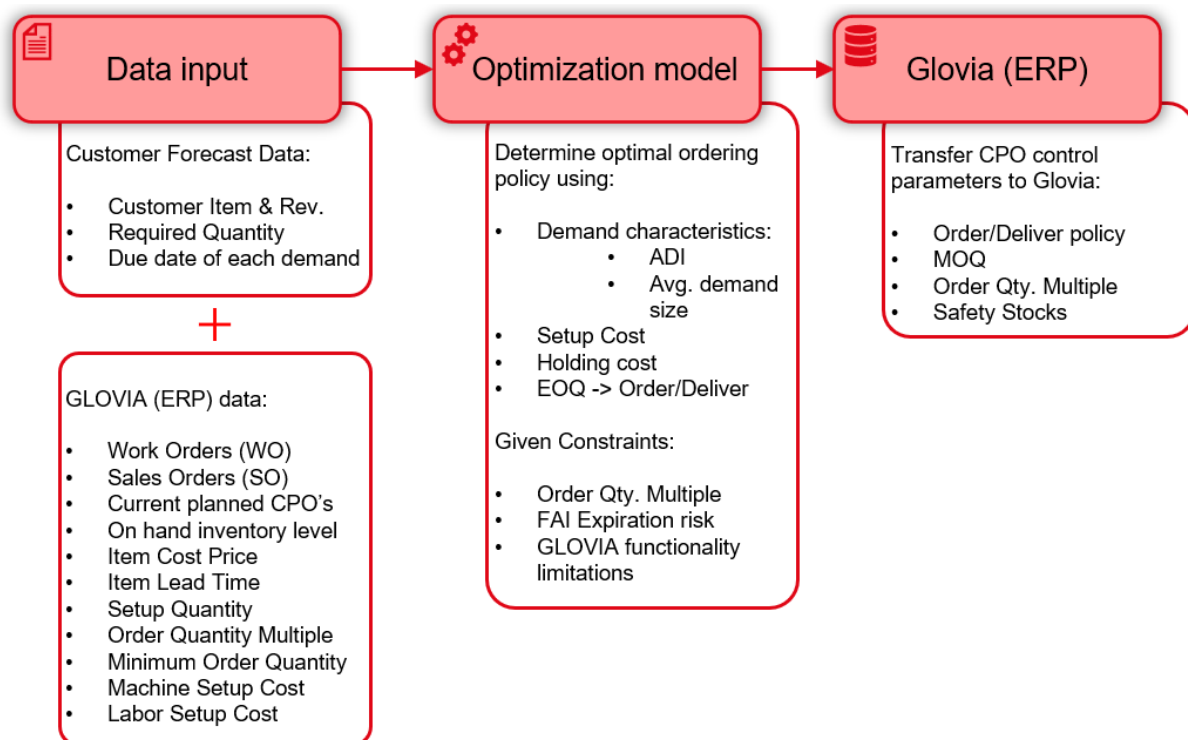
Figure 24 Conceptual model of the Ordering Policy Optimisation Tool

In addition, the knowledge and experience about forecast consumption (Section 2.3) will be implemented in the Ordering Policy Optimization Tool. This prevents the optimization model from being fed with erroneous double demand data. In addition, the due date adjustment logic and conversion of the customer item number to the internal product and revision number will also be applied to the Ordering Policy Optimization Tool.

This data input defines the solution space for the optimisation model. It provides the model with the required constrains and parameters and allows the optimisation model to generate accurate and feasible solutions. To do so, firstly the annual demand is estimated based on the average demand interval (ADI) and average demand size given the realised demand of the previous 12 months. The optimisation model will then calculate the EOQ for each individual item using the annual demand, setup costs and holding cost. This fixed EOQ lot size will then be converted to the Order/Delivery Policy parameter (Section 1.2) while taking into account the FAI Expiration risk.

Using this new Order/Delivery Policy parameter, the optimised ordering policy can be calculated and compared to the current ordering policy. Lastly, in order to implement the new ordering policy, the optimised control parameters must be uploaded to the ERP system consisting of the new Order/Delivery Policy value, the Minimum Order Quantity and Order Quantity Multiple.

4.4.   DESIGN OF THE ORDERING POLICY OPTIMISATION TOOL

In this section, we start by explaining the problem by a mathematical formulation (Section 4.4.1). Furthermore we will explore the key considerations in the "Ordering Policy Optimisation Tool" model development, including the requirements (Section 4.4.2) that must be met for the model to be effective. Lastly we included a comprehensive model description (Section 4.4.3).

4.4.1. MATHEMATICAL MODEL FORMULATION

In this section we present the mathematical formulation of the problem. The objective function (formula 1) minimizes the sum of setup and inventory holding costs considering all periods t and each product i. This type of problem is often referred to as the Uncapacitated Lot-sizing Problem (ULSP). In order to fit this specific use case the model is extended by an order quantity multiple constraint. There is no direct relationship between the products, meaning that the lot-size decisions for one product do not impact the solution space for other products. However, since the objective is to optimize the ordering policy for all products, we have included the i index. This identical procedure is applied in the ordering policy optimization tool, where the optimization loop includes all the products.

The model assumption are:
1. Backlogging is not allowed.
2. Number of periods in planning horizon is known (finite), each period is equal to one week.
3. The setup cost of each individual product is constant during the entire planning horizon.
4. The holding cost of each individual product is constant during the entire planning horizon.
5. The sales and forecasted demand for each product is know (deterministic) during the entire planning horizon.
6. Production capacity is infinite.

The indices used in the model formulation are:
i =   index for products ($i = 1, \ldots, P$)
t =   index for periods ($t = 1, \ldots, T$)

List of parameters used in the model formulation are:
K_i =   Setup cost for product i
h_i =   Holding cost for product i
$I_{i,0}$ =   Initial on hand ending inventory position of product i in period $t = 0$
$I_{i,t}$ =   Ending inventory position of product i in period t
$W_{i,t}$ =   Already planned production quantity (workorders) for product i for period t
$D_{i,t}$ =   Demand (sales & forecasted) for product i for period t
m_i =   Order quantity multiple for product i
$z_{i,t}$ =   Order quantity multiplier for product i in period t, Integer value
T =   The number of periods (weeks) included in the planning horizon
P =   The number of products included in the planning horizon
M =   A large number, Big M method

Decision variables are as follows:
$x_{i,t}$ =   Lot size for product i in period t

$$Y_{i,t} \quad = \quad \begin{cases} 1 & \text{if product } i \text{ is produced in period } t \\ 0 & \text{Otherwise,} \end{cases}$$

`

Using the above notations, the mathematical model for the lot-sizing problem is presented as follows:

$$Minimise\ Total\ Relevant\ Cost\ =\ f(Holding\ Cost + Setup\ cost)$$

$$Min\ Z:\quad \sum_{P}^{i}\sum_{T}^{t}(I_{i,t} * h_i + Y_{i,t} * K_i) \tag{1}$$

Subject to:

$I_{i,t}$	$=$	$I_{i,t-1} + W_{i,t} - D_{i,t} + x_{i,t}\quad \forall i,t$	(2)
$x_{i,t}$	$\leq$	$MY_{i,t}\quad \forall i,t$	(3)
$Y_{i,t}$	$=$	$0,1\ (\text{binary})\quad \forall i,t$	(4)
$x_{i,t}$	$=$	$m_i z_{i,t}\quad \forall i,t$	(5)
$z_{i,t}$	$=$	$0,1,2 \ldots (\text{positive integer})\quad \forall i,t$	(6)
$x_{i,t}, I_{i,t}$	$\geq$	$0\quad \forall\ i,t$	(7)

The first constraint (2) ensures the inventory flow along the periods in the horizon. It represents the balance between production (workorders $W_{i,t}$ and/or additional production $x_{i,t}$), external demand $D_{i,t}$ (sales and forecasts) and inventory. Constraint (3) sets the binary constraint $Y_{i,t}$ to true using the Big M method in case production in period t takes place. We constructed this binary property using constraint (4). The order quantity multiple property is constructed using constrain (5) and (6). Lastly constraint (7) indicates that backlogging is not allowed and that the production quantity in each period is non-negative.

4.4.2. MODEL REQUIREMENTS

In this section, we will clearly define the requirements of the model that will serve as the foundation for addressing the core problems related to research question C. Our goal is to build an effective tool that can fulfil all requirements to solve these problems.

Th first important requirement for the model is the ability to work with live data. This means that the model must be able to retrieve data in real-time from the Glovia ERP database which contains the most recent up to data information available. To achieve this, the model needs to be connected to The Glovia ERP database source that constantly updates its information. The same infrastructure that was built for the Forecast Conversion Tool is used for this. Which allows HTM-Aerotec to recalculate the optimization parameters in case costs and demand change over time. As a beneficial side effect will this procedure reduce the risk of human error during retrieving, recalculating and updating the ordering policy parameters.

Another important requirement is the ability to adjust due dates accordingly. This again uses the same logic as for the Forecast Conversion Tool, as explained in Section 4.2.1. This is particularly important for the forecast consumption to be performed correctly and to be in line with the process of entering sales orders in the ERP system where they set the scheduled due date using the exact same procedure. It is required to set the due date always to Tuesday because the forecast consumption is chosen to be performed backwards as described in the context analysis (Section 2.3). So in case when the rolling horizon proceeds and the forecasts are replaced by sales orders and the backward consumption rule type A is applied, the forecast consumption will be correctly performed ensuring a correct data input for the optimisation model. Moreover, this forecast consumption process is another requirement in itself that should be incorporated in the model. Visually indicating the forecasted demand that is consumed according tot the consumption rules would be a nice addition. This facilitates the detection of potential incorrect forecast consumption and creates awareness of the process itself for the HTM-Aerotec employees.

The most important requirement is that the tool should be able to minimise the total relevant setup and inventory cost of the forecast driven items by improving the ordering policy without compromising on on-time delivery performance. Given the findings in the context analysis and literature review we choose to use the Economic Order Quantity formula for this. The EOQ will sequentially be converted to the Order/Delivery policy allowing a dynamic lot size solution that is compatible to the Glovia ERP system.

Moreover, the Optimized Ordering Policy must meet the requirement of being compatible with the ERP system, allowing for its seamless implementation.

Furthermore should the model be able to take into account the order quantity multiples. Which acts as a constraint for the solutions space, but will ensure a feasible solution. Furthermore, an additional constraint should be implemented to prevent the FAI from expiring in case of some very slow moving items. This can be achieved by lowering the Order/Delivery policy to ensure that a new production is initiated before the FAI's expiration date.

It also is required that the model should be fool proof, meaning that it should be able to handle errors, exceptions, and unexpected inputs gracefully. This could involve implementing error-handling mechanisms or providing clear and concise error messages to users to help them troubleshoot issues. However, the prevention of possible errors always takes precedence over the error-handling mechanisms. In doing so, it should always first be evaluated if the risk-forming manual data mutations can be replaced by an automated error free process.

Finally, the model should be user-friendly and easy to use. This means that the interface should be intuitive and easy to navigate, and the model should provide clear and concise instructions to help users get the most out of it. Additionally, the model should be customizable to meet the specific needs and preferences of different users, such as sorting and filtering of data. It is also required that users are informed about the status when using the tool such as, feedback messages or progress bars. Furthermore, it is desirable to use software that most people are familiar with and have access to.

4.4.3. MODEL DESCRIPTION

This section presents the Ordering Policy Optimisation Model description including the backend infrastructure. The solutions to fulfil the requirements described in the previous section will be elaborated successively.

Given the requirement to build the application on a simple and widely used software platform, it was decided after consultation to build the model using a combination of Excel, Power Query and VBA. By leveraging the strengths of these tools, we have ensured that the model offers both ease of use and continuity throughout its development. Excel provides a familiar and intuitive interface, making it accessible to a wide range of users and with the integration of Power Query, we can easily import, transform, and cleanse data from Glovia. Power Query's functionality enables us to perform complex data transformations efficiently. Additionally, allows VBA to enhance the application's functionality and customize it according to specific requirements. VBA enables the automation of repetitive tasks and the creation of user-friendly interfaces, enhancing the overall user experience. It also facilitates the integration and implementation of advanced calculations and algorithms. By utilizing this combination of Excel, Power Query, and VBA, we have ensured that the application meets the criteria of simplicity and widespread usage while retaining the option to implement advanced calculations and algorithms.

As described in the previous section, the real-time data retrieval from the ERP database developed for the Forecast Conversion Tool is used for the Ordering Policy Optimisation tool as well. Adjusting the due dates of the point forecasts is implemented according the same procedure as the Forecast Conversion Tool. This knowledge and expertise gained is therefore gratefully used in the optimization tool.

Based on the context analysis we can conclude that the forecast consumption rules using forward consumption can be excluded. Among the remaining backward consumption rules A and B, we deem rule A as the most suitable option. Here it is necessary to consider whether it is more problematic to have more demand than actual in the system versus less demand than actual in the system. Rule A induces risk of not consuming a forecast that should be consumed and Rule B induces risk of consuming a forecast that should not be consumed.

In case of rule A, when a new sales order is added with a due date prior to the forecast due date and PLANNING UPDATE is executed, the forecast will not be consumed due to the fact that it will only consume forecasts backwards from the customer order due date. To accommodate for slight changes in due dates at the point in time where the forecast is replaced by a sales order, one additional consumption period should be added, meaning forecasts are also consumed by demands occurring one additional period prior to the customer order period. This

ensures that in case the forecast due date is in the last week of February and the sales order is placed in the first week of January instead of the expected last week of February, the forecast will still be consumed by the sales order.

In case of rule B, when a new sales orders is added in a month where two forecasts are present it will consume the first forecast. However when the new forecast will be uploaded two weeks later which will remove the first forecast in that month. The sales order will then consume the second forecast in that month. This will make it seem as if the demand is lower than it really is. Only when the second forecast is replaced by a sales order will this demand be visible again. This is therefore very undesirable and dangerous for disrupting the production schedule. This risk is especially present for relative fast moving items that can have multiple demands in the same month.

Since we consider the impact of not consuming a forecast that should be consumed less significant then consuming a forecast that should not be consumed. And given that, it is possible for the planner to logically find the incorrect forecast consumption of rule A where this is impossible in case of rule B, since the demand is no longer visible for the planner. Based on these facts we decided to advice using use forecast consumption rule A with one additional period.

To be able to optimise the ordering policy we use the Harris Wilson Model (1934), better known as the Economic Order Quantity (EOQ). The formula for calculating the EOQ is formulated as follows:

Formula 1:
$$EOQ \; [units] \; = \; \sqrt{\frac{2AD}{vr}}$$

Where:

$$D \; = \; annual \; demand \; for \; the \; item \; [units \; per \; year]$$
$$A \; = \; setup \; or \; ordering \; cost \; [euro's \; per \; order]$$
$$v \; = \; value \; of \; item \; [euro's \; per \; item]$$
$$r \; = \; holding \; cost \; rate \; [percentage]$$
$$vr \; = \; annual \; holding \; or \; carrying \; cost \; [euro's \; per \; year]$$

The result of formula 1 is the optimal order quantity that minimizes the total cost of inventory, taking into account both the costs of ordering and holding inventory. The holding costs are expressed as a percentage of the items costs price which induces that relative expensive items are charged with a higher holding cost. Given the structure of formula 1 we can conclude the EOQ induces to produce expensive items with relative low setup costs relative more frequently and produce cheap items with relative high setup costs relative less frequently.

As discussed in Section 3.1.2, the rule of thumb is that the holding costs should account for 15% to 30% of the inventory cost price but may vary across industries and organizations. To come up with a reasonable estimation of the holding costs we first defined the weighted average costs of capital (WACC) to be 5% according to the financial manager of HTM-Aerotec (2023). The handling and storage of the inventory warehousing are estimated to be 8%. The insurance is approximately 2% and costs incurring the risk of damaged or obsoleted inventory is estimated to be 5%. Which in total adds up to 20% holding costs.

On the other hand we have the setup costs, for this we will rely on the information available in the ERP system. Using the routing query we are able to retrieve the total setup costs for the standard lot size for each item individually for each routing step. This information is uploaded to the ERP system by the manufacturing engineers after performing a costs price calculation for the item. These costs are determined by means of a fixed procedure and calculation tool. The setup costs are split in labour setup cost and machine setup cost. The costs inquiring the purchase of raw materials and outsourcing as well as the costs required to prepare the documentation in order to start production are incorporated within setup costs as well.

To leverage the easy of use of the Economic Order Quantity formula while capitalizing on the benefits of dynamic lot sizing, we convert the fixed order size calculated using formula 1 into an Order/Delivery Policy using the following procedure:
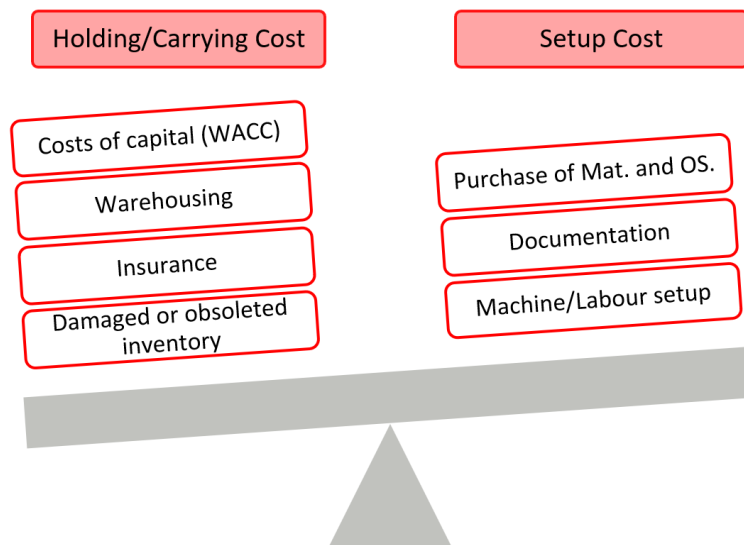
Figure 25 Illustration of the trade-off for optimizing the holding costs versus the setup cost.

Formula 2:
$$Order \backslash Delivery\ Policy\ [Weeks] = \frac{EOQ}{D} * \frac{365}{7}$$

Where:

$$EOQ\ =\ Economic\ Order\ Quantity\ [units]$$
$$D\ =\ annual\ demand\ for\ the\ item\ [units\ per\ year]$$

In case of a direct conversion we use the following formula:

Formula 3:
$$Dynamic\ EOQ\ Policy\ [Weeks] = \frac{365 * \sqrt{\frac{2ADr}{v}}}{D*7}$$

Where:

$$D\ =\ annual\ demand\ for\ the\ item\ [units\ per\ year]$$
$$A\ =\ setup\ cost\ [euro's\ per\ order]$$
$$v\ =\ cost\ price\ of\ item\ [euro's\ per\ item]$$
$$r\ =\ holding\ cost\ rate\ [percentage]$$
$$vr\ =\ annual\ holding\ or\ carrying\ cost\ [euro's\ per\ year]$$

The outcome of formula 3 is rounded up to a multiple of four using a lower bound of 12 weeks and an upper bound of 84 weeks (12 ,16, 20, 24 … 84). The lower bound of 12 weeks (approximately three months) is satisfactory due to the fact that no product require a lower order/delivery policy. Furthermore, when it comes to HTM-Aerotec, implementing it as a baseline given the item lead time offers several benefits. One notable advantage is the avoidance of handling multiple orders for the same product concurrently within the factory. We refer to this new policy construction procedure as the Dynamic EOQ policy.

In summary, by converting the EOQ resulting from formula 1 into a Order/Delivery Policy, we combine the advantages of the EOQ formula's ease of use with the benefits of dynamic lot sizing. This approach provides flexibility, enhanced efficiency, and compatibility with Glovia, aiming to improved inventory management and operational performance for HTM-Aerotec.

Another advantage of using the order/delivery policy is that it allows for reducing the risk of a FAI expiration. Given the fact that a FAI is valid for a maximum of two years (≈104 weeks) and costly to reacquire via a Full FAI. Would it be beneficial if we could prevent this using the integration of a smart function in the optimisation tool. To do so, we can reduce the order/deliver policy such that the probability of a FAI expiration is minimised using the following formulas:

Formula 4: $$number\ of\ orders\ in\ two\ years = F = \frac{104}{ADI}$$

Where:
$$ADI\ = Average\ Demand\ Interval\ [weeks]$$

The outcome of formula 4 will be rounded up to the nearest integer value, this will then be used subsequently in the next formula:

Formula 5: $$FAI\ Upperbound\ [Weeks] = F - 1 * ADI + ADI/2$$

Where:

$$F\ = Outcome\ of\ formula\ 4\ rounded\ up\ to\ the\ nearest\ integer$$
$$ADI\ = Average\ Demand\ Interval\ [weeks]$$

The outcome of formula 5 is rounded down to a multiple of four using the same logic as formula two (12 ,16, 20, 24 … 84). An illustrative demonstration of this functionality can be found in Appendix J.

Finally the order/delivery policy assigned to an product by the ordering policy optimisation tool is determined by the minimum of the outcomes of formula 3 and formula 5, see formula 6 below. Where formula 5 acts as a upper bound constraint in case there exists a risk of FAI expiration.

Formula 6: $$FAI\ restricted\ policy\ [Weeks] = MIN(Dynamic\ EOQ\ Policy\ ,\ FAI\ Upperbound)$$

Where:

$$Dynamic\ EOQ\ Policy = Outcome\ of\ formula\ 3\ rounded\ up\ to\ a\ multiple\ of\ four\ [weeks]$$
$$FAI\ Upperbound\ = Outcome\ of\ formula\ 5\ rounded\ down\ to\ a\ multiple\ of\ four\ [weeks]$$

This Dynamic EOQ value in weeks serves as a input parameter for the Order/Deliver policy in Glovia. This policy simply sums demand occurring in the consecutive λ periods (calculated using formula three or formula six in case the FAI restriction is considered) starting from period t in which the inventory level drops below zero, the lot-size of the first production run on the planning horizon is set equal to the total demand occurring in these periods. Subsequently, the lot-size of the second and consecutive production runs is calculated using the same formula until the end of the planning horizon is reached. The mathematical formulation for calculating the lot-size is represented by Formula 7. To provide a practical illustration of the policy's outcome, a example can be found in Appendix I within the New Ordering Policy section.

Formula 7: $$Lot\ size = \sum_{t}^{t+\lambda} D_t$$

Before the above optimization formulas can be applied, the required data must be obtained from the ERP system through a live data connection. The data model structure to do so is shown in Figure 26, showcasing the query dependencies that play a vital role in facilitating the data collection and preparation of the Ordering Policy Optimisation Tool.

To get an idea of the technical structure of the Ordering Policy Optimization tool, a summary is given below about what happens when the data of the tool needs to be updated. The updating procedure starts when the user presses the "Refresh ALL" button, a progress bar opens and the data model starts retrieving three data queries from the ERP system using the same infrastructure used for the Forecast Conversion Tool . The first one is the ITEM_DATA containing al required item attributes such as Order Quantity Multiple, Setup Quantity, Minimum Order Quantity and Cost price. The second one is the ROUTING_DATA containing the attributes regarding the labour and machine setup cost. The third one is the ORER_DATA including the currently planned work orders

(WO), computer planned orders (CPO) and Sales orders (SO). Subsequently, the most recent raw customer forecast file which is previously selected using the interface button will be loaded to the data model. This forecast file and ITEM_DATA will be used to convert the customer item number to the internal item number including the revision letter (FOR_ITEM_REV_LIST). This procedure is equal to the procedure developed for the Forecast Conversion Tool. This list will be used to filter the ORDER_DATA query. The on hand inventory level is added to this query and the due date of the point forecast due dates is modified, again using the same procedure developed for the Forecast Conversion Tool. Subsequently, for ease of use the structure of the AVAILABLE BEGINNING/WO/CPO/SO is changed to be equal to the Glovia PLANNING OVERVIEW interface. From this PLANNING OVERVIEW query the start and end date of the horizon are obtained. In addition the Last Day Of Weeks parameter is obtained from this query which is used to built the ROWS_TO_INSERT query containing all the week numbers starting from the first week of the horizon, up to the last week of the horizon. This is required because the point forecast do not including zero demand forecasts for the weeks with zero demand, these are therefore added using this ROWS_TO_INSERT query. This query includes a line fore each week of the four year horizon for each individual item included in the customer forecast file (52*4*280 ≈ 58000 lines).

Lastly is Power Query used to append the PLANNING OVERVIEW query with the ROWS_TO_INSERT query. This PLANNING OVERVIEW (ALL WK) query is loaded to the worksheet required for multiple sheet calculations and the Ordering Policy Optimisation using VBA as described in the first part of this section. An example of the interface of the tool can be seen in Appendix I.

Figure 26 Query Dependencies of the Ordering Policy Optimisation Tool

5. RESULTS ANALYSIS

This chapter presents the results analysis. We analyse the performance of both models using a predefined experimental design, first the results of Forecast Data Conversion Tool are presented and Secondly the results of the Ordering Policy Optimisation tool. The purpose of the analysis is to demonstrate the improvement compared to the currently used procedures as defined in the context analysis (Chapter 2). The performance analysis is performed using a finite horizon starting from the as of date up to the end of the forecast horizon in both models. First, Section 5.1 presents the results analysis of the Forecast Data Conversion Tool followed by the Ordering Policy Optimisation Tool in Section 5.2. Finally, for both models the data validation and verification will be explained in Section 5.3.

5.1. FORECAST DATA CONVERSION TOOL

In this section we will elaborate on the Experimental Design and Results of the Forecast Data Conversion Tool.

5.1.1. EXPERIMENTAL DESIGN

To test the functionality of the tool and to quantify the performance improvement we will perform a test of three conversions. We use the forecast data of ISO Week 14, 16 and 18 of 2023 for this purpose. The data of week 14 contains 3554 point forecasts, week 16 contains 3523 point forecasts. Lastly, week 18 contains 3463 point forecasts. This includes only the demand data that is unequal to zero. For each item and period combination where the forecasted demand is equal to zero, the point forecast is excluded from the data beforehand by Customer A.

The conversion will be performed by using a Dell laptop with the following specifications:
- Processor: Quad core Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz boost up to 1.80 GHz
- Cache memory: 8GB 2400MHz SODIMM
- SSD: 250GB Solid State Drive
- Windows 10 Pro 64 bits

The period measured to evaluate the performance includes; opening the file and loading it to the cache memory, Selecting and importing the customer forecast file, converting it and exporting the CSV files to the preferred folder. In other word, four of the five sequential step have be performed by the user. The option to filter by project name/ commodity is omitted during the test, in all cases the filter selection is set to "None". When all steps are finished and the output folder opens the stopwatch is paused and results are saved. The condition here is that no error message appears during the conversion. If this does happen, this must also be reported. The time required for the procedures to upload and perform the PLANNING UPDATE function in Glovia are omitted in this test, since there is no possibility to reduce the time required for this.

The experiments are performed from the facility HTM-Aerotec itself. This ensures a fast and stable connection to the database. The laptop is connected using a CAT6 data cable. The objective of this test is to evaluate the time reduction and reduction in risk of human error to occur during the data conversion.

5.1.2. EXPERIMENTAL RESULTS

As far as the results of the experiments concern, all three experiments are performed without any error messages. Which indicates a stable application and easy to use process. Except in the event that the user selects the wrong (an old) forecast file and also agrees to the question whether it concerns the correct date and ISO week, the conversion tool may give the incorrect output. Compared to the old manual sequential conversion method, the change of human error is greatly reduced.

In terms of the reduction in time required for the data conversion, the performance results of the new tool are shown in Table 3. In case of the current manual sequential procedure the time required for the conversion took approximately 90 minutes (A. Kasteel 2023). When we compare this to the new conversion tool we obtain an average result of 82 seconds. Therefore we conclude that the time saving is approximately 88 minutes, equal to an

reduction of 98,5%. The time savings are not a one-off, but will be reaped every two weeks. Possibly even more often in case changes occur for items that also need to be processed in the forecast.

Table 3 Experimental results of The Forecast Conversion Tool

Name	Loading to Cache [Sec]	Importing Forecast file [Sec]	Conversion + Export [Sec]	Total [Sec]
Experiment 1	4	15	62	81
Experiment 2	4	15	60	79
Experiment 3	4	16	63	83
Average	**4**	**15,3**	**62,5**	**≈ 82**

In addition to the reduction in time required for the conversion, the reduction in exposure to human error is the most important improvement. Because preventing erroneous data in the ERP system benefits the accuracy of other business processes that depend on this data input, such as purchasing of raw materials, but above all the production schedule. In addition will the new tool prevent unnecessary time being spent on error handling, which is difficult to measure, but to be expected.

Aside of the time savings and reduction in human error risk, it is now possible to have insight into forecast data for up to four years in the ERP system instead of at the most one year. Which offers opportunities for optimising the ordering policy and enables the purchaser and production planner to make well-informed decisions and anticipate future demand more effectively.

Furthermore, the new live data infrastructure offers a multitude of possibilities beyond its primary application. Not only does it enable the acceleration of existing business processes, but it also holds the potential to optimize various aspects of these processes. This new infrastructure empowers HTM-Aerotec to make data-driven decisions and automate repetitive tasks. By continuously analysing this live data, HTM-Aerotec can identify opportunities for cost reduction and operational efficiency such as the Ordering Policy Optimization Tool described in the next Section.

5.2. ORDERING POLICY OPTIMISATION

The Forecast Conversion Tool, as discussed in the preceding section, has enhanced the availability of forecast data within the ERP system. Previously, the system could only accommodate forecast data for up to one year, but due to this tool, we can now access forecast information for up to four years in advance. This extended time frame enables us to leverage the data more effectively in the Ordering Policy Optimization Tool.

In the subsequent section, we provide a comprehensive explanation of the Experimental Design and Results pertaining to the Ordering Policy Optimization Tool. By utilizing the forecast data made available by the Forecast Conversion Tool, we are able to optimize the ordering policy and achieve improvements. We elaborate on the specific methods employed in the experimental design (Section 5.2.1) and present the results obtained through this optimization process (Section 5.2.2).

5.2.1. EXPERIMENTAL DESIGN

The performance of the policies is evaluated using the Ordering Poling Optimisation Tool, we use five key performance indicators, Total relevant cost (TRC), the total setup cost, the number of deliveries from stock, the average inventory level and the average inventory value. The total relevant cost stands out as the most crucial performance indicator due to its ability to provide a comprehensive perspective on the overall costs. By considering all relevant cost components HTM-Aerotec can make informed decisions to minimize expenses by optimising their inventory policy accordingly.

We compare multiple ordering policies. This allows for evaluating the potential improvement of the performance indicators of the current situation of HTM-Aerotec as described in Section 1.2. with the newly developed "Dynamic EOQ" ordering policy (formula 3, Section 4.4). In addition, the Least Unit Cost heuristic is added to

the comparison as described in Section 3.2.2. This Heuristic is capable of handling the intermitted demand characteristics very well and uses total relevant costs as the objective function. We use this information to determine whether the Dynamic EOQ ordering policy is able to deliver equivalent performance to the renowned and proven Least Unit Cost Heuristic. It is not possible to implement this least Unit Cost Heuristic in the Glovia ERP system, which is a strict requirement for this research. However, it only serves as means to compare the current and New ordering policy with a proven lot-size optimisation technique. For the same reason we added the Lot For Lot ordering policy and an (s, Q) policy for which we use the EOQ formula in order to calculate the order size Q.

In case of the Dynamic EOQ policy we include four sub types:
- Dynamic EQO, Round Down, Upper Bound 104wk
- Dynamic EQO, Round Down, Upper Bound 84wk
- Dynamic EQO, Round Up, Upper Bound 104wk
- Dynamic EQO, Round Up, Upper Bound 84wk

Because Glovia assigns an order/deliver policy to a product using a letter, the maximum allowable number of order/deliver policies to assign are 26. We previously determined that an lower bound of 12 weeks is sufficient and that due to the FAI restriction, 104 weeks (approximately two years) is and upper bound. We therefore assign an order/deliver policy to the products using increments of 4 weeks starting from 12 weeks and ending at 104 weeks (12, 16, 20, … 104) this results to 24 letters which is within limitation of the Glovia ERP system. Due to the fact that the Forecast conversion Tool transforms the forecast data to monthly time buckets up to 84 weeks (Appendix G) we also included an sub type with 84 weeks as upper bound. Using this upper bound of 84 weeks we ensure proper functioning of the Dynamic EOQ policy when the rolling horizon progresses and time passes by. Because we exclude the 13 weekly (quarterly) time buckets in this case. Beside the sub type with the 84 upper bound, we included an sub type in which we round the calculated order/deliver policy (formula 3, Section 4.4) up towards the first option from the list (12, 16, 20, … 104) and a sub type in which we round down to the first option from the list.

For each of the three policies performance tests, the solution space is shaped by the same constraints, namely:
- On hand inventory
- Work orders
- Sales Demand
- Forecasted Demand
- Order quantity multiple

As well as multiple input parameters:
- Item cost price
- Item setup costs
- Holding costs rate
- Annual demand

The most recent customer forecast file is used and the annual demand is calculated using the average demand interval and order size during the previous twelve months. The B project is excluding as this project shows demand in 2027 only which is likely to change in the not too distant future. It therefore has no added value to include the items included in this project in the performance analysis. A holding cost rate of 20% is used since this is considered the most accurate value as already described in Section 4.4.3. The optimization model incorporates approximately 280 items, a unique ordering policy is assigned to each item. Thereafter, the results are analysed and compared based on the five selected key performance indicators.

5.2.2. EXPERIMENTAL RESULTS

In this section we elaborate on the result obtained using the procedure explained in the previous sections. In each of the tables we show the results of the polices to compare.

This first aspect to notice when comparing the current policy to the other policies, is that the current policy performs quate well at all five performance indicators. All types of the Dynamic EOQ polies outperform in case of the total relevant cost and setup cost indicators, as well as the number of deliveries from stock. On the other hand, the Lot For Lot policy performs best in the case of the average inventory level and average inventory value. Not entirely unexpected since these two indicators are strongly related to each other. However, this policy performs worst in case of the objective function. When analysis the (s, Q) EOQ policy we observe that it performs worse than the current policy. The cause for this is simply that the EOQ value does not take into account the upcoming order size resulting to leftover products. For example, if the order size is 100 and the EOQ is 120. There are continuously 20 items left over. This is also backed up by the relative high holding costs compared to the other policies. A fixed order size policy is therefore not ideal unless the lot-size is adjusted to the order size which is the case for the current order policy.

Evidently, the most remarkable observation is the fact that in case of the Dynamic EOQ policies, the sub type concerning rounding up outperform the rounding down types. Rounding down leads to an lower holding costs and higher setup cost, as expected. In addition we can conclude that the lower upper bound of 84 weeks does not negatively include the performance, it even provides an slight improvement. Furthermore, can we conclude that the differences between different subtypes are very small.

Table 4 and Table 5 show the annual results after the warm-up period, thus the transition period from the old to the new policy has been disregarded ensuring a fair comparison. This period is determined to be 12 months, at that point in time the average lot size and inventory level show a steady-state. In addition, the same period is used in case of the other policies to ensuring fair comparison. By doing so, the different polices are tested using identical conditions. For each performance indicator independently the best performing policy is shown in green.

Table 4 Results: One year period excl. warm-up period , excl. project B, using 20% holding cost

Ordering Policy type	Current	L4L	EOQ	LUC	Dynamic EOQ			
					Round Down		Round Up	
Sub type	-	-	-	-	UB 104	UB 84 wk	UB 104	UB 84 wk
TRC								
Setup cost								
Holding cost								
Deliveries from stock								
Avg. inventory [items]								
Avg. inventory value								

By analysing Table 5, it is evident that the Dynamic EOQ (Round Up, Upperbound 84) policy is advised to be implemented, which induces an improvement of the number of deliveries from stock by approximately xx% when compared to the current policy. Furthermore, this Dynamic EOQ policy resulted in a reduction of approximately xx% in total relevant cost and xx% in setup costs. Consequently, this outcome can be perceived as a win-win situation, offering both higher delivery reliability at lower cost. As a result, HTM-Aerotec can benefit enhanced operational efficiency and improved customer satisfaction using the Dynamic EOQ ordering policy.

Table 5 Delta Results: One year period excl. warm-up period , excl. project B, using 20% holding cost

Policy type	Current	L4L	EOQ	LUC	Dynamic EOQ			
					Round Down		Round Up	
Sub type	-	-	-	-	UB 104	UB 84 wk	UB 104	UB 84 wk
TRC								
Setup cost								
Holding cost								
Deliveries from stock								
Avg. inventory [items]								
Avg. inventory value								

To enhance the ease of comparing the performance of the various policies with respect to the objective function (TRC) and the orders delivered from stock, we included Figure 27. Whitin this graph the best performing policies are located in the bottom left corner. For convenience the Lot For Lot police is excluded.

Figure 27 Ordering Policy results analysis

When the Dynamic EOQ (Round Up, Upperbound 84) policy is implemented, there will be a transition period in which the current policy will still affect the various performance indicators. Therefore, by including this transitional warm-up phase we will get an accurate representation of the expected results that would arise if the New policy is implemented simultaneously across all items at the same time. For this, we use a two year period including the warm-up period, but again excluding the project B.

Ordering Policy results analysis
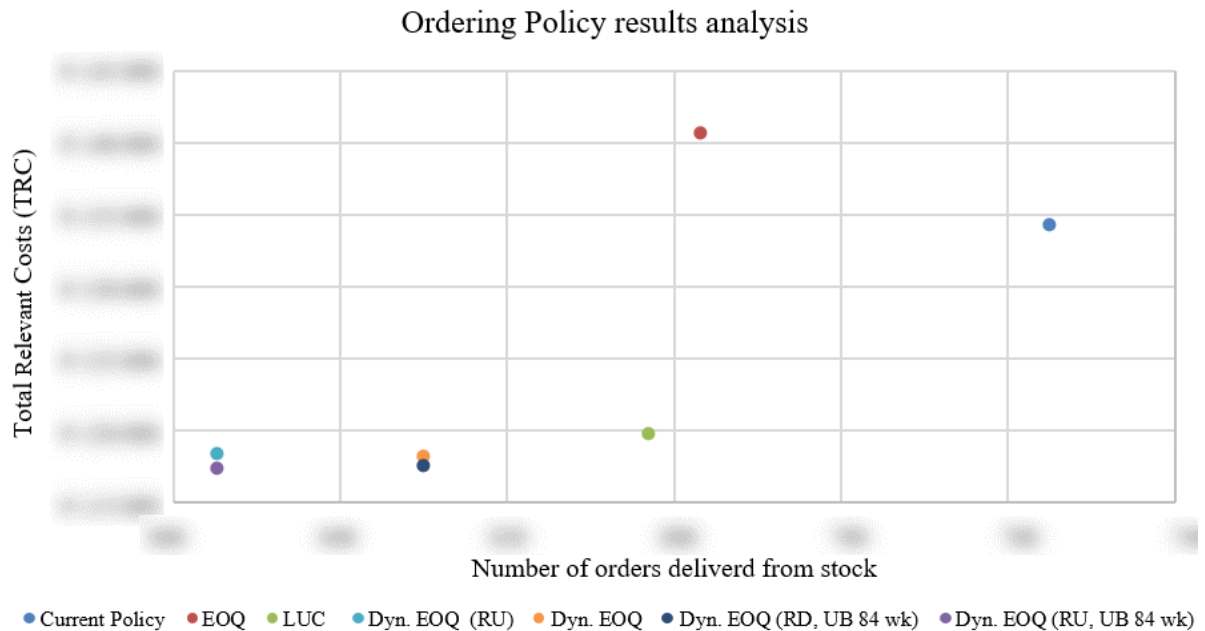
The performance of the various indicators, including the warm-up period, is not as good as the performance when excluding the warm-up period. However, this outcome is expected. Nevertheless, the total relevant cost reduced by approximately xx% instead of the xx% in case of the performance excluding the warm-up period. Below you will find the results of the other performance indicators.

Table 6 Results: Two year period including warm-up period, excl. project B, using 20% holding cost

| Policy type	Current	L4L	EOQ	LUC	Dynamic EOQ			
					Round Down		Round Up	
Sub type	-	-	-	-	UB 104	UB 84 wk	UB 104	UB 84 wk
TRC								
Setup cost								
Holding cost								
Deliveries from stock								
Avg. inventory [items]								
Avg. inventory value								

Table 7 Delta Results: Two year period including warm-up period, excl. project B, using 20% holding cost

Policy type	Current	L4L	EOQ	LUC	Dynamic EOQ			
					Round Down		Round Up	
Sub type	-	-	-	-	UB 104	UB 84 wk	UB 104	UB 84 wk
TRC								
Setup cost								
Holding cost								
Deliveries from stock								
Avg. inventory [items]								
Avg. inventory value								

5.2.3. SENSITIVITY ANALYSIS

Since the holding cost rate is the only input parameter in the model that is an estimate, we conducted a sensitivity analysis ranging from 10 to 30 percent. It is worth noting that according to literature the holding cost should be between 15 to 30 percent as a rule of thumb. In case of HTM-Aerotec, as discussed in Section 4.4.3, the estimated holding cost rate is determined to be 20 percent. Logically, the sensitive analysis is performed from 10 to 30 percent using incremental steps of 2,5 percent as can be seen in Figure 28.
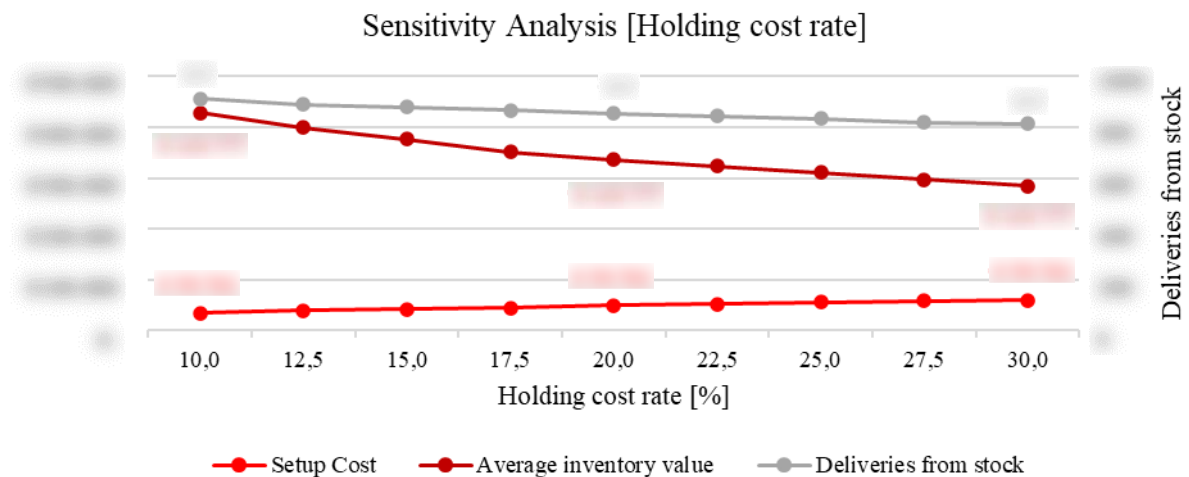
Figure 28 Sensitivity analysis on holding cost rate for the Dynamic EOQ (RU, UB 84 wk) ordering policy

When analysing the sensitivity graph, a clear correlation becomes apparent: as the holding cost rate decreases, both the number of deliveries from stock and the inventory value increase. Thus, the holding costs parameter could also be utilised to intentionally increase or lower the lot-size. HTM-Aerotec can weigh up the extent to which an increase in the inventory value outweighs the number of deliveries from stock. It allows them to tune the lot-sing in order to meet industry standards or targets set by the management.

5.3.   VERIFICATION & VALIDATION

Verification and validation are essential steps in the development and implementation of the forecast conversion tool and ordering policy optimisation tool. Verification ensures that the model is correctly implemented, while validation assesses its accuracy, reliability, and performance. In case of the forecast conversion tool we can conclude that it is already implemented and included in the standard business procedures and thus is tested against real world data. In addition, prior to implementation, a comparison is conducted between the outcomes of the new tool and the results obtained from the previous tool. This assessment ensured that any unexpected results were avoided, thus paving the way for a seamless implementation process. The first period after implementation could be considered as a test phase. No problems were encountered during this period, apart from the fact that the tool is expanded with a filter that proved useful following this test period. With this filter function specific projects can be excluded from export.

In case of the ordering policy optimisation tool we can conclude that we used all the forecast conversion tool infrastructure and functionalities for this tool again, such that the input data is in line with the forecast demand data present in the ERP system. In addition, the extra functionalities required for the optimisation tool such as the simulation of the ordering polices including workorders, sales orders, forecast consumption and CPO's are visually displayed which allows for quick and easy evaluation. We also added line graphs which help identifying mistakes. However, the results can mainly be validated and verified because we also simulated the current policy, which we compared with the results of the ERP system. If we are able to correctly simulate the current policy and use the same technique and functionality for the optimized policies, we assert with a high degree of confidence that the model has been accurately programmed. In fact, we discovered that the order/delivery policy in the ERP system currently was set to five working days instead of seven weekdays, as a result that the order/deliver policy always covered about 30% shorter period than expected. This misunderstanding provides insights into the reasons why the desired outcome of the current policy was not achieved.

6. CONCLUSION & RECOMMENDATIONS

This chapter includes the conclusions and recommendations of this research. first the answers to the research questions are presented in Section 6.1, followed by the research limitations in Section 0. Subsequently the recommendations regarding the future research are described in Section 6.3. Lastly, the contribution of this research to theory and the practical significance are presented in Section 6.4

6.1. CONCLUSIONS

The primary goal of this research is to gain knowledge on what opportunities are available in order to minimise the total relevant setup and inventory holding cost for the forecast driven items at HTM-Aerotec by optimising the ordering policy. However, in order to do so we first solved two other forecast related observed problems. Solving these observed problems will ensure that the forecast data is reliable and ready to use as input for the main purpose of this research; the optimization of the ordering policy itself. Starting with main research question A:

"How can HTM-Aerotec <u>reduce the time required</u> for transforming and transferring forecast data to Glovia, while also <u>mitigating the risk of human error</u> during this process?"

To support the process of answering main research question A, we discus the sub questions one by one. In answering the first sub question *"How are the customer forecasts currently transformed and transferred to Glovia?"* we conducted a context analysis regarding the current situation at HTM-Aerotec. Here we observed that in order to transform and prepare this data for uploading to Glovia, there is currently made use of an Excel file where multiple manual sequential data transformation tasks have to be performed before an CSV file can be transferred to Glovia. These manual tasks are not only time consuming, but also induce the risk of incorrect faulty data to be transferred to the Glovia ERP system due to the fact that the transformation process is exposed to human errors. This faulty data can potentially harm and disrupt the purchasing of raw materials and the production planning.

Based on this context analysis we conclude in case of forecast consumption that forward consumption (rule C and D) are superfluous given the updating process where forecast are replaced by sales order. When comparing the remaining two options; rule A and B we observed that rule A, induces a risk of not consuming a forecast that should be consumed, in contrast to rule B where there is a risk of consuming a forecast that should not be consumed. Since we consider the impact of not consuming a forecast that should be consumed less significant then consuming a forecast that should not be consumed. And given that, it is possible for the planner to logically find the incorrect forecast consumption of rule A where this is impossible in case of rule B since the demand is no longer visible for the planner. We decide to advice using forecast consumption rule A with one additional period (See Section 4.4.3 and 2.3.2 for a more detailed explanation) .

The answer to sub question 2 *"How can the time required for transforming and transferring the forecast data to Glovia be reduced?"* is as follows. In order to reduce the time required for the data conversion we developed a Forecast Conversion Tool using Excel, Power Query and VBA which allows users to convert the customer raw forecast file fully automated in five simple steps. A live data connection with the ERP system that has been specially developed for this purpose is used for this. As a result, manually exporting, copying and pasting data from the ERP system has become superfluous.

In addressing sub question 3 *"How can the risk of human error during transforming and transferring of the forecasts be reduced?"* we used the same Forecast Conversion Tool to reduce the exposure human error during the conversion process. Because preventing erroneous data in the ERP system benefits the accuracy of other business processes that depend on this data input, such as purchasing of raw materials, but above all the production schedule. In addition will the new tool prevent unnecessary time being spent on error handling, which is difficult to measure, but to be expected. To ensure that the tool is fool proof, several security elements have been added such as; the tool is split in five clearly numbered sequential steps including status feedback and message boxes will appear asking the user to confirm input or in case an error has been detected.

In case of the second forecast related problem, main research question B is formulated as follows:

"How can HTM-Aerotec <u>minimise the quantity of forecast data that is omitted</u> by Glovia?"

Two sub questions have been formulated to aid in answering main research question B, starting with sub research question 4 *"What causes Glovia to omit forecast data?"* we have observed that Glovia is capable of handling a maximum of 50 columns when uploading new forecast demand data. Out of these 50 columns, three columns are already dedicated to general information, one column is used for the internal item number and a column for the revision number. As a result, we are left with 45 available columns that can be utilized as forecast due date columns.

In case of sub question 5 *"What measures can HTM-Aerotec adopt to enhance the quantity of accessible forecast data in Glovia"* we developed a systematic approach to generate a dynamic calendar which we incorporated in the Forecast Conversion Tool. It enables HTM-Aerotec to fit 208 weeks/columns of data in 45 weeks/columns. Therefore, we condense the due dates in weekly, 2-weekly, 4-weekly (Monthly) and 13-weekly (Quarterly) time buckets. By doing so, we are able to leverage the benefits of having precise demand data for the near future, while also retaining comprehensive demand data for the more distant future. This enables the planner, purchaser and management with a precise understanding of required demand for the immediate future, as well as a comprehensive overview of future demand trends.

The main goal of this research is to gain knowledge on what opportunities are available for minimising the total relevant setup and inventory holding cost for the forecast driven items at HTM-Aerotec by optimising the ordering policy. An important constraint for this cost minimisation is that the on-time delivery performance should not be negatively affected. To address this main research goal, the primary question of this research is formulated as follows:

"How can HTM-Aerotec minimise the total relevant setup and inventory cost of the <u>forecast driven items</u> by improving the ordering policy without compromising on on-time delivery performance?"

To support the process of answering primary research question C, sub questions are discussed, starting with sub question 6 *"What is the current configuration of the business processes at HTM-Aerotec?"*. To address this sub question, we conducted a context analysis (Chapter 2) where we extensively analyse the relevant business processes associated with forecasts and scheduling. This analysis enables us to identify potential opportunities that could be leveraged for improvement. To finalise the context analysis, an overview of relevant business processes is summarized using a swim lane diagram.

The answer to sub question 7 *"What is presented in literature regarding the problem at HTM-Aerotec?"* is as follows. We can conclude that due to the complexity of the lot-size optimisation problem, various heuristics and approximation algorithms have been developed to find reasonably good solutions within a reasonable amount of time. However, in case of intermitted demand the options are limited, especially when taking in to account the ability to be seamlessly integrated into HTM-Aerotec's ERP system. We are especially interested in the Least Unit Cost heuristic since it is very well capable of handling the intermitted demand characteristics present at HTM-Aerotec. Although most heuristics do not meet the requirement that they should be able to be implemented in the Glovia ERP system, they can serve as valuable benchmarking tools for evaluating lot-size optimization policies which do have the ability to be seamlessly integrated into HTM-Aerotec's ERP system.

Lastly, with regard to sub question 8 *"Which solution method suits best for solving the ordering policy optimisation problem at HTM-Aerotec?"* we developed the Ordering Policy Optimization Tool. Which enables HTM-Aerotec to increase the number of deliveries from stock by approximately xx% compared to the current ordering policy. Furthermore, this newly developed Dynamic EOQ policy resulted in a expected reduction of approximately xx% in total relevant cost and xx% in setup costs. Consequently, this outcome can be perceived as a win-win situation, offering both higher delivery reliability at lower costs simultaneously. As a result, HTM-Aerotec can benefit enhanced operational efficiency and improved customer satisfaction using the Dynamic EOQ ordering policy.

6.2. LIMITATIONS

There are several limitations regarding the outcomes of this research, in particular in case of the ordering policy optimisation tool. Considering the model assumptions, the limitations arise form the data input and forecast uncertainty. For example, the model uses setup cost data from the ERP system. This is assumed to be accurate and correct. However, over the years, multiple manufacturing engineers and various calculation methods have been employed, leading to potential discrepancies in arriving at these costs. Consequently, the data may have a higher degree of unreliability and inaccuracies than intended. Furthermore, it is important to note that the holding cost is an estimation. However, according to the sensitivity analysis conducted, it seems that its impact on the outcomes is relatively minimal, thanks to the robustness property of the Economic Order Quantity (EOQ) model.

Another important limitation of the ordering optimization model is its failure to account for the inherent inaccuracy of the forecast demand data over time during the assessment, in terms of timing of demand and size. Consequently, it is plausible that a fixed lot size policy, for instance, could experience fewer negative consequences than dynamic lot size policies. This implies that the practical performance of the fixed lot size policy might be better than suggested by the current performance analysis. Adding a safety stock could potentially serve as a solution to mitigate this issue. However, there are currently too few raw forecast files available to calculate a reliable forecast accuracy, particularly when dealing with slow-moving products the sample size is often to small. Another option would be to fix the lot/order-size for a CPO once the purchasers has placed the raw material order. This way, any changes in forecasted demand would not result in a new lot/order-size for the upcoming CPO. Consequently, if the demand decreases, there will be surplus of products. Conversely, if the demand increases, the subsequent CPO after the fixed one will be advanced on the planning horizon to the first next demand which can not be fulfilled from stock after which the lot-size is recalculated accordingly.

6.3. FUTURE RESEARCH

Given that the forecast conversion tool is already implemented, a logical progression would be to leverage this new available data in the ERP system using the ordering policy optimization tool. This step enables the evaluation of its functionality and impact, allowing for necessary adjustments to the model and subsequent policy as deemed appropriate. At the same time, the advantages and disadvantages of a dynamic lot-size policy (Dynamic EOQ) can be mapped out.

A potential next step would involve archiving raw forecast files for a minimum duration of one year, thereby facilitating the calculation of forecast accuracy based on a sufficient volume of reliable data. Based on this, it can be determined to what extent applying safety stock to (certain) products can offer benefits and how much additional costs this entails.

6.4. CONTRIBUTION TO THEORY & PRACTICE

The contribution of this research to theory lies in the conversion of the Economic Order Quantity model into a dynamic lot-size ordering policy. The EOQ model has long been used as a popular inventory management technique. However, the EOQ model assumes a static environment, where demand and other factors remain constant over time. The Dynamic EOQ Policy builds upon the EOQ model by introducing a dynamic lot-size ordering policy. This policy takes into account the variability and fluctuations in future demand, allowing for more responsive and adaptive inventory management. This approach, which is not currently described in the existing literature, represents a contribution to the field. By introducing this policy, the developed research expands the existing knowledge base and contributes to the advancement of theory and literature in the field of inventory management. It not only fills a gap in the current literature but also opens up possibilities for future research and practical implementation.

As far as the contribution to practice is concerned, we can tell that Forecast Conversion Tool is already implemented and used by HTM-Aerotec. First and foremost, the tool not only saves valuable time, resulting in cost savings for HTM-Aerotec, but it also provides the company with reliable forecast demand data. It enables the company to leverage the benefits of having precise demand data for the near future, while also retaining comprehensive demand data for the more distant future. Which enables the planner, purchaser and management

with a precise understanding of required demand for the immediate future, as well as a comprehensive overview of future demand trends. Furthermore, the new live data infrastructure offers a multitude of possibilities beyond its primary application. Not only does it enable the acceleration of existing business processes, but it also holds the potential to optimize various aspects of these processes. This new infrastructure empowers HTM-Aerotec to make data-driven decisions and automate repetitive tasks. By continuously analysing this live data, HTM-Aerotec can identify opportunities for cost reduction and operational efficiency such as we do using the Ordering Policy Optimization Tool for example.

BIBLIOGRAPHY

Baker, K. (2009). *Optimization modeling with spreadsheets.* John Wiley & Sons.

Bookbinder, J., & Tan, J.-Y. (1985). Two lot-sizing heuristics for the case of deterministic time-varying. *International journal of Operations & Production Management*, 30-42.

Chopra, S. &. (2021). *Supply Chain Management: Strategy, Planning, and Operation (8th ed.).* Pearson.

Chopra, S., & Meindl, P. (2016). *Supply chain management.* Pearson.

Davies, B. (2017). *First Article Inspection: A Practical Guide.* Springer.

Defeo, J., & Juran, J. (2016). *Juran's Quality Handbook: The Complete Guide to Performance Excellence.* McGraw Hill Professional.

Dessler, G. (2021). *Human Resource Management.* Pearson.

GLOVIA G2. (2023). Glovia user Manual.

Groover, M. (2016). *Fundamentals of modern manufacturing: Materials, processes, and systems (5th ed.).* John Wiley & Sons.

Groover, M. (2016). *Fundamentals of modern manufacturing: Materials, processes, and systems (5th ed.).* John Wiley & Sons.

Karmarkar, U., & Thomas, A. (2017). *The impact of MRP on inventory, lead time, and lot size.* Management Science.

Klaassen, E., & Van der Veen, R. (2017). Metrology in manufacturing: A literature review. *Procedia Manufacturing*, 1146-1153.

Lee, S., & Yoo, S. (2016). The role of the sales department in the era of social media. *Journal of Business Research*, 3401-3408.

McNurlin, B., Sprague, R., & Bui, T. (2009). *Information Systems Management (8th edition).* Pearson.

Monks, J. (2005). *Inventory management: principles, concepts and techniques.* Pearson Education.

PM Group. (2022, 10 4). *PM History*. Retrieved from PM: https://www.pm.nl/en/about-pm/history

Silver, E., & Meal, H. (1968). A heuristic for selecting the order quantity in a multi-item inventory system. *Journal of purchasing*, 54-58.

Silver, E., Pyke, D., & Peterson, R. (1998). *Inventory management and production planning and scheduling.* Wiley.

Smith, J. D. (2021). Advances in Computer-Aided Design and Manufacturing. *Journal of Manufacturing Technology*, 45-56.

Vollmann, T. E., Berry, W. L., Whybark, D. C., & Jacobs, F. R. (2017). *Manufacturing planning and control for supply chain management.* McGraw-Hill Education.

Vollmann, T., Berry, W., Whybark, D., & Jacobs, F. (2017). *Manufacturing planning and control systems.* McGraw Hill Education.

APPENDIX

APPENDIX A. FACILITY LAYOUT

= Automated machines

APPENDIX B. ROUTING ID OVERVIEW AND MACHINE GROUPS

Table 8 Machine/function list including ID, description, department, and Capacity

ID	Description	Department	Capacity [hr/week]

Table 9 Machines/functions ID grouped by department

Department	ID

APPENDIX C. INTERNAL TRANSPORT TIME

Table 10 Internal transport times between machines/departments

Machine/department description	Transport time [Days]

APPENDIX D. SCHEMATIC EXAMPLE OF A CUSTOM VIEW

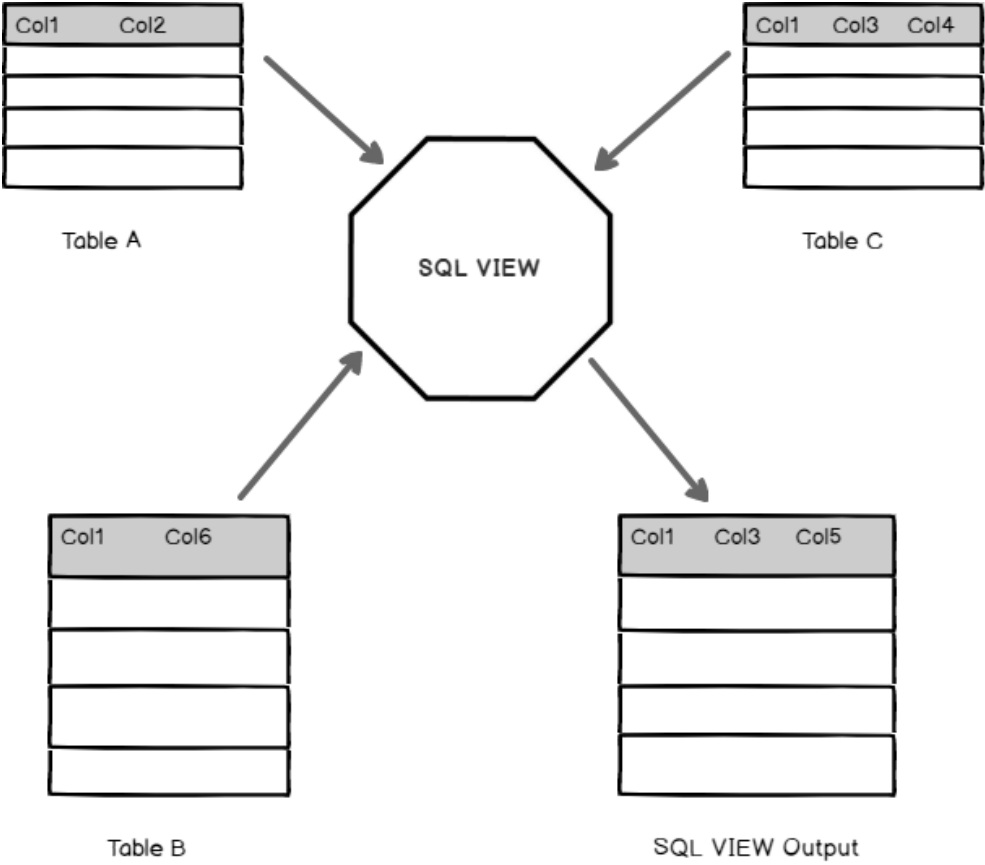**Figure 29 Custom View**

APPENDIX E. EXAMPLE OF THE POWER QUERY ADVANCED EDITOR CODE

Figure 30 Example of the advanced Editor code of Power Query

APPENDIX F. VBA CODE | FORECAST CONVERSION TOOL

```
Dim RngOff As Range
Dim RsfCloseOff As Double
Set RngOff = Range("B4:AI494")
RsfCloseOff = WorksheetFunction.CountIf RngOff, "VF") + ABS  )
Range("AL:AN") = RsfCloseOff  Select
```

```
End With
    .PrintArea = New Check sum
    Sheet1.Pages("Screen_Area_1").Visible = False
    ActiveSheet.Pages("Part_1").Visible = True
    MsgBox "To force the following outcome code numeric are not linked to an external code codes"
Else
    'Everything is old and add was outdated
    'Save Check 1 point
    With Sheet1.Shapes("TABBOARD").Pages("Part_1").Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(48, 255, 0)
        .Transparency = 0
        .Solid
    End With
    'PrintScreen + Show Check out
    Sheet1.Pages("Screen_Area_1").Visible = False
    ActiveSheet.Pages("Part_1").Visible = True
End If

Application.Wait Now + Tio:00:01 AM

End Sub

Sub NetImportFileHash()

    Dim ImportHash As String
    Dim Analog As FileSharing

    'NextScreen + Hide check out
    Sheet1.Pages("Screen_Area_1").Visible = True
    ActiveSheet.Pages("Part_1").Visible = False
    Application.Wait Now + Tio:00:01 AM

    ImportHash = Sheet1.Range("FolderHash").Value

    With Application.FileSharing.netFileSharingFileArchive
        .AllowMacroAccess = False

        'Remove last folder when last stash of FolderHash
        Dim hashTempHash As String
        hashTempHash = Left(ImportHash, InStrRev(ImportHash, "\"))

        .NetworkFileName = hashTempHash
        .New
        If .NetworkFrame.Count <> 1 Then
            .ImportHash = .NetworkFrame.Item(1)
        End If
    End With

    Sheet1.Range("FolderHash").Value = ImportHash

    'Check 1 point
    With Sheet1.Shapes("TABBOARD").Pages("Part_1").Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(48, 255, 0)
        .Transparency = 0
        .Solid
    End With

    'PrintScreen + Show check out
    Sheet1.Pages("Screen_Area_1").Visible = False
    ActiveSheet.Pages("Part_1").Visible = True

End Sub
Sub ImportCSVFiles()

    Dim netImport As Boolean
    Dim dirCSVImport As Boolean

    Dim Import_Path As String
    Dim Nnl_Import As String
    Dim User As String
    Dim DateString As String
    Dim TimeString As String
```

```
```

```
Sheets("VBA.xls").Sheets("Volumes").Visible = False 'Hide sheet

'Show dashboard
ThisWorkbook.Sheets("DASHBOARD").Select
Range("A1").Select

'Check if green
With Sheets("DASHBOARD").Shapes("Check_1").Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(146, 208, 80)
    .Transparency = 0
    .Solid
End With

Shell "explorer.exe" & " " & Output_Path, vbNormalFocus 'Output folder opens

End If

'Scrollstops + More sheets work
Sheets().Shapes("Screen_Stop_1").Visible = False
ActiveSheet.Shapes("Check_1").Visible = True

End Sub
```

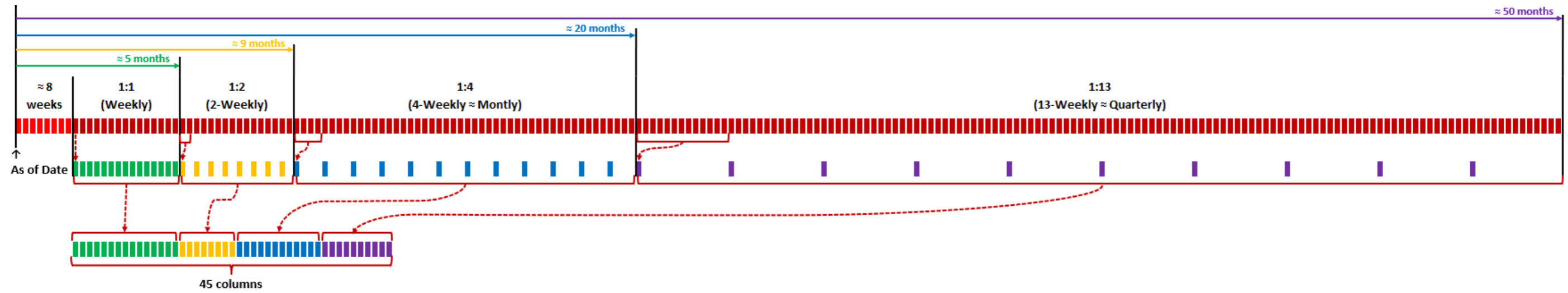## APPENDIX G. COLUMN ALLOCATION ILLUSTRATION

Figure 31 Column allocation for condensed due date

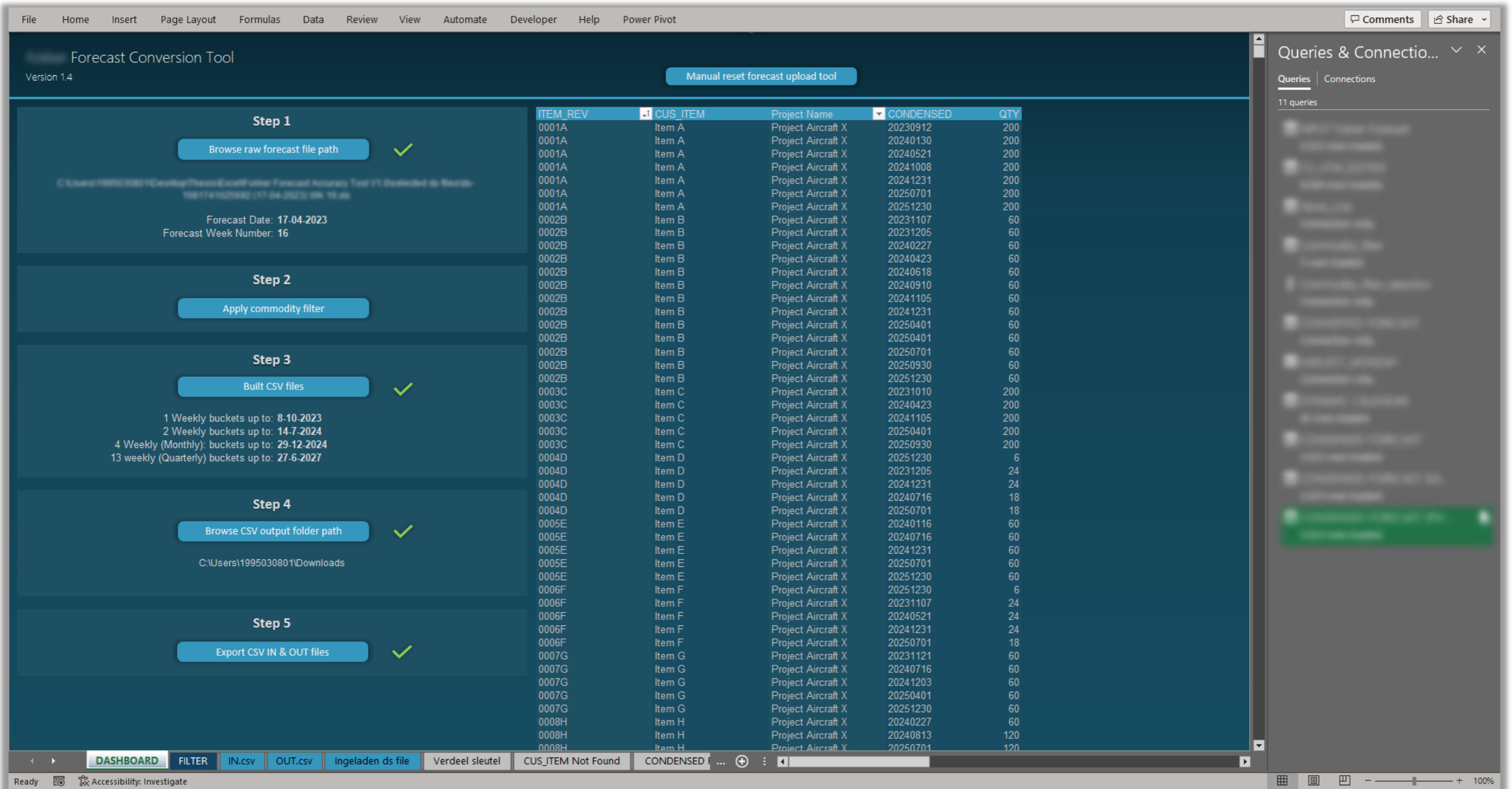# APPENDIX H. MAIN INTERFACE OF THE FORECAST DATA CONVERSION TOOL

Figure 32 Main interface of the Forecast conversion tool

Figure 33 Main interface of the Ordering Policy Optimisation Tool

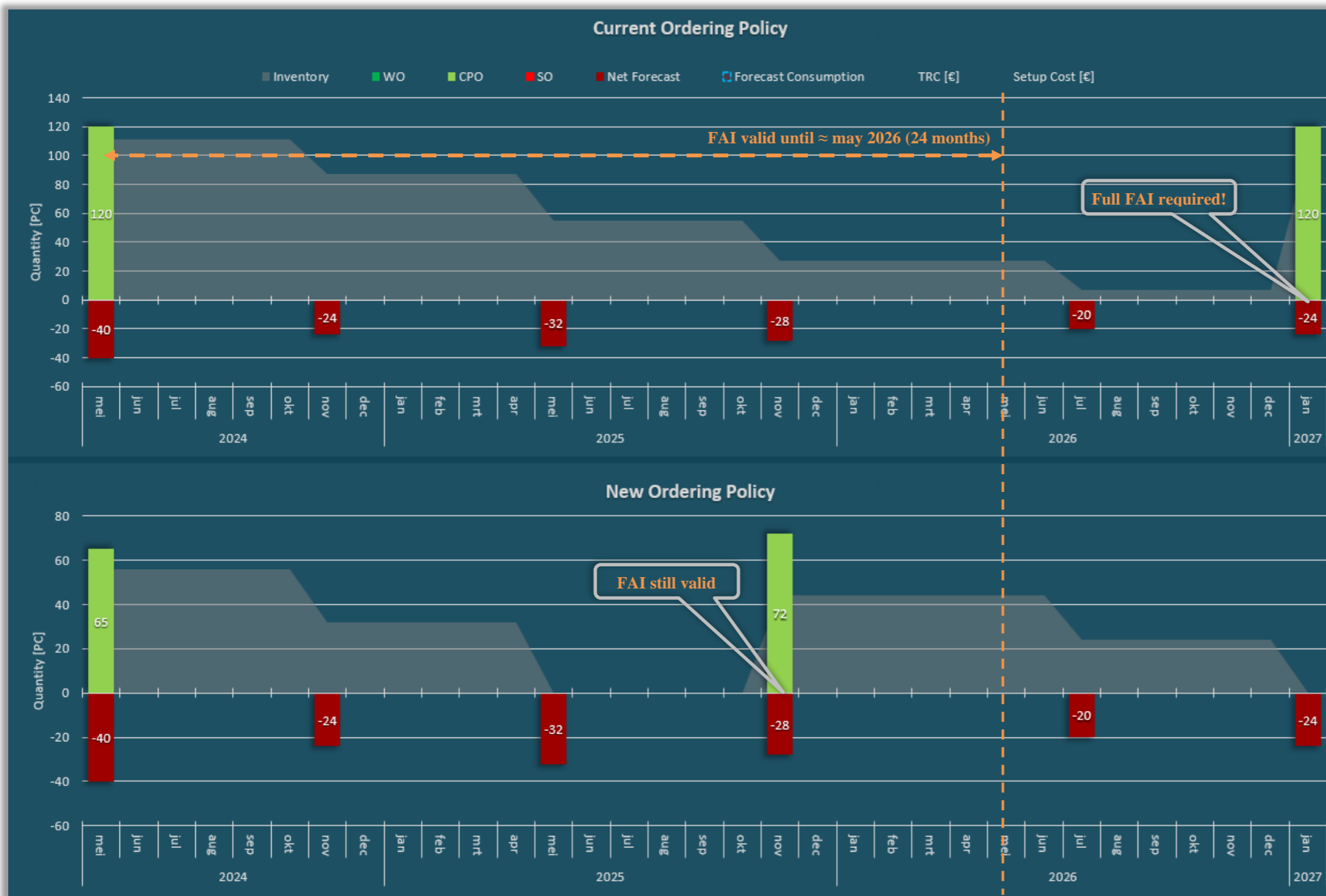## APPENDIX J. FAI EXPIRATION EXAMPLE: CURRENT VS NEW POLICY (DYNAMIC EOQ, ROUND UP, UPPER BOUND 84 WK.)

Figure 34 FAI Expiration Example