MASTER

Including Advanced Scheduled Demand Information in ASML's Forecasting and Planning Framework

Sander, Angelique W.

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Department of Industrial Engineering and Innovation Sciences
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Including Advanced Scheduled Demand Information in ASML's Forecasting and Planning Framework

Master Thesis

A.W.(Angelique) Sander - 1261819

Supervisors:
Prof. Dr. Ir. G.J. van Houtum, TU/e
Dr. Ir. M. Drent, TU/e
PDEng. Ir. J. Stip, ASML
Ir. C. van Cooten, ASML

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Abstract

ASML produces and delivers machines and provides service-level agreements to ensure the uptime of the machines. To maintain machines, spare parts are required. ASML uses a spare parts forecasting and planning model to determine the optimal base stock levels for the spare parts in their warehouses. Currently, ASML considers all service after-sales demand as unscheduled demand. However, Customer Service (CS) and Development & Engineering departments have indicated that there are planned maintenance activities. The service forecasting and planning team of ASML wants to include Advance Demand Information (ADI) about scheduled demand in their spare parts forecast and planning. To design a method to reach this goal, semi-structured interviews are performed. The interviews have revealed that ADI is available within the different teams of ASML, but it does not always have the following characteristics: timely, accurate, available, and complete. As a result, it can be concluded that teams within ASML have imperfect ADI.

Subsequently, a concept design to use this imperfect ADI was developed. The opportunities for including the ADI in the forecast and planning were discussed. Before the detailed design was formulated, the imperfect ADI provided in the interviews was verified using historical usage data. Unfortunately, the ADI given did not match the usage of the parts in the data. As a result, requirements for the ADI were given to ensure data quality in the future. From now on, an assumption is made that the ADI in the future meets these requirements.

The detailed design explains the planning and forecast method in dept. In summary, the parts used for scheduled maintenance activities, with ADI known more than three weeks in advance, are stored in the global warehouse instead of the local warehouse. The CS local teams can indicate which maintenance will be performed, but not the exact moment. Therefore, the parts should be temporarily stored locally and reserved for the specific maintenance activity of a customer to ensure the waiting time and Customer service degree commitments. The order fulfillment process and the restricted customer-specific storage location will manage this reservation.

To conclude, this reservations method results in less stock in the local warehouses, fewer emergency shipments, and flexibility for the customer service engineers to perform maintenance within an interval instead of on a date. In addition, the priority, for scheduled maintenance, in the order fulfillment process will lead to an incentive for CS teams to communicate the scheduled maintenance information with other teams.

Preface

Dear reader,

This Master Thesis Project is the final step in completing my Master's Degree in Operations Management and Logistics at Eindhoven University of Technology (TU/e). Overall, the process of conducting and writing this thesis has been challenging, but I have gained a lot of knowledge, and I am proud of the result. The project was conducted within the Service Forecasting and Planning team at ASML. During my time at ASML, many people supported me and provided knowledge to complete this project successfully. Therefore, I would like to express gratitude towards those who helped me during my Master's Thesis Project and my student life in general.

I would like to thank my university supervisors for their guidance and academic input throughout the project. Especially, I would like to express my appreciation to my first supervisor, Geert-Jan van Houtum, from the TU/e, for his time and support. I am grateful for our valuable discussions on the use of Advance Demand Information. Your experience in the field of service supply chains was a crucial aspect of this project. Additionally, your feedback and critical questions motivated me to improve my research quality. Furthermore, I would like to thank my second supervisor, Melvin Drent, for his valuable insight. Your open-minded view on the research was of great value during our meetings. Thereby, your constructive feedback greatly contributed to the quality of the report.

In addition, I am grateful for the opportunity to conduct my Master's Thesis Project at the world's leading manufacturer of chip-making equipment. Therefore, I would like to thank Joan Stip for giving me the opportunity to perform this Master's Thesis Project at ASML and for creating an environment where I felt really part of the team. During our meetings, the valuable discussions and feedback helped me keep the focus during the project. Furthermore, I would like to thank Cas van Cooten for sharing his expertise on the service forecast and planning processes. Next, I would like to thank all the employees who participated in the interviews for their open attitude and time. Additionally, I would like to thank my colleagues from the Service Inventory Management team at ASML for making me feel welcome.

Lastly, I would like to thank my family, boyfriend, and friends for their unconditional support during this project and my academic career. I feel blessed that I grew up in this supportive environment where they encourage me to be the best version of myself. Thank you all!

Angelique Sander,

Eindhoven, February 2023

Executive Summary

ASML is a company that designs, builds, and services machines for the semiconductor industry. The lithography machines produced by ASML form the bottleneck workstation in the multi-stage production-inventory system of the chip manufacturing process of their customers. This means that downtime of ASML's lithography systems has a negative effect on the performance of downstream processes, leading to overall reduced performance for AMSL's customers. To ensure compliance with service level agreements (SLAs), ASML manages a network of service engineers, service tools, and spare parts. The Service Forecasting and Planning (SFP) team is responsible for the tactical planning of spare parts and tools and their positioning over warehouses around the world to meet SLAs and minimize downtime for the customers.

The SFP team aims to minimize the inventory value of service parts and tools while ensuring the SLA is met as cost-efficient as possible. To ensure the service inventory levels worldwide, the SFP team has extensive forecasting and planning methods. This forecasting method uses historical usage data. The forecast is then communicated to service planning, which is divided into global warehouse planning and local warehouse planning. The global warehouse planning ensures the waiting time and Customer Service Degrees for all parts can be met, and the global warehouse (GW) can always deliver stock to the local warehouses. The local warehouse planning sets the base stock levels for the service materials in the local warehouses (LW). This planning is called the SpartAn cycle. The operational planning decision, such as the order fulfillment decision, is made by an automated replenishment system called NORA and GESA.

Assignment

At the moment, the spare parts forecasting and planning model used by ASML considers all service after-sales demands as unscheduled demands, i.e. caused by a failure of a part (Figure 1). This assumption is too generic. The Customer Service (CS) department can give information in advance about the spare parts after-sales demand. This advanced spare part demand information can influence the expected model performance regarding service performance, inventory value, and freight costs. The consequences of only considering unscheduled demand while more information is available about the demand are too much stock for uncertainty, too many last-moment shipments, neglecting service performance potential, and an incident-driven working method. The quality of this Advance Demand Information (ADI) is variable in terms of timeliness, accuracy, availability, and completeness. The SFP team wants to incorporate ADI in the spare part forecasting and planning model. However, currently, there is no method to include scheduled event information in the spare parts forecasting and planning method.

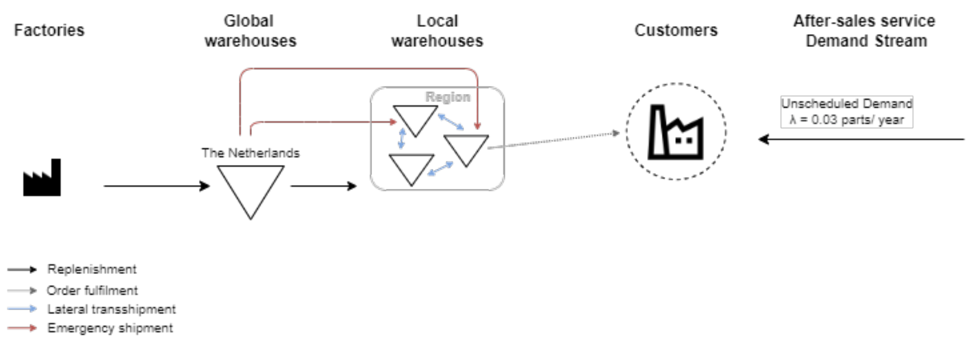

Figure 1: Single unscheduled demand stream situation (As-Is situation)

In this design study, an integrated framework has been developed to include the scheduled maintenance demand stream into the current unscheduled demand service demand forecasting and planning method. The current after-sales demand stream should be divided into a scheduled and unscheduled demand (Figure 2).

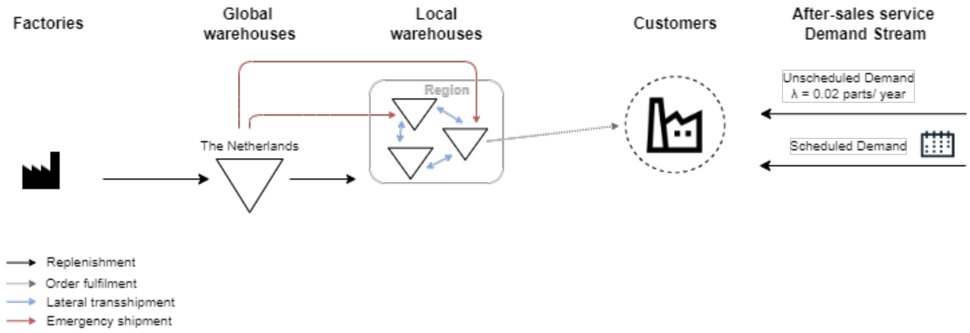

Figure 2: Multi-demand stream situation (To-Be situation)

Current situation & Conceptual design

The first step was to investigate the perspectives on scheduled demand of different teams, the available ADI resources, and the quality of the ADI. This was done by conducting semi-structured interviews with the stakeholders of the service supply chain. The interviews revealed that there is ADI about scheduled maintenance events, but it is not always timely, accurate, available, and complete. Therefore, the first conclusion is that the ASML teams have imperfect ADI about the scheduled maintenance events.

Based on the available imperfect ADI and the current method of forecasting and planning, a conceptual design for an integrated framework was made. In this conceptual design, the opportunities and requirements for the method were discussed. This has resulted in the following concept. The after-sales demand of an SKU consists of three categories: (i) unscheduled demand, (ii) demand of maintenance known less than three weeks in advance, and (iii) demand of maintenance known more than three weeks in advance. For demand category (iii), the Customer Order Decoupling point (CODP) should be located at the GW, and for categories (i) and (ii), the CODP stays at the LW. The local CS teams can provide a fraction of their ADI three weeks in advance, but the exact date the maintenance is performed is uncertain due to external factors such as a limited number of engineers or tools. The planning concept should work as follow: The fraction of scheduled demanded parts should be stored in the GW instead of the LW. The CS local team should provide ADI about when and which parts will be used. Based on this information, a reservation for the part should be created at the local warehouse with an interval around the due date. The GW forecast for these parts should be based on a combination of ADI and historical demand information.

Detailed Design

Subsequently, before the details of the forecast and planning method are defined, the accuracy of the imperfect ADI from CS Local given in the interviews was verified using the historical usage data. Unfortunately, the ADI given in the interviews did not match the usage of the parts in the data. Therefore, requirements for the ADI were given to ensure data quality in the future. From now on, it is assumed that the ADI in the future meets the requirements.

The detailed planning will work as follows: In the As-Is situation, parts for all after-sales are stored in both the local and global warehouses, see Figure 3. In the To-Be situation, only scheduled demanded parts that meet the requirements are given in the figure. When a maintenance activity has been planned, a reservation for a part on a local stock point should be created. This reservation is created from two weeks before until two weeks after the due date. The reservation is restricted to a specific customer and locked when the part is at the local warehouse. When the part is used for the maintenance event, the temporary local stock point is removed from the local warehouse. The execution of this method will influence the order fulfillment rules. When a customer has both an unscheduled and a scheduled demand for a part, the customer can choose to use the locked part, while another customer can not use the customer-restricted locked part. This will result in an incentive for Local CS to manage their ADI.

Figure 3: Detailed design supply chain

The reservations method results in less stock in the local warehouses because the stock is only temporarily stored locally, which will result in lowering the holding cost. Fewer emergency shipments are expected because the ADI ensures the parts can be sent earlier on a routine shipment, which is advantageous for transportation costs. Additionally, due to reservations for a period instead of service orders on a specific date, the CS engineers are more flexible in their maintenance planning. Furthermore, the priority in the order fulfillment process will lead to an incentive for the CS teams to communicate the scheduled maintenance information with other teams. If all the parts needed for the maintenance are locally stored, the CSD and WT performance is expected to improve. On the other hand, the forecast process becomes more complex, the operational planning becomes more work-intensive, the planning depends on the accuracy of the information provided by the CS teams, and there is less pooling of local parts.

Conclusion & Recommendation

In conclusion, the advantages outweigh the disadvantages of the reservation method. It can be concluded that integrating ADI in the spare part forecast and planning process with reservations provides ASML with a stock solution that is not only based on historical demand information but also includes the knowledge and plans of the customer service experts in the field. For ASML, the main recommendation is first to improve the ADI quality. Future research should test the effect of the reservations on the local warehouse planning with the operational planning system.

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List of Abbreviations

Abbreviation	Definition
ADI	Advance Demand Information
ASML	Advanced Semiconductor Manufacturing Lithography
BOM	Bill Of Materials
CODP	Customer Order Decoupling Point
CS	Customer Service
CSCM	Customer Supply Chain Management
CSD	Customer Service Degree
CPA	Central Parts Availability
DAL	Demand Allocation Lead
D&E	Development & Engineering
DUV	Deep Ultraviolet
EUV	Extreme Ultraviolet
FMA	Field Material Availability
GESA	Global Emergency Sourcing Automation
GOC	Global Operations Center
GPA	Global Parts Availability
GW	Global Warehouse
IFR	Increasing Failure Rate
LPA	Local Parts Availability
LW	Local Warehouse
NORA	Network Oriented Replenishment Automation
OEM	Original Equipment Manufacturer
ONE	Our New Enterprise
PDL	Pre defined list
PLM	Product Lifecyle Managment
ROP	Reorder point
SFP	Service Forecasting and Planning
SM	Service Management
SPartAn	Spare Part Analyzer
SLA	Service Level Agreement
SLOC	Storage Location
SSL	Safety stock level
TSMC	Taiwan Semiconductor Manufacturing Company
UI&R	Upgrade, Install & Relocation
WT	Waiting Time

Introduction

In the semiconductor industry, ASML is the world's leading Original Equipment Manufacturer (OEM) of lithography systems, which are an essential component in a chip manufacturing process. For ASML to maintain its leading global technology position in the semiconductor industry, it must keep innovating to provide its customers with a high level of service. The implementation of advanced lithography technology requires large investments from customers. Moreover, the unavailability of lithography systems usually brings an entire production process to a standstill, resulting in serious economic losses. Therefore, to ensure the uptime of the systems, a good maintenance policy is required. When a system breaks down, a corrective maintenance action is needed as soon as possible. Part of the unavailability time consists of waiting for the required spare parts and service tools to become available. Considering the high downtime costs, the relevance of having the right materials available at the right time for the right costs is evident. ASML and its customers draw up service-level agreement-based service contracts to limit the negative consequences of downtime. Failure to meet these agreements results in penalty costs and reputation damage for ASML.

The availability of spare parts is the focus of this master's thesis study. This is the responsibility of the Customer Supply Chain Management department (CSCM). The department operates a global network of warehouses where spare parts and service tools are stocked to meet the availability commitments. Within the CSCM organization, the Service Management(SM) department is responsible for deciding on strategic and tactical supply chain settings and optimizing processes such that other departments can deliver the agreed-upon Service Level Agreements (SLAs) at minimal costs. In this department, the Service Forecasting and Planning team (SFP) drives and develops the primary CSCM planning processes to ensure an efficient service supply chain by 'State of the Art' planning methodologies and processes. The SFP team has two main tasks;

- Providing insights into the expected future demand for spare parts and service tools (material demand forecasting);
- Determining and setting target stock levels for spare parts and service tools at ASML's warehouses (material demand planning) (Aerts, 2022)

This report describes the design process of a method to include schedule advance demand information in the current forecasting and planning framework. The design process has been split into three main phases: a scoping phase, a design phase, and an integration phase. Due to the time constraints of this master thesis project, this study focuses on the first two phases of the design study. The design phase consists of the development of a conceptual and detailed design.

In the first chapter, ASML and the SFP team are introduced. Subsequently, the second chapter defines the problem by a problem context and problem statement. The third chapter starts the design process with the scoping phase. This scoping phase includes the functional and design requirement of the design. In the fourth chapter, an analysis is made of the available ADI and the communication flows of this information.

With this information in mind, the conceptual design is formulated in Chapter 5. In this conceptual design, the trade-offs for each design parameter are discussed, and for each parameter, a design decision has been made. Eventually, this led to the basis of the detailed design in Chapter 6. Before the detailed design is formulated, the requirements for ADI are given. Subsequently, the integrated framework for including the ADI in the forecasting and planning is given. Finally, in Chapter 7, the conclusion is formulated, and recommendations for ASML are made for further research and development of the process.

Chapter 1

Service Forecast & Planning

In this first chapter, an introduction to ASML is given in Section 1.1. After that, in Section 1.2 a description of the service supply chain of ASML is given. This section highlights the differences between parts and tools and the different service demand types. Subsequently, the tactical forecast and planning method of ASML is discussed in respectively Section 1.3 and 1.4.

1.1 Company Background

ASML was founded in 1984 as a joint venture between Philips and ASM International. Over the years, ASML has become the world's leading provider of advanced lithography systems for the semiconductor industry. its main customers include the world's leading chip manufacturers, such as Samsung, Intel, and Taiwan Semiconductor Manufacturing Company(TSMC). ASML does not only design and manufacture lithography machines but also integrates and services them. Currently, ASML employs more than 32,000 people in full-time equivalents across more than 60 cities in 16 countries. The majority of the employees are based at the headquarters located in Veldhoven, the Netherlands (ASML Holding N.V, 2022a).

ASML produces various types of advanced systems that either use Deep Ultraviolet (DUV) or Extreme Ultraviolet (EUV) lithography. The company also refurbishes its older systems to ensure they perform to their original specifications. The guiding principle at ASML is to continue on Moore's Law towards smaller, cheaper, more powerful, and energy-efficient semiconductors. Moore's law predicts that the number of transistors on an integrated circuit doubles every two years. Driven by Moore's law, ASML continues to improve its entire system portfolio to achieve new levels of productivity and imaging performance while keeping the costs affordable (ASML Holding N.V., 2022).

ASML's business strategy involves close cooperation with suppliers and customers. As a result, after-sales events become increasingly important for ASML to gain a competitive advantage. An important part of the after-sales activities at ASML involves service operations and system maintenance. This is described as service and field option sales and accounted for almost €5.0 billion of the €18.6 billion turnovers in 2021 (ASML Holding N.V, 2022a). Therefore, after-sales services are not only valuable for competitive advantages but also generate remarkably high direct revenues.

The lithography machines produced by ASML form the bottleneck in the multi-stage chip manufacturing process for their customers. Downtime of ASML's systems can negatively impact the performance of downstream processes and result in reduced performance for customers. Due to the high cost of downtime, which can cost customers thousands of euros per minute (ASML Holding N.V, 2022b), it could be stated that the service provided by ASML is critical to its customers.

ASML has service contracts with its customers, including strict Service Level Agreements (SLAs). These agreements guarantee a specific availability of an installed base. When ASML fails to meet the agreed-upon target, a considerable amount of penalty costs must be paid to the customer. To be able to meet the SLAs, ASML manages a network of service engineers, service tools, and spare parts.

1.2 ASML's Service Supply Chain

ASML operates a network of global and local warehouses which together form a multi-echelon network that includes lateral transshipments (i.e. shipments between two nearby local warehouses) and emergency shipments (i.e shipments with a shorter lead time than regular order fulfillment). The service network of ASML is illustrated in Figure 1.1.

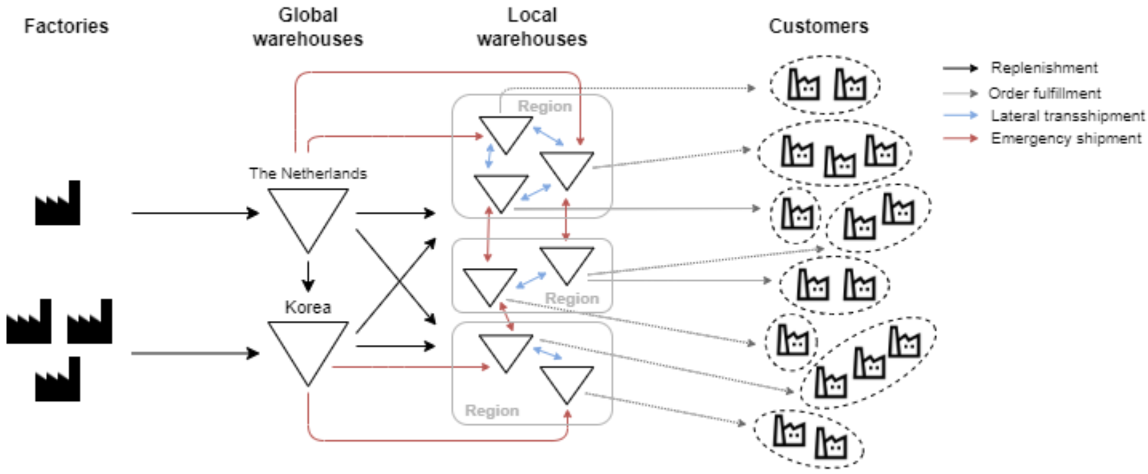

Figure 1.1: ASML's service network (Aerts, 2022)

The service network currently comprises two global replenishment warehouses and a set of local warehouses. The global warehouses (GW) act as an inventory buffer between the factories/suppliers and the local warehouses (LW). The inventory at the global warehouses, which serve as a main warehouse for replenishment purposes, is mutually exclusive. Most service parts and tools are sourced in Europe and stocked in the global warehouse located in Veldhoven. The remaining parts and tools are sourced in the United States. These service materials are stocked in the global warehouse located in Korea. Besides being a replenishment warehouse, the global warehouse in Korea also serves as a worldwide emergency hub in case of stock-out at a local warehouse. Therefore, this global warehouse also stocks at least one part of every service material for emergency shipment purposes (Aerts, 2022).

Depending on the type of contracts, the set SLAs, and the customer served from that warehouse, the Service Forecast and Planning team (SFP) of ASML positions the different spare parts and service tools at the different warehouses. Each plan group is assigned to a single warehouse (a plan group consists of one or multiple systems of ASML installed at the same customer and the same factory of that customer). Orders are always fulfilled from this dedicated warehouse when the requested material is available. For customers with low utilization plants and less strict SLAs, longer downtime of the system is acceptable. Therefore, in that case, the dedicated warehouse of ASML could be located further away from the customer's plant. However, for customers with relatively high system utilization and strict SLAs, the transportation times of a spare part or service tool significantly impact the up-time of the system. Consequently, ASML desires to shorten the delivery times effectively by operating local warehouses close to the plants of these customers.

Within this service network design, the emphasis is on transportation times. For every plan group a set of supporting local warehouses is defined that is capable of supplying within a pre-agreed time. These local warehouses together form a region, supporting each other through lateral transshipments. A local warehouse could only be part of one region. In case the requested material is out of stock at the dedicated local warehouse, a lateral transshipment from another nearby local warehouse could be performed. In case the requested material is not available at one of the local warehouses within the region, it is checked whether the material could be delivered from another local warehouse or one of the global warehouses through an emergency shipment. As a final recourse or alternative, the part could be delivered from one of the factories; however, this could potentially disrupt the production process of new ASML machines (Aerts, 2022).

1.2.1 Service Parts and Tools

The complex systems produced by ASML are composed of thousands of parts. However, not all of these parts are within the scope of ASML's service supply chain. The Development & Engineering (D&E) department defines a list of service parts for each system; these parts have the potential to fail or degrade and may need replacement in the field. This list, referred to as the service Bill Of Materials (BOM), also includes the parts that could be damaged or lost during service actions and may need to be replaced. For the set of parts that are classified as service parts, spare parts are kept in stock which can be used to repair or replace failed units in an installed base. In addition to spare parts, the service supply chain includes service tools required for maintenance. According to Vliegen (2009), service tools are all tools used during a machine's repair, for instance, diagnostic and calibration tools. Both service parts and tools have similar and dissimilar characteristics. A similarity is that they are kept in stock and used for service activities. The most important dissimilarity is that service parts are consumed, whereas service tools are used. This means that a service tool will, in most cases, return to the supply chain after it is used. After a service tool has been used, it may need to be cleaned, calibrated, or certificated before it can return to stock. For this research, the focus will be on spare parts.

1.2.2 Service Demand Types

The total service stock should fulfill multiple types of service demand. There are three types of service demand; After-sales, Upgrades and Installs, and Sales. An overview of the service demand is given in Table 1.1

- Sales are parts that the customer buys in addition to their service contract to improve the machine's performance. Sales demand could be known in advance as short-term (e.g., one day) and long-term (e.g., one year). ASML does not have an SLA on the delivery of sales parts.
- The second category is the Upgrades, Installs, and Relocation (UI&R) of machines. These actions are always planned and should be known before the UI&R pool size run, a quarterly control moment to arrange the parts and tools for the UI&R actions. Because the UI&R demand is always known beforehand, the parts and tools are only stocked in the global warehouse. The UI&R demand is therefore considered separately in the tactical forecast and planning.
- Lastly, the After-sales service demand, this is demand caused by maintenance actions such as breakdowns or periodic replacements of parts. The after-sales demand is assumed to be unscheduled.

Table 1.1: Service demand types

Service demand	**Unscheduled/ Scheduled**
After-sales	Unscheduled
Upgrades, Installs, and Relocation	Unscheduled
	Scheduled
Sales	Unscheduled
	Scheduled

The Service Forecasting and Planning team determines the safety stock levels and base stock levels for service parts and tools at the local and global warehouses. This decision involves balancing the need to meet agreed upon service levels with the need to keep inventory, stock-out, and obsolescence costs as low as possible. The SFP team addresses this trade-off by using the spare part inventory model as derived by Van Houtum & Kranenburg (2015). Their logic is used in a multi-item multi-echelon algorithm which helps to propose base stock levels for all service parts in scope. The most important input parameters for this algorithm are the service network structure, service level agreements, spare part cost prices, and spare part demand rates. The SFP team is split into two parts: the Service Forecasting team, which is responsible for generating the spare part demand forecast, which is the most important driver of the planning process, And the Service Planning team, which is responsible for determining the stock levels. The following sections will provide further details of these processes.

1.3 Service Forecasting

Forecasting spare part demand within ASML is a complex task. Unlike other industries, ASML services a relatively low number of machines but has a large number of spare parts defined. Additionally, ASML's systems are highly reliable. According to the research of Lamghari-idrissi (2021), 88% of the spare part demand at ASML is classified as "lumpy demand". As described by Cavalieri et al. (2008), Lumpy demand is characterized as 'demand for which there are many periods with zero demand and demand sizes will be highly variable when it occurs. According to the research of Van den Oord (2021), the selection of spare parts with forecast information could be indicated as "intermittent demand". Intermittent demand, as defined by Cavalieri et al. (2008), is characterized by random occurrence with many periods having no demand, but when it occurs, the demand size is stable. Both resources highlight that the demand timing is highly variable. Due to these characteristics, the forecast of spare parts is complex.

The spare part forecast at ASML is based on historical demand data. The data is based on internal documentation, where the field engineer records the need for a part and indicates whether or not the part was used during maintenance events. This information is used to enrich the bill of material per service action. The historical data is collected for the past twelve quarters, and the demand data is divided per quarter by the size of the installed base in that period to retrieve the demand rate per system per quarter. An exponential-weighted moving average methodology is used to predict the demand rate for the upcoming quarter, where the most recent observations are given the most weight. This usage rate per platform is multiplied by the sum of the current and future installed base for the upcoming eight months. This process is detailed in Appendix A.

After the initial forecast is created, it is refined through multiple steps, including re-balancing towards regional trends, review and enrichment with expert knowledge, and optimization of parameters in the exponential smoothing process. For a mathematical explanation of the forecast and more details on the enrichment steps used in ASML's forecasting process, we refer to Van den Oord (2021). This process is only applicable when historical demand data is available. However, when there is no historical demand data, the Initial Failure Rate (IFR) must be provided by the D&E team. As more demand data becomes available or the installed base grows, the forecasting team will transition to a historical demand-based forecasting approach.

1.3.1 Forecast types

To plan for the service demand, a service forecast is created. The total service forecast for a part can be split into five forecast types based on the different service demand types. These forecast types are taken into account differently in operational and tactical planning. The sum of the five types is the total forecast of a part. The five types are;

- **Forecast -** The forecast of parts confirmed as used.
- **Diagnostic Forecast -** The forecast of parts indicated as required but subsequently not used.
- **Factory Forecast -** Sometimes parts are needed as service parts that are not yet defined as service parts, or in the past, a factory part was used for service because the comparable service part was not available. These parts have a different prefix than service parts. The forecast for these parts is determined in the same way as the Forecast type.
- **Additional Demand -** Occasionally, additional information about the future demand reaches the service forecast team. This forecast could be added manually to the total forecast.
- **Upgrades, Installs, and Relocation's (UI&R)-** The UI&R forecast is determined differently. The usage rate is defined in one of two possible ways. In the first situation, the historical usage rate is compared with the information on the pre-defined list (PDL) of parts needed for the UI&R events. With this information, a triangular distribution is created with the likeliness of the number of parts used. A second possible way is when there is no historical information the usage is based on the PDL. (See this process in the lowest part at the Figure in Appendix A)

The proportion of the sum of all items per forecast type is given in the blue bar in Appendix A. The maturity of the forecast had forecast type: Forecast, followed by the diagnostic forecast and the UI&R. The forecast, diagnostic forecast, and factory forecast for the upcoming month a forecast is calculated for over eight months. For example, in December the team calculates the forecast for January based on the install base of Augustus. The UI&R and Additional demand forecast for January are based on the install base of January. The forecast is calculated in this way because the forecast is taken into account in the local warehouse planning. This run in done two times per year for the upcoming eight months. To ensure the install base in the total period is covered the forecast is calculated for over eight months, Further explanation of the LW planning will be described in Section 1.4.2. For the global warehouse run, this same eight months correction for the install base is taken into account. This method is questionable because the global warehouse run is performed monthly.

1.3.2 Timeline of the forecast

The Service Forecast team delivers forecasts at different moments and in different formats. Firstly, each Monday morning, a weekly forecast report is created. This forecast is used as an input file for the operational planning in the Network Oriented Replenishment Automation (NORA) system and the Field Material Availability team (FMA). The information in this file is given per forecast type, plant, platform (e.g., NXE or NXT machine platform), demand rate group, material type, and forecast per month/ per part.

The monthly forecast is used for global warehouse planning. This forecast information is similar to the weekly forecast, but it also includes information for the upcoming eight months about the growing install base, as explained above. The last forecast type is a bi-annual made forecast. This forecast is used for the tactical planning process of the local warehouses. This forecast is very specific, namely forecast per day/per part/per machine. This last type of forecast is provided for the upcoming eight months because the local warehouse planning is a bi-annual process, and the update of the local stock levels is two additional months reserved. More information about the time intervals will be described in Section 1.4.3.

1.4 Service Planning

The tactical service planning is carried out by the Service planning team. In recent years, much research has been conducted into the development of ASML's service planning algorithm. The customized spare part planning model is based on the study of Kranenburg (2006). He concluded that it is beneficial to use partial pooling with lateral transshipment which led to the supply chain network represented in Figure 1.1. Subsequently, research efforts have been made by Vliegen (2009), Van Aspert (2015), Lamghari-idrissi (2021), and Aerts (2022). Van Aspert (2015) decomposed the service network of ASML in two single-echelon models, where the global warehouses are one echelon and the local warehouses are the other echelon. The two single-echelon models are referred to as global warehouse planning and local warehouse planning, respectively. The echelons are coupled through the replenishment lead time. The global warehouse planning is executed every month, while the local warehouse stock planning (also referred to as SPartAn, i.e., the SpareParts Analyzer) is only executed biannually.

In the following sections, first, the tactical global warehouse planning and the local warehouse planning will be explained. After that, a section will be dedicated to the timeline of these plannings. Finally, the operational planning of the spare parts and tools is explained.

1.4.1 Global warehouse planning

The global warehouse planning is executed monthly. Whenever a demand occurs at the global warehouse (i.e., an emergency shipment or replenishment to local warehouses), replenishment from the supplier is triggered to fulfill the base stock levels of the global warehouse. To determine the base stock levels, a constraint is set on either a Waiting Time (WT) or a Customer Service Degree (CSD), fill rate in literature, per Stock Keeping Unit (SKU). The waiting time is the time a customer waits for a part or tool. A constraint is based on the worldwide forecasted usage, which is divided into four categories (A, B, C, & D). Category A classifies SKUs with high forecasted usage, whereas category D has SKUs with low forecasted usage. There are four categories (0,1, 2 & 3), to classify the value of an SKU (in Euros). Category 0 distinguishes relatively cheaper SKUs below 500 euros, whereas, respectively category 1, 2, and 3 distinguish more expensive SKUs. There are in total 16 different objectives that can be set per SKU. With the model of (Van Houtum & Kranenburg, 2015, Chapter 2), the base stock levels, denoted by S_i^{GW}, are determined for each SKU $i \in I$, such that the constraint is met. This model uses a so-called item-approach, where every SKU $i \in I$ is analyzed individually. The GW stock model considers an item approach because the local warehouse planning assumes there is infinite stock in the global warehouse. Global warehouse planning does not consider holding cost in the objective because the constraints are the most important.

$$
\begin{aligned}
&\text{Minimize } S_i^{\mathrm{GW}} \\
&\text{Subject to} \quad && \mathrm{WT}_i\left(S_i^{\mathrm{GW}}\right) \leq \mathrm{WT}_i^{\mathrm{obj}} \text{ Or } \mathrm{CSD}_i\left(S_i^{\mathrm{GW}}\right) \geq \mathrm{CSD}_i^{\mathrm{obj}} \\
& && S_i^{\mathrm{GW}} \in \mathrm{N}_0
\end{aligned}
$$

The CSD base stock level is obtained via the so-called Erlang loss probability. (Van Houtum & Kranenburg, 2015, Equation 2.15) and the waiting time is obtained via the waiting time formula given in (Van Houtum & Kranenburg, 2015, Chapter 2).

The global warehouse planning is executed every month using the latest monthly demand forecast data as input. As explained in Section 1.3.1 there are multiple different forecast categories. The forecast, factory forecast, and additional demand are taken into account as stochastic demand. The lead time considered in this is calculated based on the new buy lead time and the repair lead time and the scrap rate. The diagnostic forecast is probably not used and will return to stock in approximately two weeks. Therefore, the lead time of two weeks will be used. The demand for the diagnostic forecast is uncertain and therefore also assumed to be stochastic. In the last category, UI&R demand is known at least six weeks in advance. Therefore this demand is assumed to be deterministic and taken into account with the weighted average methodology and the lead time calculated in the same way as the first category. This process is graphically presented in Figure 1.2. The forecast per day and the specific lead time are used as input in the model mentioned above. This results in three base stock levels (ROP; Reorder Point), for the global base stock level, the three individual base stock levels are summed. Simplified, it could be stated that the safety stock level (SSL) is equal to the ROP minus the demand during the lead time.

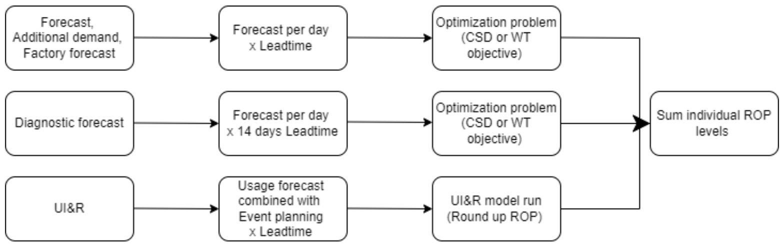

Figure 1.2: Global warehouse planning

1.4.2 Local warehouse planning

Local warehouse planning has a complex approach. Within ASML, this approach is called the SPartAn cycle. As input for this process, the forecast for the upcoming eight months is used. For an extensive explanation of the local warehouses, it is recommended to read the explanation of Aerts (2022). The forecast taken into account in the local planning is every forecast type except the UI&R forecast because the UI&R stock is only stored in the global warehouses (Figure 1.3). Moreover, the lead time of all types of forecasts is assumed to be two weeks, because it is assumed that the local warehouses can always be replenished from the global warehouses.

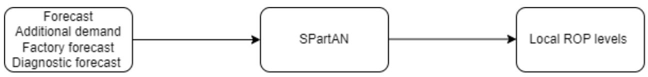

Figure 1.3: Local warehouse planning

1.4.3 Timeline of the service planning

The local and global warehouse stock levels are not adjusted continuously. This has multiple reasons. The main reason for the global warehouse is the fluctuation in stock levels. Too much fluctuation could lead to unnecessary stock changes. For the local warehouse planning, the duration of the planning process is, in total, more than three months. Adjusting the tactical planning more than two times a year will lead to too much workload for the tactical planner. For example, the number of manual information collections and the manual adjustments after the model run.

The stocking planning cycle is performed bi-annually and takes a total time of twelve weeks to complete. The first two weeks are used for, among other things, preparation by the forecast teams to deliver a reliable forecast. Subsequently, the model run is performed, and the adaptation is reviewed and aligned with the field observations. This alignment with the field is the moment of human judgment on forecast and demand enrichment. Discussing the options of adapting the stock and differing from the model output with the local CSCM teams is part of the alignment that makes the task time intensive. Once the new stock levels are approved and uploaded, rearranging the stock takes another two weeks, assuming the global warehouse can deliver the parts. To conclude, the process from receiving the forecast to updated stock levels takes a minimum of

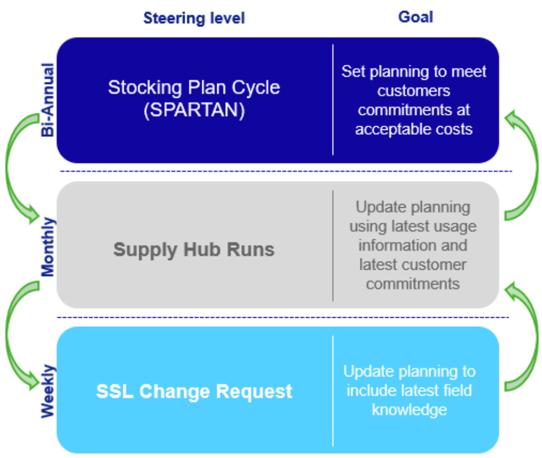

Figure 1.4: Three levels of planning (SFP ASML, 2021)

ten weeks, which means the forecast should cover the next eight months.

The supply hub runs, known as the global warehouse run (Section 1.4.1), are performed monthly. The global warehouse stock levels are updated each month, and the forecasting team delivers the forecast on the Monday of the model run week. After the model run is completed, the new stock levels should order a new supply. The average lead time for DUV and EUV parts is nine and twelve months, respectively.

Local teams have the opportunity to submit an SSL change request on a weekly basis to include the latest field knowledge. The SFP team aims to minimize stock changes but may adjust stock levels if the information is valuable. The three levels of planning are presented in Figure 1.4.
The UI&R forecast is made quarterly to ensure parts are available for upcoming events, expected demand for events for the next eight or nine months should be indicated.

1.4.4 Operational service planning

The operational planning of the service parts is divided into three processes; the replenishment decision, the order fulfillment decision, and the allocation decision. The replenishment decision, represented by the black arrows in Figure 1.1, ensures the stock is on the right level. The replenishment decision is based on the risk of the non-availability of a part. The order fulfillment decisions, represented by the grey arrows in Figure 1.1, determine which stock item will be used in the local stock planning when a customer has demand. For this fulfillment of demand, in each plan group, a pre-specified order of warehouses is defined, which are checked for stock in case a part is requested. If no local stock is available, other warehouses within the region are checked in a pre-specified order. Lastly, the allocation decision is made if there is insufficient stock, determining which customer will receive the stock unit.

The daily sourcing and allocation decisions for most parts are made by an in-house developed Java program called Network Oriented Replenishment Automation (NORA). The planners can also alter the allocations of parts and tools created by NORA if they know a better option. In addition to making sourcing and allocation decisions, NORA directly arranges service materials replenishment throughout the supply chain. When the demand is labeled as an emergency order, the order fulfillment system called Global Emergency Sourcing Automation (GESA) begins sourcing and executing the order.

Chapter 2

Problem Definition

In this chapter, the problem context will be discussed in Section 2.1 by highlighting an assumption of the current forecasting and planning method and indicating why this assumption should be relaxed. Subsequently, the problem statement is presented in Section 2.2.

2.1 Problem Context

For ASML, the key challenge of managing its spare parts and service tools is balancing the costs and the value of service for the customer. On the one hand, holding inventory in the warehouses leads to increased costs, such as purchase costs, handling costs, used storage space. On the other hand, inventory facilitates service by providing parts to demand without delaying production and transportation. Therefore, the stock levels of the spare parts and service tools should be carefully planned. The stock levels are computed based on a model explained in Section 1.3 and 1.4.

In the spare parts forecast and planning method is assumed that the after-sales demand is solely based on unscheduled demand as a result of a machine breakdown (See Table 1.2.2 for an overview). However, indications within ASML suggest that this assumption may not be entirely accurate. Earlier internal research at ASML indicated the orders for spare parts booked in the order management system could be indicated as a scheduled demand activity. The frequency of the indication of scheduled demand depends on the different plant locations, with some indicating up to 65% of demand as scheduled, while others indicate as little as 24%. This suggests that customer service engineers perform planned actions. Furthermore, research by Lubbers (2016) into a selective maintenance model for ASML EUV machines found that there were a total of 100 preventive maintenance actions and recommended that ASML should focus on predictive and condition-based maintenance.

The Customer Service (CS) department responsible for performing the service mentioned that there is more planned maintenance than is currently registered and communicated to other departments. Currently, engineers do not have the incentive to administrate the difference between scheduled and unscheduled demand correctly. The CS department has started a project to let the CS engineers administrate their planned tasks for the upcoming period in a planning tool called Fleetplanner. The vision for the Fleetplanner is to have transparent and fact-based planning for all service events across the installed base. This will improve demand-supply matching and readiness, i.e., alignment between the required and available planning for manpower and resources. These service events could be planned on a short horizon, such as one day ahead, but preferably on a longer horizon.

Additionally, the SFP team occasionally receives a request to adjust the stock levels because it is expected that a maintenance action will be performed. These manual adjustments to the stock levels are not desirable as they disrupt the planning method outlined in Section 1.4.

2.2 Problem Statement

The spare part inventory planning method currently implemented at ASML, as presented in Section 1.4, is a highly advanced and complex customized planning method. A model will always be a simplification of reality at an operational level, the goal is to achieve an as close as possible model to reality. The CSCM department presented a dream state for 2025, the goals of this dream state are *80% predictable, 90% no-touch, 100 % circular supply chain.* An 80% predictable supply chain refers to a total supply chain from customer demand to the supply of parts and tools that should be predictable. To achieve this goal, scheduled maintenance may be a valuable strategy. The CSCM automation and standardization team has devised a process to accomplish this objective. One of the 21 steps to achieve the dream state is *Scheduled events are included in the material planning and forecast for new buys.* This step falls under the responsibility of the SFP team.

The current planning framework assumes all demand is unscheduled, while in reality, a fraction of the demand may be scheduled. Consequently, the stock levels are based on a situation with more uncertainty in demand than is actually present. Including this additional uncertainty could result in overstocking, leading to higher costs. This uncertainty could be reduced by using Advance Demand Information (ADI). Including advance spare parts demand information about scheduled events can make the supply chain more predictable. This increased predictability can lead to reduced local stocking against uncertainty, decreased emergency shipments, and an improvement in Customer Service Degree (CSD) by decreasing the non-availability of spare parts for scheduled demand. Non-availability of a spare part is defined as the number of used spare parts not available in the designated warehouse(s) in case of a system failure.

Different types of demand information are valuable for scheduled maintenance (Fischer et al., 2020). Firstly, the demand lead time, which is the time that the scheduled maintenance action is known in advance. If the demand is known before the forecast for that period is made, the information could be valuable. The demand lead time also affects the order due date in the different warehouses. Secondly, the order cancellation date. If a scheduled activity changes the moment that the activity will be performed, the ADI will be valuable for the parts forecast and planning. The information should give of demand should be forwarded or delayed. The information about the flexibility of the scheduled planning has a significant impact. Thirdly, the order quantities of the spare parts needed for the planned maintenance activities are valuable. Knowing the parts needed for the maintenance action increases the certainty of which specific parts should be stocked. According to Topan et al. (2018), the use of (imperfect) advance demand information can yield substantial savings, but the amount of savings is sensitive to the quality of the advance demand information.

The combination of both unscheduled and scheduled demand for spare parts does not only apply to ASML but is a general topic in spare parts management of capital systems, such as trains or airplanes (R. J. Basten & Ryan, 2015). ADI is used by equipment manufacturers who also serve the machine and forecast and plan their service parts. The information is used to enrich the input of the planning or forecast (Zhu et al., 2020). To conclude, using advance scheduled demand information could expand the forecasting and planning method. The main problem identified is as follows:

> The spare parts forecasting and planning model used by ASML considers all customer service after-sales demands as unscheduled demands. This assumption is too generic. The Customer Service department could give information in advance about the spare parts after-sales demand. This advance spare part demand information could influence the expected model performance in terms of service performance, inventory value, and freight costs. The quality of this Advance Demand Information is variable in terms of timeliness, accuracy, availability, and completeness. The Service Forecasting and Planning team wants to incorporate ADI in the spare part inventory control model. However, currently, there is no method to include scheduled event information in the spare parts forecasting and planning method.

The consequences of the problem described on ASML are:

- **Stock for uncertainty-** Due to the Poisson assumption, more uncertainty is incorporated in the stock levels than in a situation where the demand for maintenance events is known beforehand. This uncertainty will lead to higher stock levels than needed in a real-life situation which, in its term, lead to high inventory cost.

- **Last moment shipments-** The lack of information regarding the timing of expected demand in forecasting and planning can result in the need for emergency shipments. Utilizing ADI could give information about the timing of the demand. If this moment is known timely, the most cost-effective transportation method could be selected.
- **Neglecting service performance potential-** Not incorporating information about future demand will result in an unused potential for the Customer Service Degree (CSD) and the Hit Ratio. This Hit Ratio is defined as the percentage of observed demand delivered within an SKU-specific lead time.
- **Incident driven working method-** The absence of a standard approach to incorporate ADI in the forecast and planning methods leads to confusion regarding the inclusion of received information. This results in increased communication through unnecessary emails and meetings. Not solving this issue will result in an unnecessary workload.

Chapter 3

Assignment and Scoping

In Section 3.1, the project deliverables are presented, followed by the project assignment in Section 3.2. Subsequently, the functional requirements and design parameters are discussed in Section 3.3 and 3.4, respectively. Finally, the scope of the project is discussed in Section 3.5.

3.1 Project Deliverable

In this section, the As-Is situation and the To-Be situation are described. The gap between these two situations will result in the deliverables of the project. In addition, the managerial insights for ASML are defined.

3.1.1 As-Is Situation

Currently, the Service Planning and Forecasting team assumes that all the after-sales service demand is demand caused by unpredictable unscheduled events, i.e., maintenance due to a failure of a part, see Figure 3.1. There are maintenance actions performed to prevent the failure of a machine. Based on this statement, there should be ADI about spare part demands available at other teams. Currently, this ADI is minimally communicated to the SFP team. Consequently, it could be stated that there is unused potential for improving the spare part forecast and planning accuracy by including information about scheduled after-sales maintenance events.

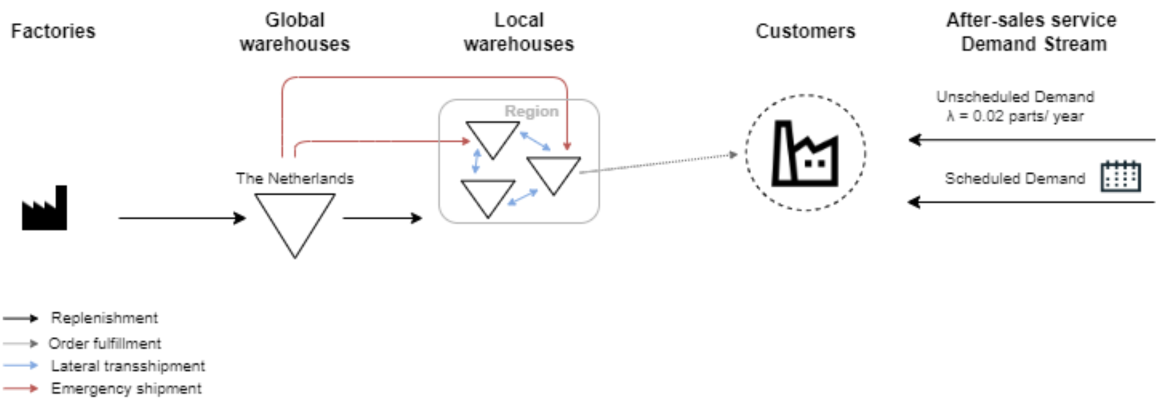

Figure 3.1: Single unscheduled demand stream situation (As-Is situation)

3.1.2 To-Be Situation

In the to-be situation, the information about the scheduled maintenance events is included in the tactical planning and forecasting process. The after-sales demand stream will be split into two parts; an unscheduled demand stream and a scheduled demand stream, see Figure 3.2. In the to-be situation, an addition to the current forecast and planning method should be designed so that both demand streams can be taken into account. In addition, it should be clear how these tactical processes will interact with the operational planning process.

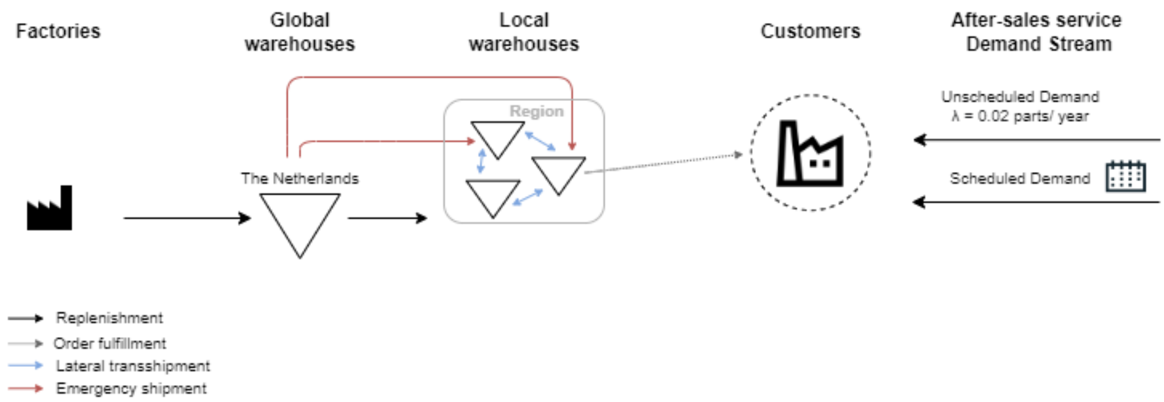

Figure 3.2: Multi-demand stream situation (To-Be situation)

3.1.3 The Gap, Deliverables and Managerial Insights

The gap between the As-is and To-be situations is a method to incorporate the scheduled demand in the tactical forecast and planning processes. Schematic this is shown in Figure 3.3.

Figure 3.3: Gap between As-Is en To-Be situation

To bridge this gap, this project should have the following deliverables;

- An overview of the different views on scheduled maintenance at ASML.
- An overview of the available ADI from scheduled maintenance at ASML.
- An integrated framework for tactical service forecasting and planning including ADI about scheduled maintenance.
- The requirements for the operational planning order fulfillment process and allocation process after the tactical forecasting and planning changes.
- An overview of the advantages and disadvantages of including advance scheduled demand information in the forecasting and planning framework.

Furthermore, this project will provide ASML with the following managerial insights;

- **Why** advanced scheduled demand information could improve service performance, inventory value, and freight costs.
- **What** are the characteristics of the ADI?
- **How** the ADI will be integrated into the forecasting and planning processes.
- **Which** ADI is available?

3.2 Project Assignment

The project Assignment can be stated as follows:

ASSIGNMENT:
Develop an integrated framework to include scheduled maintenance demand into the current forecasting and planning framework.

3.3 Functional Requirements

A design project starts with specifying the functional requirements. The framework that will be developed in this project should adhere to these requirements. The following requirements are defined for the to-be integrated framework:

- FR1: The integrated framework should be such that ASML meets the Service Level Agreements;
- FR2: The integrated framework should be beneficial for the total cost; the total cost consists of transport costs and holding costs;
- FR3: The integrated framework should work together with the current tactical service forecasting and planning process; The SPartAn tool should be untouched, but the input parameters and decision rules linked to the tool could be adjusted;
- FR4: The integrated framework should cooperate with the operation planning process;
- FR5: The integrated framework should consist of clear building blocks and a clear structure such that it can easily be implemented into software used by ASML and adapted in the future when necessary;
- FR6: The integrated framework for the forecasting process should have the ability to indicate the fraction of the input data that is based on ADI;
- FR7: The forecasting and planning algorithm inclusive ADI should be able to run in a reasonable amount of time.

3.4 Design Parameters

To satisfy the functional requirements and complete the project assignment, several design-related decisions need to be made. The design parameters are defined as follows:

- DP1: What are the ADI requirements for including the information in the spare part forecast and planning?
- DP2: Which ADI resources could be used for the spare part forecast and planning?
- DP3: For which time horizon will the integrated framework be made?
- DP4: What will be the stocking policy for parts with ADI?
- DP5: What type of forecast method will be used based on the ADI?
- DP6: How will the integrated framework interact with the global and local warehouse base stock levels?
- DP7: How will the ADI influence the operational order fulfillment and allocation process?

3.5 Scope

The duration of this master thesis is limited, which stresses the importance of a realistically bounded scope to fulfill the research objective. A clear scope is essential to perform all the design study tasks and make a meaningful contribution to the existing literature within the time given. However, the scope should be broad enough to maintain an acceptable level of relevance for ASML.

Service materials

As mentioned in Section 1.2.1, the after-sales service demand consists of the demand for parts and tools. These are tools needed to carry out any service action on the installed base of ASML. Both in the forecasting and the planning process, differences exist between parts and tools. Tools are used and returned to stock after use, and parts are consumed. For the forecasting process, the difference is in the input parameters. The forecast is based on the usage and initial failure rates. For tools, it is assumed that there is no failure, and the usage depends on the user registration of the engineer. Due to the differences in the forecast process, only service parts will be in the scope of the design study.

For the planning process, the same situation is applicable. The planning process for service tools is not entirely similar to the planning process for service parts. The differences in the process are very decisive, for example, tools will after usage come back in stock. Due to these differences, it is chosen to focus on spare parts only and leave service tools out of scope for the service planning process.

Demand streams

As explained in Section 1.2.2, the complex machines of ASML consist of thousands of parts. However, not all parts are in the scope of maintenance. In total, thousands of service parts are under the direct control of the SFP team. The service demand categories are presented in Table 1.1. In this design study, the focus will be on after-sales service demand. After-sales service demand is the demand created from maintenance actions.

Business lines

ASML distinguishes multiple different business lines EUV, DUV, MPS, and APPS. From earlier research, it has been concluded that the maintenance actions for the DUV machines have the opportunity to be scheduled because the machines are in service by ASML for more than 20 years. The scheduled demand information will mainly be based on the knowledge obtained in the past years.

ASML produces and services EUV machines, which are modern relatively new machines. The scheduled demand information from these machines is expected to come from predictive information from monitoring from distance. The new integrated framework should apply to both the DUV and the EUV machine portfolio. Therefore, both EUV and DUV are in the scope of the design study. MPS and APPs are a relatively small percentage of the system portfolio and are therefore out of scope for this specific study, but in the future, the integrated framework should also apply to these business lines.

Return flow

Maintenance activities have resulted in parts that are no longer used. For example, a broken part that is exchanged or a part still functioning that is preventively replaced. These parts could, for example, be repaired, (partly) re-used, or scraped. The return flow of these parts is out of scope.

Chapter 4

Current Situation

The goal of this chapter is to provide the first two deliverables. In Section 4.1 an overview of the different views of ASML teams on scheduled maintenance will be discussed. In Section 4.2, an overview of the available ADI about scheduled maintenance at ASML is given. These deliverables are formulated to understand and quantify the available ADI for scheduled maintenance in the service process.

4.1 Scheduled Maintenance

To my knowledge, there is no clear distinction between the definitions of scheduled maintenance and planned maintenance in scientific literature. However, according to a non-scientific source, the difference between scheduling and planning could be formulated as follow; Planning refers to the process of developing a guide to design and produce the desired product or service, while scheduling involves determining the time frame in which the project will be completed, the resources and costs requirements, and the sequence of tasks. One type of planned maintenance is preventive maintenance, which happens before a failure. This is in contrast with corrective maintenance, which is carried out after a failure has occurred (Arts, 2017).

Within ASML, there is no formal definition of scheduled and planned maintenance. Semi-structured interviews are conducted with stakeholders in the service supply chain to gather their perspectives on the definition. A list of roles of the participants and the interview questions can be found in Appendix B.

4.1.1 Tactical forecast and planning

The tactical forecast analyst considers scheduled maintenance as an event with a start and end time. He makes no distinction between planned and scheduled. The maintenance should not be corrective and prevent a corrective action in the future. Moreover, it is known beforehand that there will be downtime and which parts and tools are needed. For a forecast analyst, maintenance could be considered as scheduled when at least two months in advance, the needed parts are known. A condition for this two months interval is that the parts are available in stock. If this is not the case the forecast analyst indicates that he could only consider the maintenance as scheduled as the parts needed are known at least a supply lead time in advance.

The tactical planner considers spare parts demand as planned as the demand per part is known longer in advance than the new buy lead time of that part. In this case, the tactical planner could make sure that the stock levels are sufficient to cope with the upcoming planned maintenance. The tactical planner does not use the term scheduled maintenance because they only plan based on expected demand in a period and not on a schedule with maintenance activities.

4.1.2 Operational planning - ASML Central teams

Design and Engineering (D&E) and Customer Support (CS) Central, the teams located in Veldhoven, define planned maintenance with a list of preventive maintenance actions. Preventive Maintenance (PM action) is required to detect, correct, and prevent failures during the lifetime of the system and to keep the system within Acceptance Test Protocol (ATP) specifications for optimal product performance (e.g. highest possible system availability of good wafers per day). For scheduled maintenance events, a moment in time is reserved and resources are allocated. The resources are people (with specific qualifications), parts, and tools.

CSCM Field Material Availability (FMA) considers scheduled maintenance as every maintenance action with part demand that could be planned. Demand could be planned in two situations. First is the 'happy flow'. In this case, there is stock in the global warehouses. In this situation, every demand known three weeks (two weeks of transport and one week of communication) in advance could be called planned. The second situation is the 'nonhappy flow', in this case, there is no global stock. A Demand Allocation Lead (DAL) could only plan the demand for scheduled maintenance if this information is known as a supply lead time in advance. The average supply lead time of DUV and EUV parts are nine and twelve months respectively.

A team member from the Fleetplanner team, a tool to manage the maintenance of the machine, stated that he formulated a maintenance plan as he plans the event for the upcoming three to six months. At this moment they only plan to perform maintenance on a specific machine in a rough period. Subsequently, with scheduled maintenance, the exact moments when the maintenance will be performed and which resources are needed are indicated. This is done at most eight weeks in advance.

4.1.3 Operational planning - Local teams

The local CSCM team indicates that scheduled maintenance is when they know the order in advance and unscheduled is a hard breakdown of a machine. The time interval of 'advance' depends on the location and the customer. The moment they decide which action will be performed on which date differs between four weeks to a few days before the maintenance. The local CS team gave multiple perspectives on scheduled maintenance. Firstly, scheduled maintenance is all the maintenance that is not caused by an unscheduled down. There is no fixed time interval. But for a scheduled event, a preparation cycle is needed. This preparation cycle will take a couple of weeks. A second person defined scheduled maintenance as something that is prepared. Everything is arranged: parts, tools, manpower, certification, and safety requirements. A scheduled down is driven by ASML, and an unscheduled down is driven by a machine. Planned maintenance refers to maintenance actions that are included in a preventive maintenance list and are likely to be executed but without a specific scheduled date. The frequency of the maintenance on the list differs between bi-weekly and tri-annual. Another local CS employee stated; planned maintenance is maintenance planned further than a week and indicated that there is no difference between planned and scheduled. A fourth CS Local team member indicated that technically formulated an action tomorrow is scheduled.

4.1.4 Conclusion first deliverable

The first deliverable of this project is to get an overview of the different views teams of ASML have on scheduled maintenance (see Section 3.1). To conclude there are different perspectives on planned and scheduled maintenance activities. On a tactical level (SFP team), there is no clear distinction between planned and scheduled maintenance. Maintenance could be considered planned if the spare part demand is known at least a supply lead time in advance, otherwise, it can be considered unscheduled. On an operational level, the time interval for considering an event as planned is shorter. The operational plan could be formulated from a week ahead until three years ahead, depending on the operational team. For scheduled maintenance, preparation of the maintenance is started, this can be four weeks to one day in advance. These differing perspectives are the starting point for mapping the available ADI for these scheduled maintenance events.

4.2 Available ADI

In order to define the available ADI in the service supply chain, the same employees were asked in the interviews which information about the maintenance is available. The questions for these interviews are outlined in Appendix B. The ADI flows that are identified are mapped in a model. A BPMN model of the communication flows is presented in Appendix C

4.2.1 Process description

The D&E team provides the instructions for the recommended preventive maintenance of the machine when a new machine is introduced. Every quarter they update the list with potential new maintenance. In this maintenance instructions, among other things, the frequency of the maintenance is given (time-based or condition-based maintenance), and the list of materials. D&E owns this data and is responsible for the feedback loop from the users of the list. For example the accuracy of the recommended parts. D&E communicates their newly defined maintenance to CS System Engineering. This is a central team that looks into the recommended PM list and decides which actions can per performed in parallel and within the contractual requirements such as budget and downtime. Occasionally, D&E may check at the CSCM Field Material Availability teams if these parts are in stock.

CS System Engineering makes a customer-specific recommendation for the PM plan. Subsequently, this list is communicated to the local CS team. The local CS team decides together with the customer which actions of the recommended PM list will be included in the customer-specific PM list. The local CS manages the maintenance in a so-called "local PM tracker". This PM tracker is an Excel file with the actions, the frequency, the last moment that the maintenance is performed, and the upcoming due date of the maintenance.
CS Local team and the customer decide together which maintenance action will be performed in the upcoming period. This decision can be taken in a (structured) meeting. The frequency of this meeting differs per customer. Some customers have a weekly meeting to decide on the upcoming maintenance plans, other customers meet bi-weekly or every four weeks. The planning horizon discussed in these meetings also differs from one to six weeks ahead of the maintenance. In addition, the planning for the EUV machines may be included in the Fleetplanner. The use of the Fleetplanner depends on the site. Some locals use the planner as their scheduling mechanism to control the resources, others only use it as an agenda.

When the customer has decided on which preventive maintenance to perform, the local CSCM team checks the required resources for the defined scope. For example engineers, parts, tools, and required time. For the parts, CSCM checks the preventive maintenance actions on critical materials. To determine if a part is critical they ask themselves questions such as; Are there parts that are not locally available? And do we have experience with parts that often arrive late? If this is the case, CSCM already submits a service order to request the part. For the other parts, CSCM waits til four, two, or only one week in advance of the maintenance, depending on the customer, to lock the scope of the maintenance. When the scope is locked an action plan could be created. A section of the action plan is the parts needed for the maintenance. These parts are selected based on a so-called Coach file created by D&E that gives a handout for the maintenance activity. The selection of parts is a small fraction of the parts recommended, mainly because the Coach file assumes a worst-case scenario of the maintenance where all the parts should be replaced. Another reason could be that the customer has small parts such as an O-ring that are already locally available to the customer, so they do not have to be ordered.

The service orders which trigger the operational fulfillment system are submitted by CSCM locally approximately seven to three days in advance of the maintenance. CSCM local tries to minimize the time between submitting the service order and the maintenance to ensure that the parts are directly sent to the maintenance activity. If a service order is submitted earlier, there is a change that in the meantime the part is needed for corrective maintenance action. The corrective maintenance action has always priority over the preventive maintenance action.

When a service order is submitted, the stock is sufficient, and will arrive on time NORA will process the order. If the order is an emergency order, GESA takes over the fulfillment. If the order is expected to arrive too late NORA notifies the Global Operations Center (GOC) and if this is a critical part the CSCM Central Demand Allocation Lead (DAL) will allocate the part to a customer.

Besides the DAL is the contact person for the local CSCM teams, if they have additional information about upcoming event CSCM Local could communicate this in the weekly call. Mostly they wait on the service order because then the demand information is complete. Accordingly, the DAL receives at least two types of information; adjusted failure rate information of D&E and Expected higher demand information of the local team. Subsequently, DAL checks the reason for the increase in demand at CS central, Product Lifecycle Management (PLM), and D&E. If the information is about an incident the DAL decides on the allocation of the part, if the information is about a structural change, DAL communicated the information to Service Forecast and Planning.

Within Service Forecast and Planning, the forecast team receives the information via a shared excel or mail. Based on the argumentation, the forecast team decides if they will adjust the failure rate mainly or not. This change will potentially lead to changes in GW stock levels. If the LW stock levels should be adjusted, the planning team could adjust them, but this is an exceptional action.

A simplified graphical representation, in comparison with Appendix B, of the advance demand information flows between teams can be found in Figure 4.1. From the process mapping of the ADI three main insights are created.

- There is no direct communication between the central teams (D&E and CS) and SFP about scheduled maintenance. The team of CS in Veldhoven and SFP both work on the tactical level but do not consult each other for information.
- There is a lack of distinction between tactical and operational processes. For example, the local teams check the inventory levels themselves before submitting the service order. This has negative consequences for the automated systems, as the input data is no longer representative due to manual intervention. The operation team should indicate that there is a demand, and not decide their planning based on the local stock availability. Thereby, FMA, decides which ADI is communicated to SFP and which is not. Ideally, all the information is communicated to SFP, and this team decides which ADI is useful or not.
- And finally, there is no standardized way of working with the customers. The local CS and customer decide on their own how often a scheduled maintenance planning is made and for which time horizon. Also, the communication with the Central CSCM team in Veldhoven differs

4.2.2 Service order

A service order is a method to order parts or tools. In one service order, multiple parts and tools could be ordered. The CSCM local employee is responsible for filling in the correct information and monitoring the service order. Besides they should ensure the parts are on time on location. The service order record could be indicated with a so-called Z-code, what type of order it is. For example, a part that is needed for a 'System hard down' or for 'Period maintenance'.

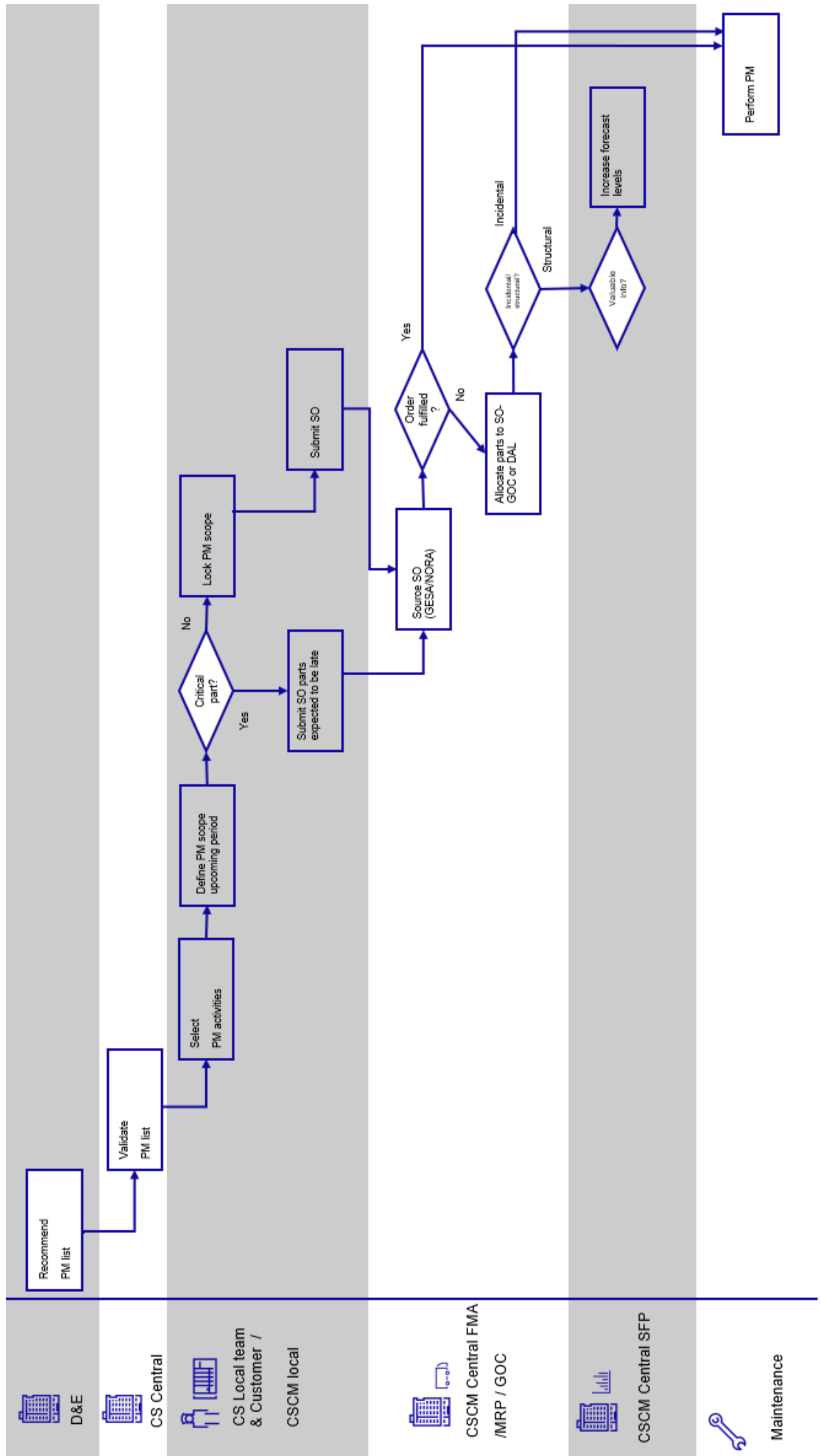

Figure 4.1: Simplified graphical representation ADI

In Table 4.1, the distribution of the service order Z-codes in the first half year of 2022 is given. Before conclusions about this information could be drawn, two things should be kept in mind. First indicating the right Z-code is a complex task, due to the wide range of different codes (42 codes). Second, of the service orders created in the first half of 2022 (All service demand), one-third of the service orders are canceled, before the maintenance is planned to be performed. The percentages in the table do not include orders that are canceled. From the distribution, it could be concluded that 24% of the after-sales service orders are for scheduled maintenance actions, while in the current forecast and planning methods is assumed that all after-sales demand is unscheduled. The average time between submitting the service order and the time indicated that the part should be on location is for after-sales orders on average 5 days, for only the scheduled after-sales this duration increases to 9.5 days and for only the periodic after-sales the average time is 17.5 days. This is in line with the information provided in the interviews. The information which the CS and D&E could provide is mainly for periodic maintenance events. A routine shipment needs the information two weeks in advance. The average time information of the scheduled after-sales is given before the maintenance is smaller than 14 days, so the parts will often be fulfilled with a priority (duration of 7 days) or an emergency shipment (duration of 72 hours).

Table 4.1: Distribution service order Z-codes January-June 2022

Service demand	**Category**	**Unscheduled/ Scheduled**	**Maintenance type**
Total	After-sales 100%	Scheduled 24%	Periodic maintenance 37%
			Other scheduled maintenance 63%
		Unscheduled 76%	
	Upgrades, Installs & Relocations		
	Sales		

4.2.3 Future of scheduled maintenance information

During the interviews, it was noted that there are ongoing efforts to improve the information flows. An example of a project is a mail template to communicate the information from FMA DAL to service management. A large project is executed by ONE field execution team (Our new enterprise). This team aims to develop an integrated process for field services, supported by a set of integrated solutions with SAP* back-end, that will transform field execution. Part of this solution is a Work list manager with a standard list of maintenance activities. subsequently, an action plan is created for the activities and a potential time slot is reserved for the activity in the Fleetplanner. Currently, the Fleetplanner is mostly used as an advance agenda for the upcoming four weeks. with this tool, resources could be scheduled. In the future, the Fleetplanner will be connected with the SAP service order system. This link will have a consequence that when maintenance is added to the agenda, the link between an SO and an event could be made easier. The link between the Fleetplanner and SAP is expected from 2023, this change depends on the willingness of the sites to use the Fleetplanner. A link between the logistics system with the stock levels and the Fleetplanner is expected in 2028. This more advance Fleetplanner will only be used for EUV sites.

4.2.4 Scheduled Advance Demand Information overview

The problem description states that the ADI has four characteristics; timeliness, accuracy, availability, and completeness. If the four characteristics are all 100 percent there is perfect ADI, otherwise, there is imperfect ADI. For each stakeholder category interviewed and the two data sources: service orders and Fleetplanner, the ADI characteristics are indicated with a Yes (100%), No (information does not have the characteristic based on the interviews), or Sometimes (The information has sometimes this characteristic). To give an indication the following questions are answered:

- Expected timeliness: Is the demand information lead time larger than the supply lead time?
- Expected accuracy: Is the demand information completely accurate?
- Expected availability: Could the information be communicated to the SFP team?
- Expected completeness: Are the parts and expected demand moment known?

This results in Table 4.2. Based on this table, it can be concluded that there are no resources with four times yes, therefore there is imperfect ADI.

Table 4.2: Advance Demand Information stakeholders (Y= Yes, N= No, S = Sometimes)

	Timeliness	**Accuracy**	**Availability**	**Completeness**
D&E Central	Y	N	Y	N
D&E - Condition monitoring	N	Y	Y	N
CS Service Engineering	Y	N	Y	N
CS Central Service and quality	Y	N	Y	N
CS Local/ SAP coordinator/ Scheduled down PL	S	N	Y	N
Customer	N	N	S	N
CSCM Local	S	N	S	N
CSCM FMA	S	N	Y	N
CSCM Operations	N	N	Y	N
CSCM SFP	N	N	Y	N
CSCM/ CS Local - Service order	N	N	Y	Y
CS - Fleetplanner	S	N	S	Y

ADI is the most valuable when the specific moment and content are known. When there is a probability for demand in a time period, the information is similar to that in the current unscheduled planning method. Despite the imperfect information, it is desirable to strive for a situation where more information is available regarding the specific moment and necessary components for maintenance than in an unscheduled situation.

4.2.5 Conclusion

This section aimed to get an overview of the available ADI about scheduled maintenance within ASML. Based on the interviews, it can be concluded that there is information about planned maintenance available at tactical (D&E, CS en CSCM Central) and operational levels (CS and CSCM local. The reliability that maintenance actions will be performed is low. From the moment local CS and customer have to decide on which maintenance will be performed from the local PM tracker activities, the probability that maintenance will be performed increases, only the exact time period remains uncertain. When the CSCM local team submits the service order, the moment and the parts used in the maintenance are known. Although, there is still a probability that the submitted service order will not be used. The reliability of the parts needed and the moment of the maintenance increases as the maintenance approaches, but it can never be guaranteed with certainty.

To conclude, the individual sources provide imperfect ADI about scheduled maintenance demand. To enrich the current forecast and planning with ADI, the information should give a specific moment of the maintenance and the parts needed instead of a probability. From now on, the imperfect ADI about scheduled maintenance activities is taken into account.

Design conclusion: The ASML teams have imperfect ADI regarding the scheduled maintenance events

Chapter 5

Conceptual Design

In Chapter 3, seven design parameters have been defined. This chapter will discuss the different choices that have been made concerning these design parameters. Some design parameters will depend on each other. Therefore a sequence is created to make the design decisions. The sequence of the decisions is presented in Figure 5.1. Section 5.1 discusses the requirements for including ADI in the forecast and planning. After that, the advantages and disadvantages of the available ADI for different teams are discussed in Section 5.2. In Section 5.3, the time horizon of the framework is set. Based on the available ADI and the preferred time horizon, five different stocking policies are discussed and compared in 5.4. Next, the options to forecast the spare part demand are discussed in Section 5.5. Finally, in Section 5.6, the interaction with the current planning method is explained. Unfortunately, the last design parameter, how the designed framework influences the operational processes, could not yet be answered in the conceptual design because the detailed design of previous design parameters is needed to answer this question.

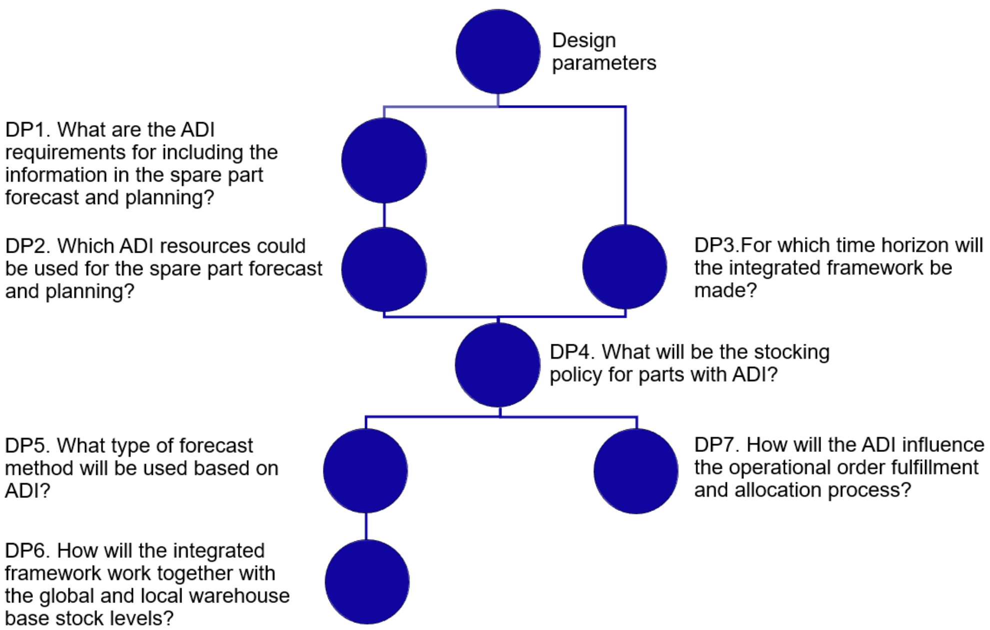

Figure 5.1: Design parameter priority tree

5.1 DP1: ADI Requirements

This section aims to answer the first design parameter. The first design parameter is: What are the ADI requirements for including the information in the spare part forecasting and planning? An overview of all the imperfect ADI available is given in Table 4.2. In this overview, the general theoretical view on the timeliness, accuracy, availability, and completeness of the ADI is given. In this section, the requirements for these ADI characteristics on tactical planning and operational planning level are given.

5.1.1 Tactical process information

Timeliness

The ADI should ensure that the spare parts flow is more customer-order-driven than forecast driven. The information about the scheduled demand is preferably known as upstream as possible in the supply chain (Mason-Jones & Towill, 1999). The transparency of the information through the supply chain will enrich the forecast process and, accordingly, the planning process. The Customer Order Decoupling Point (CODP) is the point where the forecast-driven demand matches the order-based demand. The CODP is the point in the material flow where the product is tied to a specific customer order (Olhager, 2010). The ADI can move the CODP more upstream. Moving the CODP upstream in a spare part supply chain beneficially impacts the ordering, and stock levels dynamics Mason-Jones & Towill (1999). In the current unscheduled demand supply chain, the CODP is located at the local warehouses because the parts are linked to a service order on average five days before the maintenance action. (See upper scenario in Figure 5.2) There are three types of ADI:

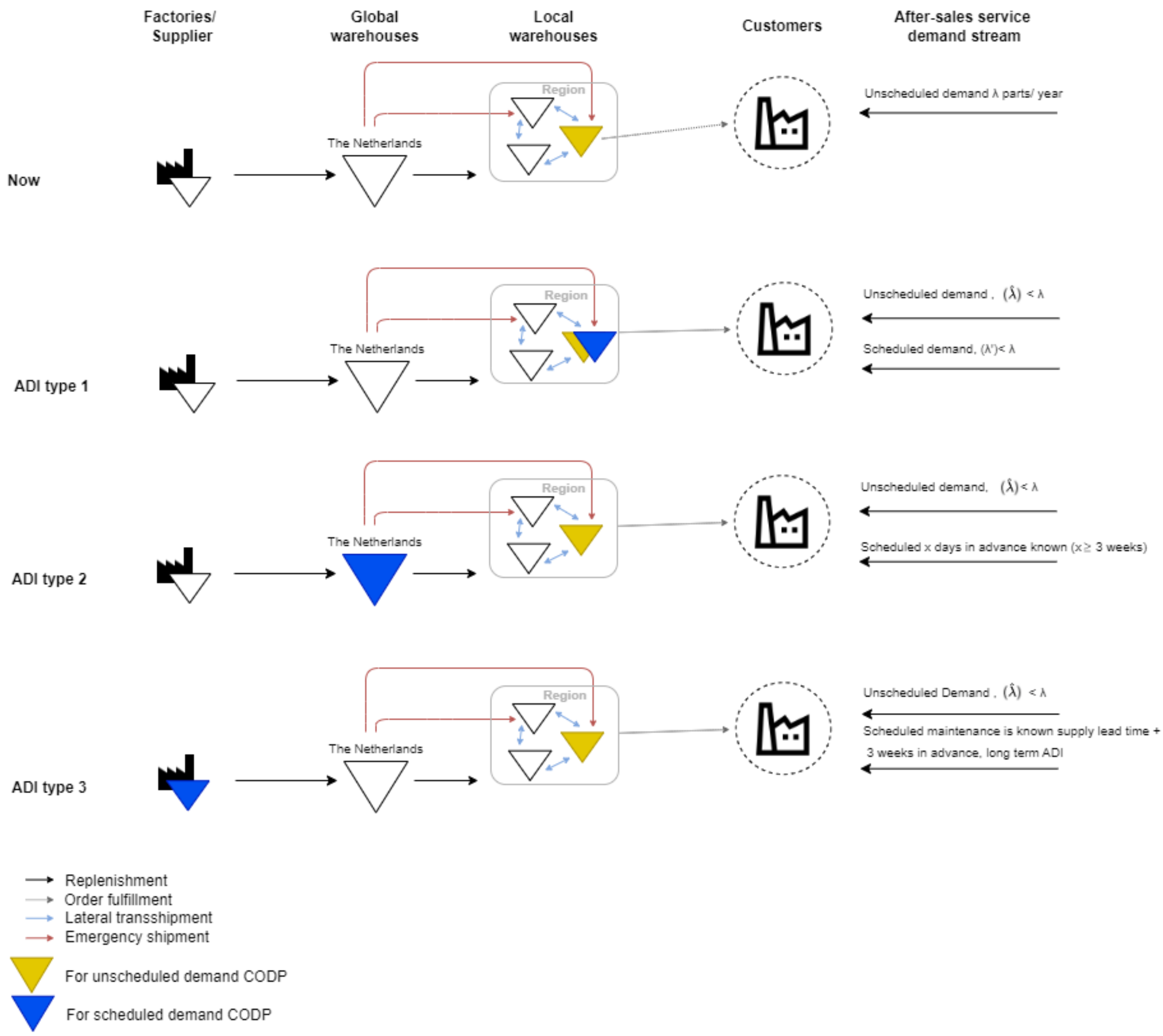

Figure 5.2: Customer Order Decoupling Point

1. The first type is comparable with the unscheduled demand. The demand is known short in advance. The routine shipment from the GW to the LW takes two weeks. The service orders placed shorter than two weeks in advance can be considered the same as unscheduled demand. If the ADI is given in another format than a service order, the information should first be processed manually. For these tasks, one week is reserved. In this situation, the ADI information given shorter than three weeks in advance can be considered as unscheduled demand. In this situation, the CODP stays at the local warehouse.

2. The second type of ADI is the formation known more than three weeks but shorter than a supply lead time in advance. The demand rate is already known. If the ADI for scheduled demand is known at least three weeks in advance (two weeks transport, one week ADI processing time), the CODP can be moved upstream to the global warehouse. The CODP can not yet be moved to the supplier, as the information should then be known at least a new buy lead time in advance.

3. The third type of ADI is where the demand lead time is longer than the supply lead time. In this situation, the ADI could also be given as follows: the part has to be changed once in ten years. In this case, the parts can be ordered directly from the supplier, and the CODP can be placed directly by the supplier for the scheduled maintenance activity parts.

The ADI types are presented in Figure 5.2.

In this study, the aim is to move the CODP for scheduled maintenance parts from the local warehouse to the global warehouse. From the interviews, we obtained that local CS set up a maintenance plan, including demanded parts, from one to six weeks ahead, depending on the different locals. With the ADI given from three to six weeks ahead, it is possible to move the CODP upstream to the GW. Moving the CODP to the suppliers is currently still too ambitious because the customer order is not known a supply lead time + three weeks replenishment and processing time in advance. To be able to move the CODP to the GW, ADI option 2 is needed. ADI option 3 can be used to enrich the data in the forecast and planning process. The scheduled demand information is timely if the ADI is known at least three weeks in advance.

Design decision: The after-sales demand of an SKU consists out of: (i) unscheduled demand; (ii) demand of maintenance known at less than three weeks in advance; (iii) demand of maintenance known more than three weeks in advance. For demand category (iii), the CODP should be located at the GW. For categories (i) and (ii) the CODP stays at the LW.

Accuracy

Ideally, the ADI provided for the tactical processes is 100% accurate. Unfortunately, there is no ADI source with 100% accurate information. The overall local planning accuracy should be at least 95 %, as this is the current local planning objective of the SFP team. Before the design of including ADI in the forecast and planning is made, it is not possible to indicate the needed accuracy of the ADI. Afterward, an evaluation can be made on which accuracy level of the ADI can improve the planning.

Availability

For the tactical forecast and planning the information should be available for the service forecasting and planning team. Customers should be willing to share their maintenance plans with ASML. Next to that, other ASML teams with the ADI should be willing to actively communicate the information with SFP.

Completeness

ADI type 2 should give the exact parts, moment, and location for the ordered parts. For ADI type 3, an expected list of parts is specific enough. The exact machine where the part is used is not needed, because the CSD and WT commitments are formulated based on plan group. Not mandatory but valuable for enriching the tactical process information is the probability that a part will be used/unused and the latest moment that the maintenance is performed.

5.1.2 Operational process information

The operational processes start when the demand is linked to a specific customer order. For operational planning ADI type 2 is needed. ADI type 3 will not be used on an operational level until the moment the transportation from the GW to the LW is needed.

Timeliness

For the operational process, the replenishment system has three options; Routine, Priority, and Emergency. The engineer who submits the service order indicates the preferred replenishment. The routine, priority, and emergency shipments take a minimum time of two weeks, one week, and three days respectively. If the CODP is wanted at the global warehouse, and a routine shipment is preferred the ADI type 2 should be given at least three weeks in advance (two weeks of transport + one week time to process the information). If a priority shipment is sufficient, the ADI can be known shorter in advance, with a minimum of one week. If the scheduled demand information is given less than one week in advance, the information is obtained as timely as unscheduled demand information. The routine shipments are less expensive than the other shipment options. ASML should aim for a situation where the scheduled parts are only transported with routine shipments because this has the most potential in transportation costs.

Accuracy

The ADI type 2 in the operational planning should preferably be 100% because based on this information the parts are shipped over the world, and transport costs are made. Unfortunately, due to multiple external factors, this is unrealistic. Therefore the ADI accuracy should be as high as possible.

Availability

To include ADI type 2 in the operational planning, the information should be available in SAP so that the information can be taken into account in the NORA and GESA automation.

Completeness

The automated replenishment system should know which exact parts, when, where, and for which specific machine. This information should be provided in a service order.

Conclusion DP1

Based on the four characteristics, DP1 can be answered. The requirements for including the information in the spare part forecast and planning depend on the type of ADI. For one SKU, there are different types of demand information. The CODP of the fraction of the demand that has ADI more than three weeks in advance of the maintenance should be located at the GW. For the rest of the demand of the SKU, the CODP should be located at the LW. To move the CODP to the GW, the ADI for both the tactical and operational processes should be known at least three weeks in advance. Information known further in advance can enrich the tactical forecast and planning. For both tactical and operational processes, the information should be as accurate as possible. The tactical ADI should be available for the SFP team, and the Operational ADI should be available for the automated replenishment system. Finally, the operational ADI is considered complete if the exact parts, location, date, and machine are known, while the tactical planning considers ADI type 2 as complete when the parts, date, and location is known. ADI type 3 is complete when expected demand can be given for a plan group.

5.2 DP2: ADI Resources

According to the interviews, there is information about scheduled demand. The available resources are given in Table 4.2. In this section, five out of the twelve resources will be considered for tactical planning. First, the advised maintenance list of D&E and the condition monitor information will be discussed. Subsequently, the recommended PM list of CS Central and the proposed pm list of CS Local are analyzed.

The CS Service Engineering information recommendations are not included because the CS Central information has the same information, only more specific. The customer information is not considered because the information is often not accessible for SFP. The CSCM information is often last-minute and reactive information. Therefore this information is not considered. The use of the Fleetplanner is still minimal. Moreover, the development of the planner and connection with other systems will take several years. For this reason, the Fleetplanner is not yet considered as an ADI resource. Although service orders are often known last minute, the information is complete. So the service order is considered as a resource. In this section, the advantages and disadvantages of taking the information into account in the forecast and planning are discussed. A summary of the information available is given in Table 5.1. Eventually, this section answers the second design parameter: Which ADI resources could be used for the spare parts forecast and planning?

5.2.1 D&E Central

As described in the process description, D&E provides a list of recommended maintenance activities when a new machine is introduced and updates the list every quarter. An advantage of using this information in tactical planning is that the demand is expected before the first demand ever occurs for that maintenance activity by SFP. New activities are for the SFP team the most difficult because there is no information about usage in the past of the part. When scheduled maintenance is performed multiple times in the past, the maintenance is already taken into account in the expected usage rate. Thereby, D&E provides a list of all parts that are advised to be used while performing the maintenance. Considering the D&E information will result in an overview of all parts expected to be used for scheduled maintenance. This last argument directly links to a disadvantage while performing maintenance; not all advised parts are used. For example, because an advised part is still functioning or there is a comparable part locally available. Moreover, not all maintenance recommended is performed. This can be because the PM list does not consider contractual agreements.

5.2.2 D&E Condition monitoring

D&E has a team that develops condition-monitoring algorithms for the most important parts. For condition monitoring, three phases are available; red (failure), orange (there will be a failure soon), and green (part functioning). The time between the transition from the orange phase to the red phase differs per part. Unfortunately, this information is only available for approximately twenty parts. According to Zhu et al. (2020), including condition-based information in the planning could result in cost savings. Because of the limited scope of parts, this information is not included in this research study and Table 5.1. Due to the potential of the information, it is recommended to investigate the possibilities of incorporating condition monitoring information in the spare part forecast and planning when the D&E process is more mature.

5.2.3 CS Central

As described in the process in Section 4.2, the central CS teams ensure that the list of maintenance activities is feasible within the service contract agreements. The advantage is that the list provided by CS is customer specific, and the advised maintenance, with advised parts, frequency, and plan group, are known. A disadvantage of this information is that CS central only provides advice to the customer and CS Local, there is no certainty that the maintenance will be performed. Thereby, the recommended parts are still not the demanded parts. However, the information is timely enough for ADI type 2.

5.2.4 CS Local

In the end, the customer decides which preventive maintenance will be performed or not. Some locals have created a list of maintenance activities they plan to perform for a specific machine. On this list, the procedure with parts, frequency, and last performed moment when this maintenance is performed can be given. The advantages of this information are that the customer plans to perform the maintenance and that the expected due date of the next occurrence is known. For time-based maintenance, the due date is calculated by the last performed date plus the frequency of the event. On the other hand, the due date set by the CS Local is more than 80 percent of the cases not attained. This has several reasons. For instance, another machine may be already down, and the customer can not afford to lose further production capacity. Other reasons can be that the necessary resources, such as engineers, tools, or parts, are unavailable. Alternatively, the machine is still functioning, and the customer takes the risk and waits for the failure instead of performing preventive maintenance. Another additional disadvantage of incorporating this information is that by the time the maintenance is performed for the first time after the maintenance is added to the list, it can theoretically be planned for the next week. In this case, the information is too late to function as ADI type 2.

5.2.5 Service orders

Service order data has the advantage that all the details of the demand are known. For example the machine and the specific ordered parts. A disadvantage of this data is the timing of submitting the service order. Periodic maintenance service orders are given on average 17.5 days in advance, for operational processes this information can be on time, for tactical processes this information is too late.

5.2.6 Conclusion DP2

To conclude, there is no imperfect ADI source that provides ADI type 2 information where a customer order is created with the complete information at least three weeks in advance. Next to that, if the information is on time there is always uncertainty about the parts needed or the exact moment/ frequency of the maintenance activity. In Table 5.1 a summary is given. Based on the characteristics of the ADI resources available, it is not possible to conclude which resource the spare part forecast and planning should be taken into account. For this reason, all four resources are taken into account as an option in the following design parameters.

Table 5.1: Advance Demand Information overview

Information source	Team	Parts	Frequency	Date needed	Last performed part change date	On time for ADI type 2?
D&E advised PM list	**D&E Central**	Recommended parts	Advised frequency	No	No	Yes
PM total list	**CS Central**	Recommended parts	Advised frequency	No	No	Yes
FAb specific PM list	**CS Local**	Recommended parts	Proposed frequency	Sometimes	Yes	Sometimes
Service order	**CS/ CSCM local**	Exact parts	No	Yes	No	No

5.3 DP3: Time Horizon

In this section, the appropriate time horizon for the implementation of the integrated framework will be evaluated. The extent to which ADI can be utilized in advance of a maintenance event will be discussed. For example, if a maintenance plan indicates that a part should be replaced in five years, this information is not immediately useful for forecasting and planning purposes.

The global warehouse planning plans for at least a new buy lead time plus a one-month run lead time in advance. ADI type 2 can be utilized from three weeks until this moment. The forecast is preferably known for the upcoming three years as this information can be incorporated into the long-term forecast, and this forecast can be communicated to the suppliers. with this information, the suppliers can at least produce the parts that will be demanded based on the forecast. ADI type 3 can enrich the forecast up to three years in advance.

Conclusion DP3

In conclusion, the integrated framework will consider two different time horizons. For ADI type 2 the ADI can be used up to a supply lead time plus a monthly run in advance. So the information can be included in the global warehouse planning. ADI type 3, used to enrich the forecast, can be included for the upcoming three years because this is the horizon of the long-term forecast.

5.4 DP4: Stocking Policy

In this section, the stocking policy options for the incorporation of ADI will be examined. The stocking options will depend on the various information sources discussed in the conclusion of Section 5.2. The objective of this section is to determine what the best stocking policy for parts with ADI is.

5.4.1 D&E Central or CS Cental as ADI resource

Both at D&E and CS Central, information is known of a recommended parts list and an advised frequency. As there is no specific customer order, this information can enrich the current data that is used for unscheduled demand (ADI type 3). With this information, the following planning options are possible.

Two different processes

With the recommended PM list, a selection of the total after-sales demand can be made, which was probably used for preventive maintenance in the past. The fraction scheduled maintenance parts can in the future, be demanded directly from the GW and should not be distributed from the local warehouses. For the operational planning, the direct link to the global warehouse implies that the CS Local team should submit the SO at least fourteen days before the maintenance, such that the part can be shipped with a routine shipment from the GW. Based on the interviews and the SO data, this should be possible. Unfortunately, the CS Local team does not yet have the incentive to submit the SO fourteen days in advance. If the scheduled maintenance parts are stored globally instead of locally, the local holding cost will decrease. A graphical representation of the situation is given in Figure 5.3.

The unscheduled section becomes smaller but still follows a Poisson process. The Poisson process is a discrete distribution that is characterized by the probability of a given number of events occurring within a specified period. Poisson processes have a known constant mean rate, the events are independent, and only one event can occur at a point in time.

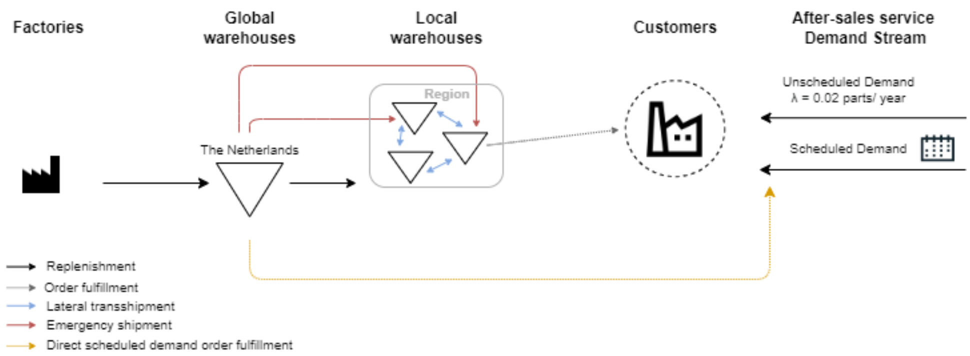

Figure 5.3: Scheduled demand directly demanded at global warehouse

The scheduled demand arrivals for a specific part probably have no independent arrival, as the demand is dependent on the timing of previous demand, which can be a demand resulting from a breakdown. Subsequently, when multiple parts are ordered in one SO, they are ordered at the same time. For a Poisson process, this is not possible. From the interviews, it can be concluded that the scheduled demand is not deterministic because of the uncertainty in timing and parts used. So, scheduled demand probably follows a stochastic process. Suppose the uncertainty in this demand is less than in the Poisson process, the global warehouse can reduce the stock levels, and the holding cost will decrease compared to the current situation. If the scheduled demand distribution is Poissgives on distributed, there will be no difference for the global warehouse compared to the current situation. The total sum of demand stays the same because the merger of two Poisson processes is a Poison process. (Berkum & Di Bucchianico, 2016).

To test the distribution of the scheduled maintenance parts demand over time, distribution fitting over the usage of a subset of approximately 40 NXE scheduled maintenance parts is used. This fitting is performed based on the distribution fit of SciPy (SciPy documentation, 2022). From this analysis could be concluded that every part demand occurrence has a stochastic distribution but that there is variety in distributions; Exponential, Chi(2), beta, Erlang, f, and Lognormal. For the unscheduled demand, a Poisson distribution is assumed. Testing the hypothesis that the individual parts are also Poisson distributed results in an acceptance of the hypothesis for all parts.

Scheduled maintenance stock level

The CS Central information contains the recommended part and the frequency of the maintenance. This information can result in a steady state scheduled stock level; see Figure 5.4. If maintenance of a specific part is expected to occur once a year for machine x and a minimum of two parts are needed for this action. Using the traditional method, the expected demand per day would be 2/365, plus the failure probability, for example, once in ten years (0.1/365). As a result of this method, one part will be stored for the whole year. The planned maintenance action in this example can only start when there are two parts available. Therefore a scheduled maintenance stock level should be introduced with two parts and an unscheduled stock level with one part.

This scheduled steady stock level situation can be used on both local and global warehouse levels. The parts can be stored in the global warehouse when ADI type 2 is also present. Considering only the CS Central information, the scheduled stock level should be implemented in the local warehouse, resulting in more local stock. Therefore, it should be determined if the unscheduled and scheduled stock can be shared and under what circumstances. Maintenance can only be performed if all necessary resources are available. When parts are stored locally, it is crucial to ensure that all parts required for the event are stored locally. Otherwise, the advantage of a fast response time when storing locally is lost, as the maintenance action will have to wait for all parts to arrive. As a result, stocking the parts locally results in a low WT for scheduled demand, but it will not improve the CODP compared to the current unscheduled demand situation.

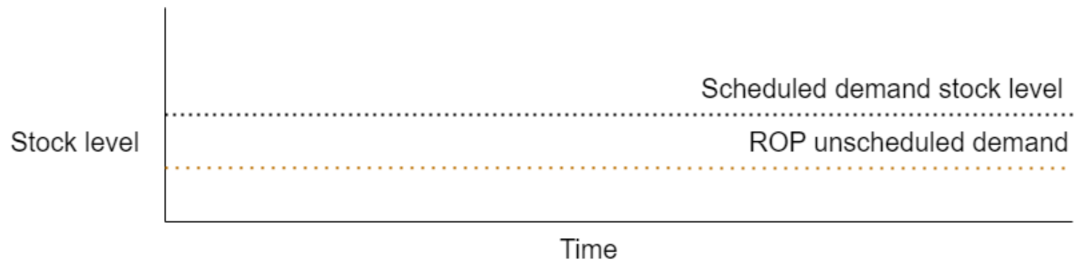

Figure 5.4: Scheduled steady stock level

5.4.2 CS Local as ADI resource

In this section, the CS Local information: Recommended parts, the proposed frequency, and the last performed date. The due date of the maintenance is obtained based on the last performed date plus the proposed frequency. There are two options to include CS Local ADI; Demand information probability distribution and Reservations.

Demand information probability distribution

From the interviews can be concluded that the due date is often seen as a flexible date. If the machine experiences a breakdown, the planned maintenance can be brought forward to minimize the total downtime. Another option is that the customer can not miss the production capacity at the due date moment, and the maintenance is postponed. A third option is that the maintenance is not performed at all for that time. This results in uncertainty about when the next demand will take place and a due date that will not directly lead to an order.

From the CS Local information is known that if a maintenance frequency is bi-yearly, and the maintenance was performed last month, the probability that maintenance occurs the next month is smaller than over one and a half years. Therefore a planning method option can be to incorporate a probability in the demand of the parts, see Figure 5.5. The ADI can be used to enrich the current planning method. Preferably, the local stock levels are not adjusted in between SPartAn updates. So when the frequency is smaller than eight months, this method does not make a difference compared to the previous method. Another disadvantage is that the standard deviation of the date the maintenance will be performed is unknown and not available in the data. Therefore performing this method solely based on data will not be possible.

Reservations

The fourth option to be considered is a method utilizing reservations. Based on the local PM tracker, a maintenance action has a start and end date. In the current planning method, demand is not linked to an event, but only to an order on one specific date. With a reservation, a part is reserved in stock for a scheduled maintenance event. The reservation can be linked to a group of events at a plan group. This makes the planning less flexible but ensures there is stock for scheduled activities. In Figure 5.6 a graphical representation is given of the effect of reservation on the local stock levels. In the first situation, the local warehouse has frequent reservations, the stock levels can be adjusted based on the reservations. Instead of stocking parts continuously, a scheduled stock is only reserved for a specific period. At one time period, multiple reservations can

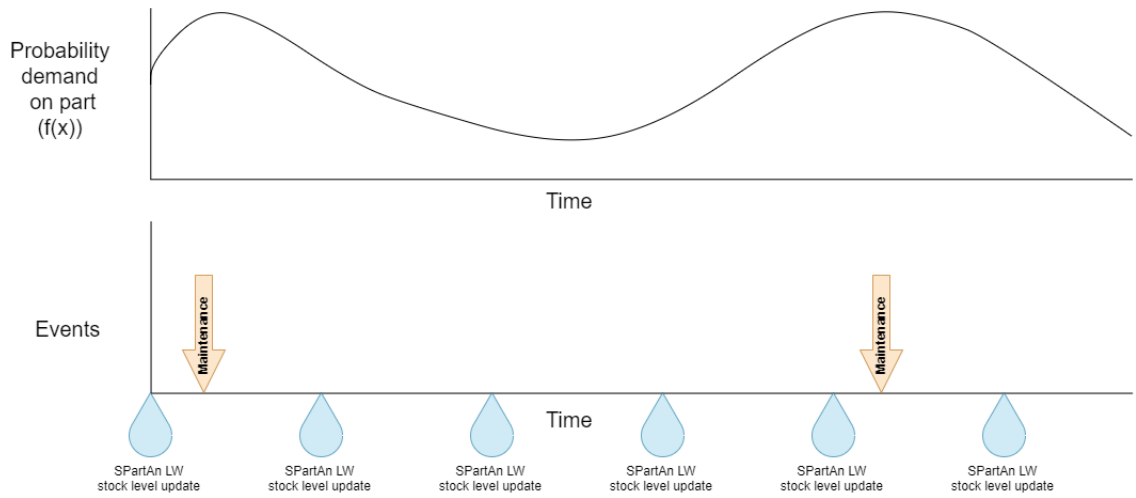

Figure 5.5: Scheduled spare part demand based on a normal probability distribution

take place. If a maintenance action is performed and the reserved parts are used, the reservation should disappear. A difference between the reservations and the scheduled maintenance stock level method described earlier is that the reservation is temporary.

In the second situation, there are no frequent reservations but only one in the time interval. For SFP, information about this less frequent demand is the most valuable because frequent demand is already taken into account in the usage rate. With this reservation method, the less frequent peaks in demand can be covered (e.g., one machine has tri-annual maintenance on one specific part).

In the third situation, there is frequent maintenance. For example, a bi-weekly part change on twelve comparable machines served in one plant group. In this case, a steady demand can arise. If the same employees serve the machines, the activities will probably be spread over time because the employee resource will be the limiting factor. In most cases, not all machines are served on preventive maintenance at the same time because the customer does not want to lose all production capacity at the same moment. In this last situation, when there is a steady demand rate, the situation is the same as the unscheduled Poisson situation because, in both situations, there is a fixed demand rate.

The confidence interval taken into account for the start and end date of the reservation influences the cost-reducing potential of the reservations. If the confidence interval is very broad this will lead to a steady state for scheduled demand, which will result in the same situation as the current planning method. The smaller the confidence interval the better the reservations work, unfortunately, due to the uncertainty in the start time of the event there will always be a confidence interval. The variance in an event's start time depends on many factors, e.g., customer, failure of machines, and available resources.

If the CS Local information is assumed to be reliable, so all the recommended parts are used, the proposed frequency is attained, the last date that the parts are replaced is known, and the maintenance is performed just before the given due date or the moment that the failure is expected. In this situation, the information at CS Local can be used as ADI type 2. Consequently, the parts can be stored in the global warehouse, and two weeks before the due date the part can be sent to the local. As a consequence, the holding cost and transport costs will decrease. Unfortunately, this is an unrealistic situation because there is still a lot of uncertainty in the current CS Local information.

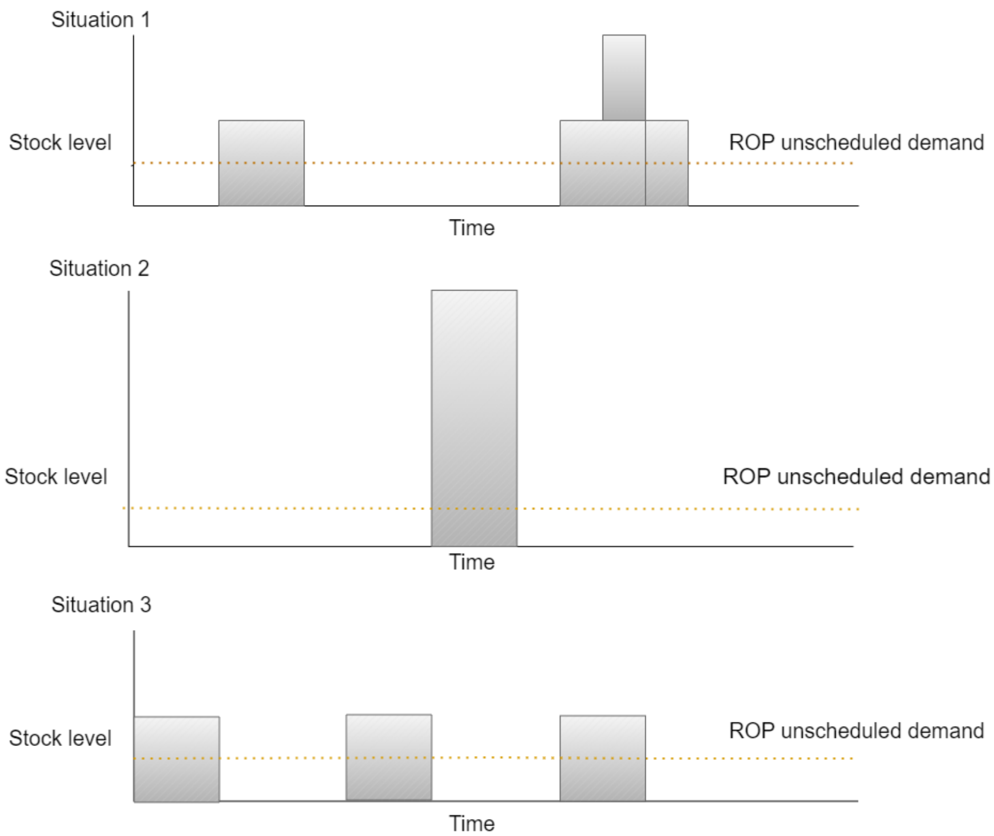

Figure 5.6: Reservations

5.4.3 Service Orders as ADI resource

From Table 5.1 and Section 5.2 can be concluded that the service order data is the most reliable, but unfortunately, this information is not always available three weeks in advance.

Real demand

As presented in Table 4.1 an analysis of service orders is performed. From the category, after-sales demand, 11% of the service orders are submitted at least fourteen days before the date indicated that the part must be available on location. For the scheduled service demand category this is 19%. For these orders, there is time to transport the parts from the global warehouse to the local warehouse. 5% of the after-sales service orders are more than three weeks in advance submitted. This information can be used as ADI type 2 information. 52% of these service orders were indicated with a scheduled Z-code.

Conclusion DP4

As presented in Figure 5.1, the stocking policy design parameter is crucial in determining the rest of the design. Therefore, a decision has to be made on which method to be used before deciding on the other design parameters. The planning method should aim to move the CODP of the scheduled parts upstream to the GW.

For the stocking policy, the combined method has the most potential. The scheduled parts should be stored in the GW, and when CS Local has their PM plan complete, the parts should be temporarily stored in the local warehouse as a reservation. This ensures the CODP, for these scheduled demanded part known three weeks in advance, is moved upstream. This reservation should take into account the uncertainty of the timing and the parts required for maintenance. This stocking method has the most potential as it takes into account the actual moment of maintenance and not just the probability of usage over a time interval, resulting in a more effective stocking. Additionally, the reservations method is preferable over the normal distribution method as the probability distribution method requires information for over at least eight months, and it will lead to a probability of expected demand. Furthermore, the reservation method can ensure all parts required for an event are available at the start of the event, while a probability can result in an average expected demand which can be too low for an event. Moreover, the plans on the Fleet planner (Section 4.2.3) can cooperate with the reservation method. In the detailed design, additional research should be performed into the confidence interval of the start date of an event that should be taken into account and the uncertainty that should be considered if planned maintenance will be performed or not.

Design decision: The scheduled maintenance demand should mainly be stocked in the global warehouse. The ADI of the CS Local team should initiate a reservation to temporarily stock the part in the Local warehouse around the demand date.

5.5 DP5: Forecast Method

The fifth design parameter is the forecast method that should be used. The forecasting method can be divided into unscheduled and scheduled demand. The unscheduled demand can be forecasted with the same method as it currently happens, described in Section 1.3 and Appendix A. This unscheduled after-sales proportion will be smaller because a part will be included in the scheduled forecast. The scheduled maintenance parts forecast can be made based on historical demand information, ADI, or a combination of both.

5.5.1 Historical demand information

In the historical demand data, the usage rate of the spare parts per machine is available. This information can be used to determine the last replacement date of a part and the frequency of usage in the past. Incorporating this information into scheduled event forecasting can enrich the accuracy of future predictions. However, solely using historical demand information will result in the same forecast as the unscheduled forecast.

5.5.2 Advance Demand Information

The ADI which is on time to include in the forecast is the recommended parts and the advised frequency. ADI should ideally be of type 3, but it does not necessarily have to be an actual order. For example, the frequency of maintenance. However, the disadvantage of this ADI is that it will give the information which is advised, not what is executed, which can lead to an over-forecast. on the other hand, using the ADI ensures that all proposed maintenance is taken into account in the forecast.

5.5.3 A combination of ADI and historical demand information

The third option is a combination of historical usage data and ADI type 3. This option has the most potential. The ADI should be used as a basis and enriched with eventual historical demand information. For instance, if the ADI recommends a preventive frequency of two years, and in the historical usage information can be seen that the part was changed due to a breakdown last month, the demand is expected in two years instead of two years later than the last preventive maintenance moment. During the interviews, CS indicated that for some maintenance activities, multiple of the same parts are needed. More research into this topic can be found in Appendix D.

Unfortunately, this is the case for a very small scope of the parts, so this will be out of scope for this project.

Conclusion DP5

The fifth design parameter aims to give a forecast method for parts with ADI. It is recommended to combine ADI type 3 and historical information at the global warehouse level, as parts used for preventive maintenance are stored in the global warehouse. Meanwhile, the forecast for the local reservations should be based on the CS Local ADI type 2. Additionally, the forecast is dependent on the lead time. The lead time of the scheduled demanded parts should be the same as the lead time of the unscheduled parts forecast.

5.6 DP6: Interaction Current Planning

The sixth design parameter, the interaction of the ADI with the current planning method will be discussed in this section. First, the interaction options with the global warehouse planning are discussed in Section 5.6.1, subsequently, the interaction with the current local warehouse planning is discussed in Section 5.6.2.

5.6.1 Global warehouse planning options

The current global warehouse planning is described in Section 1.4.1 and summarized in Figure 1.2. From this method can be concluded that the demand has first been split into three categories; 1. Forecast, additional demand, and factory forecast, 2. Diagnostic demand, and 3. UI&R. These calculated ROP levels are added to one global warehouse ROP level. The scheduled maintenance forecast as described in Section 5.5 can be included as a separate demand category or combined with a current demand category. In the following sections, the method and the advantages and disadvantages of the method will be described.

Separate scheduled and unscheduled demand global warehouse ROP levels

Before 2022 the planning of the global warehouse was made based on one stochastic demand stream. From 2022, the forecast has been split into three forecast categories to calculate three individual ROP levels. This splitting has been done for the following two reasons. First, the UI&R has been considered separate because ASML can plan the moments and the content of the upgrades, installs, and relocation, and consequently can decide on the moments the parts are demanded. Based on these characteristics the demand can be considered deterministic. The uncertainty for this part of the demand can be removed. Second, the not used diagnostic demand is considered separately because the parts are not used and will be back in stock in fourteen days, the lead time considered in the ROP calculation is therefore considered fourteen days. The average supply lead time of parts is multiple months. From the total after-sales demand approximately 30 percent of the demand is not used. The SFP team analyzed the effect of splitting the used and unused demand in the ROP calculation and concluded that the advantages of the reduction in lead time between the supply lead time and the diagnostic lead time but including two times stochastic uncertainty is bigger than the advantages of considering the two stochastic demand streams as one demand stream and only considering one-time stochastic uncertainty. This effect holds as long as the lead time is significantly longer than the diagnostic lead time.

With this in mind, the first option is to separate the scheduled maintenance forecast in the planning. When the scheduled demand has other characteristics in timing and content as the existing categories, this split is justifiable. The ADI can give additional information about the moment the maintenance will take place and which parts are needed. When this ADI results in an exact moment when a specific part is needed, the scheduled demand could be considered deterministic. The ROP calculation for deterministic demand according to Chiang ' & Gutierrez (1996) is the ROP (Order up to level) for scheduled demand that could be calculated by the demand during (lead time+ review period). The review period for the global warehouse planning is one month. The ROP calculation can be found in Figure 5.7.

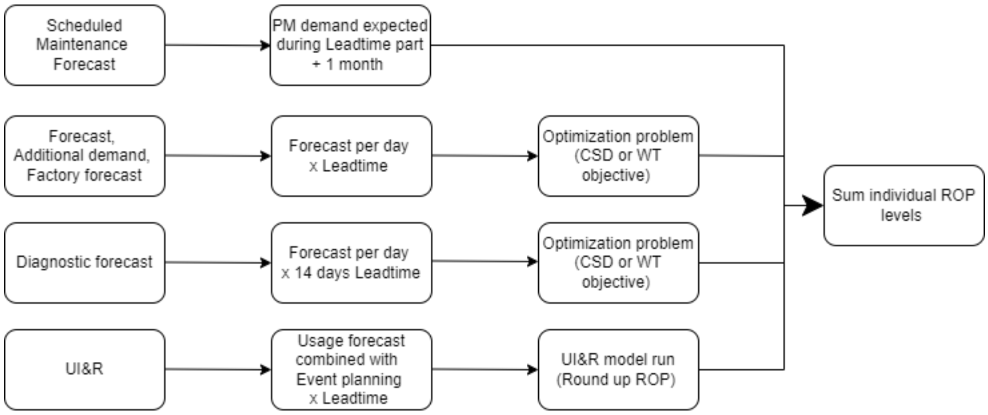

Figure 5.7: Separate scheduled and unscheduled ROP global warehouse planning

This method has multiple requirements. Firstly, the ADI should be of type 3, so be known at least a new buy lead time + one month in advance. Secondly, the maintenance has to be carried out with certainty, preferably the demand is already linked to a customer order. Thirdly, the scheduled demand should not change in terms of timing and content. For example, the scheduled demand should not be influenced by other factors that can change the expected time of content. Practically, if a machine interchanges a part automatically for example with an automatic supply line, no matter the external factors. The demand for this change can be considered deterministic if the usage is at a constant level. If the part replacement is dependent on the availability of different resources, such as engineers, the demand can be delayed in comparison with the planning. The advantage of this method in comparison with the current method is that the uncertainty taken into account for the fraction demand that was included in the stochastic stream can be removed.

The scheduled ROP level should be added by the other three ROP levels in the GW planning, resulting in one single-item ROP level per part. However, if the scheduled demand is characterized by uncertainty in both timing and size, and with another stochastic distribution, such as a binomial distribution (as tested in the research of Zhu et al. (2020)), then the scheduled demand could also be considered separately. However, the impact of splitting the scheduled demand in a separate stochastic demand stream should be tested in comparison with the old situation because the sum of multiple stochastic demand streams is also stochastic. In a theoretical scenario where a part only has scheduled demand, the demand distribution can be fitted and an optimal policy could be determined. When the scheduled demand is the maturity of the demand, other distributions could be more cost-efficient.

Additionally, the lead time has a significant impact on the ROP. If, in theory, the scheduled parts are not supplied by the supplier but are repaired, the lead time can differ from the current supply lead time method. If this difference is significant, it can be a reason to separate the scheduled demand.

Combining scheduled and unscheduled in global warehouse ROP levels

When the scheduled demand has the same characteristics as one of the three current categories it is advantageous to sum the forecast with other categories before the ROP is calculated, to ensure the optimization problem is based on as few optimization problems as possible.

Scheduled maintenance is often influenced by the unscheduled maintenance moments, for example, if scheduled maintenance is performed each half year, but if there is a breakdown this scheduled maintenance interval moves in time. The failure probability is Poisson distributed, so the moment the scheduled demand appears is uncertain. The scheduled demand should therefore be included in the stochastic demand categories. The global warehouse planning inclusive scheduled demand is given in Figure 5.8.

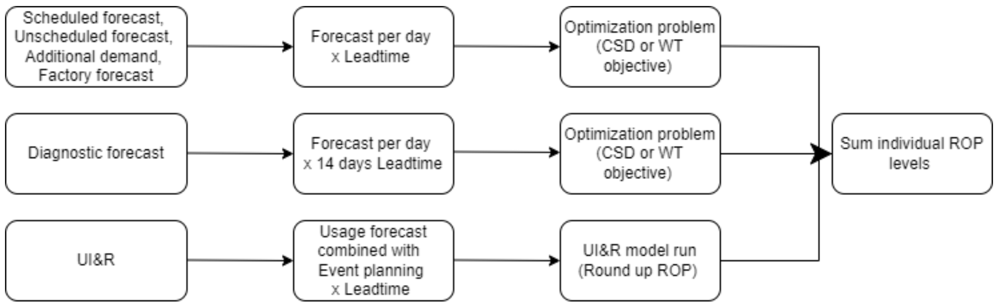

Figure 5.8: Combined scheduled and unscheduled ROP global warehouse planning

5.6.2 Local warehouse planning

The interaction of the reservations method with the current local warehouse planning is given in Figure 5.9. The SPartAn algorithm only considers Poisson demand. The UI&R demand is only stored centrally, so not included in the local warehouse planning. With the reservations method, the scheduled demand will mainly be stored global. Although the temporary local ROP characteristics should be determined, but this will not interact with the current SPartAn process.

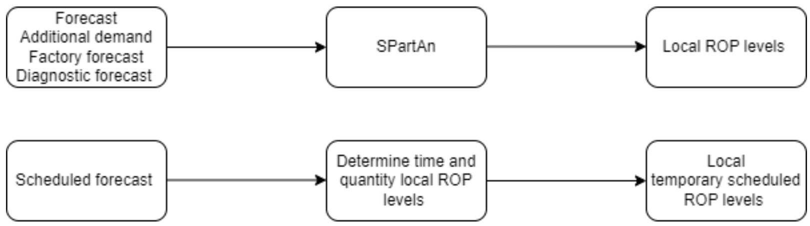

Figure 5.9: Local warehouse planning scheduled

Conclusion DP6

The sixth design parameter describes how the integrated framework works with the global and local warehouse base stock levels. The planning of scheduled maintenance action of ASML is affected by the unscheduled maintenance of the same part, but also the maintenance on other machines due to resource constraints. Therefore, the approach with the most potential is the combined scheduled and unscheduled forecast in the global warehouse planning. This is mainly because the separate method needs order information (ADI), which is available a new buy lead time + one month in advance (type 3), which is currently unavailable. The interaction between the GW planning and the ADI will be facilitated through the use of a separate forecast type, while the global warehouse plan categories will remain unchanged. It is important to note that local warehouse planning on a tactical level should not interact with the reservations method.

Chapter 6

Detailed Design

In this chapter, the details of the conceptual design in Chapter 5 will be studied. Before this detailed design could be formulated, the ADI available indicated in the interviews should be compared with the actual usage data of the parts. From this analysis, an accuracy of the ADI is obtained in Section 6.1. Based on this analysis, ADI requirements for the detailed design are defined in Section 6.2. Subsequently, it is assumed that the ADI meets these requirements. Based on this assumption, the detailed design of the tactical planning is given in Section 6.3. The detailed design has been divided into the global warehouse detailed design in Section 6.4 and the local warehouse detailed design in Section 6.5. Next, the operational planning consequences and the seventh design parameter (How will the ADI influence the order fulfillment and allocation process?) will be discussed in Section 6.6. In Section 6.7, the details of the forecast method including ADI are discussed. Additionally, the effect of the design on the SLA and costs are given in Section 6.8. To conclude, an overview of the advantages and disadvantages of including advance scheduled demand information in the forecasting and planning framework will be given in Section 6.9.

6.1 Test Accuracy of ADI

In Section 4.2.4, four characteristics of ADI are given; timeliness, accuracy, availability, and completeness. Before the detailed design is formulated, the accuracy of the ADI should be tested. In Chapter 5 is concluded that the ADI available at CS Local has the most potential to be used as ADI type 2. The timing, how far before the maintenance the usage is known, of this information will be sufficient because the CS Local introduces the PM list at the introduction of each machine. The content of the PM list is expected to be less accurate than the timing. The preventive maintenance list of the CS Local team has a frequency, a due date, and a link to the description of the event. In the interviews, CS indicated that the due date is not always attained due to the low priority of preventive maintenance actions. However, CS indicated they plan to perform the activities on the PM list at the corresponding machines.

To validate this information, the PM list of the machines in a specific location is compared with the historical usage of the parts on these machines. The historical usage data of the parts indicated in the maintenance description on the machine are controlled for the past three years. Surprisingly the historical usage of the parts on the specific machine does not align with the PM list. This difference can be caused by several factors, such as the service part is never used on the machine over the past three years, the frequency of the part usage does not match the frequency established by the CS engineers, or the part was not used in or around the expected usage month based on the last preventive maintenance action. Remarkable is that the pilot location is known to be one of the most advanced locations in terms of preventive maintenance activities. Therefore, it is plausible that this local has one of the most accurate and up-to-date PM lists for EUV compared to the other locations.

To conclude, the CS Local information in this specific location is less accurate than how it is presented in the interviews. Using the CS Local information of this location will lead to overstocking because maintenance is planned but not performed. For future research, it is recommendable to look into the PM list of other locals and compare their plans with the historical usage data. Thereby it is recommendable to look into the data of other business lines (DUV or MPS).

6.2 ADI Requirements Detailed Design

Based on the findings in Section 6.1, it can be concluded that the already defined imperfect ADI is even less accurate than indicated in the interviews. The ADI will not be accurate enough to include in the tactical forecast and planning process. The information should be more accurate in content and should be available for SFP. The following data requirements for the preventive maintenance list of the local teams are needed to function as ADI type 2.

- The accuracy of the parts listed in the maintenance instruction (Coach file) should be 100 percent.
- The maintenance actions on the PM list should be performed.
- The frequency of the maintenance actions determined by the CS Locals should correspond with the actual exchange rate of the part.
- The actual usage date of the part should be within an interval around the due date. For example, if a part is exchanged every 300 days, the maintenance can be performed fifteen days before the due date until fifteen days after the due date.
- If there are changes in the PM list or Coach data, these changes should be communicated to the forecast team.
- The list of PM activities should be known at the time the machine is put into use.

The first item on the list, the accuracy of the parts, is a responsibility of D&E. Currently, the usage registration of parts is not linked to a specific event, only to an event type (Z-code), which makes it difficult to control the accuracy of the parts list. CS engineers should actively communicate any outdated information on the list, as this is not a priority and is often not communicated now. In the Fleetplanner 2.0 application, the maintenance event and the service order can be linked to the systems. In 2024, the first EUV site will switch to Fleetplanner 2.0. The rollout to all sites is expected in 2028 but depends on the readiness of sites to administrate/ perform scheduled maintenance. With the introduction of Fleetplanner 2.0 at all sites, the accuracy of the parts list could be improved, and the parts in service orders could be indicated as Used or Unused. This information could be linked with the recommended parts.

The second and third items are agreements between ASML (CS) and the customer. Together they should determine the maintenance actions and the frequency of the maintenance. ASML should present the advantages and disadvantages of performing preventive and scheduled maintenance so that when the actions are planned, the customer and CS are aware of the consequences. Only the actions should be listed where they are certain that the actions will be performed on the stated frequency. The mindset change for the CS Local and customer, to prioritize the scheduled maintenance more in comparison with the current situation, will take some years. When the mindset is changed, data improvement is probably possible within a year.

Giving accurate information about the exact moment the maintenance will be performed is difficult due to all the external influences that can influence the moment of the maintenance. For example, if another machine is down and the engineers are needed for the unscheduled breakdown. The ADI should give a due date, and the maintenance should at least be performed within an interval around the due date. The date the part is needed on location may deviate from the due date, with a certain percentage of the frequency. The maintenance should be scheduled based on multiple factors, e.g., production capacity and engineer availability. So a deviation in the due date is reasonable.

In addition, the PM list information and maintenance procedure information (Coach) should actively be communicated to the forecast team so that updates can be taken into account. Thereby, the PM list of the new machine should be known when the machine is put into use, so the forecast and planning team can take this information into account. The mindset change and the active management of the quality of the PM list will take multiple years.

The detailed design will be formulated based on a situation where the ADI type 2 information fulfills the above requirements. Based on the interviews and the project timeline of the Fleetplanner, it is expected that the first pilot with one local can start in 2024. The worldwide execution depends on the readiness of sites to work with scheduled maintenance, but assuming that they are willing to perform scheduled maintenance, the design is formulated for post-2024.

Design conclusion: The currently available ADI does not have the necessary accuracy to be incorporated into service forecasting and planning processes. However, it is assumed that the ADI will meet the required standards in the future and can thus be utilized in service forecasting and planning.

6.3 Detailed Design Planning

When the ADI meets the requirements, the following method can be used to include the scheduled maintenance information in the current forecast and planning method. The design is presented in Figure 6.1. In the As-Is situation, the total after-sales demand supply chain is given. Parts for scheduled maintenance (included in unscheduled demand) are stored in both the local and global warehouses. In the detailed design, the To-Be situation for solely the scheduled demand is given. In this situation, scheduled demanded parts are stored in the global warehouse. As the scheduled maintenance date approaches, a part is stored in a local temporary stock point and locked for the maintenance activity. Once the part is used, the temporary stock point disappears. The following sections will discuss the detailed design of the global warehouse planning, local warehouse planning, and the forecast method.

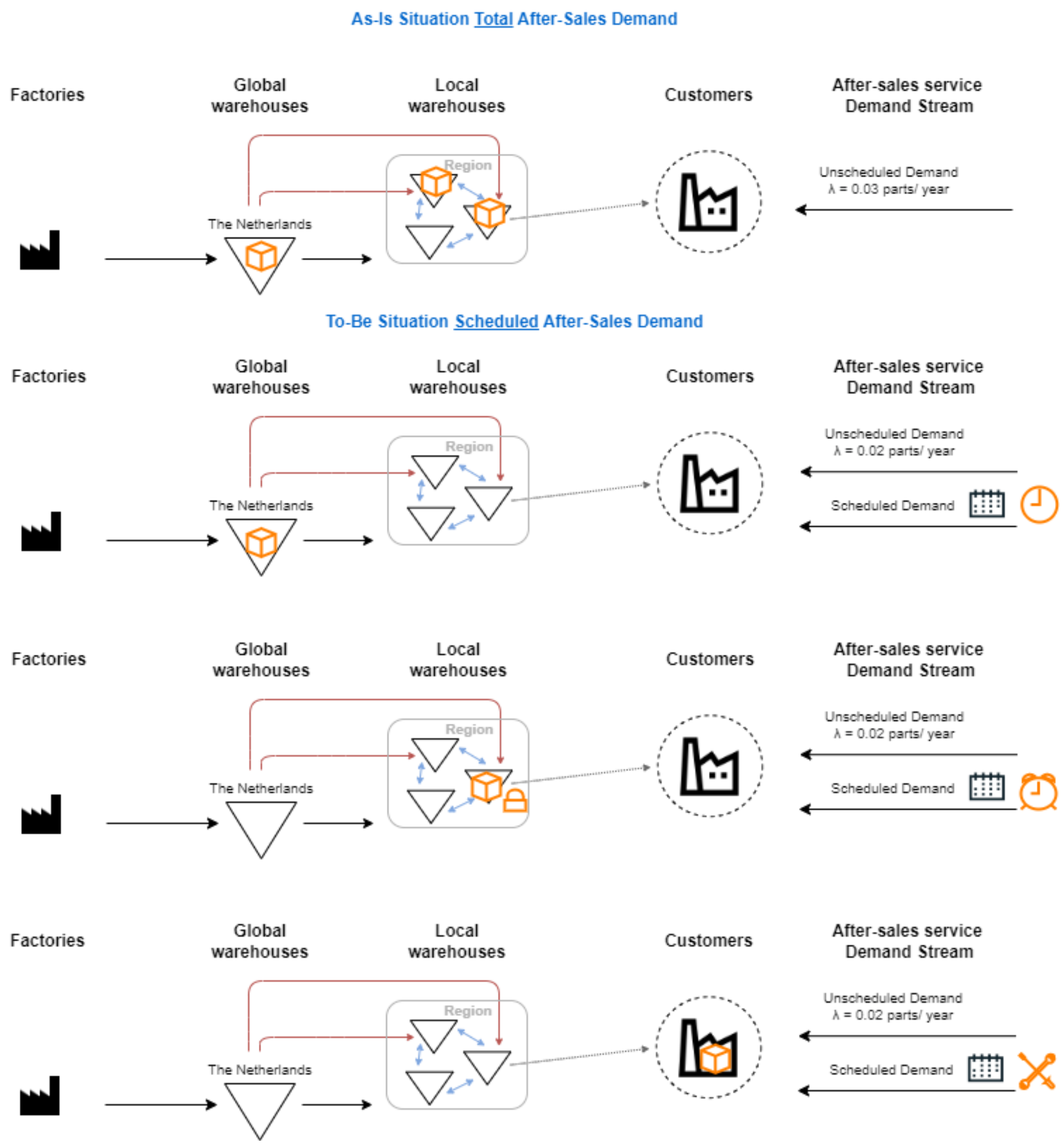

Figure 6.1: Detailed design supply chain

6.4 Detailed Design Global Warehouse Planning

In Section 5.6.1 is concluded that the global warehouse planning should combine the unscheduled and scheduled forecast in the global warehouse planning. When the service demand is divided into unscheduled and scheduled demand the total demand at the global warehouse stays the same compared to the current situation. To determine whether the demand is currently included in the diagnostic forecast or other forecast categories, the following analysis is conducted.

Used vs. Not Used

The unscheduled forecast is divided into used and unused parts. Not all service orders will result in the usage of a part. A service order could be canceled, or after the maintenance activity indicated as used or unused. In general, local teams find it difficult to order the parts that will be used. Of the service orders created in the first half of 2022 (all service demand), one-third are canceled, and almost one-third of the involved parts are unused. The other parts are used. From the service orders that were not canceled and the parts demanded from January until October 2022, the percentage of used and not used parts can be compared. In Figure 6.2, the usage percentages are given. For the total after-sales demand, the parts that are ordered and confirmed as used are more than half of the number of parts. For a selection of the service order lines with Z-codes that indicate that the parts are needed for scheduled maintenance (Z22, Z24, Z27, and Z38), the used percentage is higher than for the total after-sales selection. And for periodic maintenance (Z27 and Z38), the usage percentage is even higher. This usage indication has no limit in terms of time, so a part may be used two weeks after the moment that part is indicated as needed. The local teams are more capable of ordering the part that will be used for scheduled maintenance than general after-sales, but this will not say that the parts will be used immediately.

The CS engineer can indicate which parts are needed for the maintenance. It can happen that some parts are not used. But with active management of the maintenance instructions, this can be minimized. Based on this ADI assumption and the used/unused history, the scheduled demand is not included in the diagnostic forecast category. The global warehouse planning can be calculated as described in Figure 5.8. The effect on the GW planning when the current scheduled unused demand is included in the used demand is tested. The change in inventory value is minimal. In terms of computational time, there is not expected to be a change because the total number of parts stays the same, and the complexity does not increase.

In the future, when part usage is linked to a maintenance event, a correction can be made on the scheduled demand based on the probability of the used and unused parts. Although, it will be more effective to proactively monitor this and improve the list of parts needed for a maintenance activity than reactive correct the usage afterward.

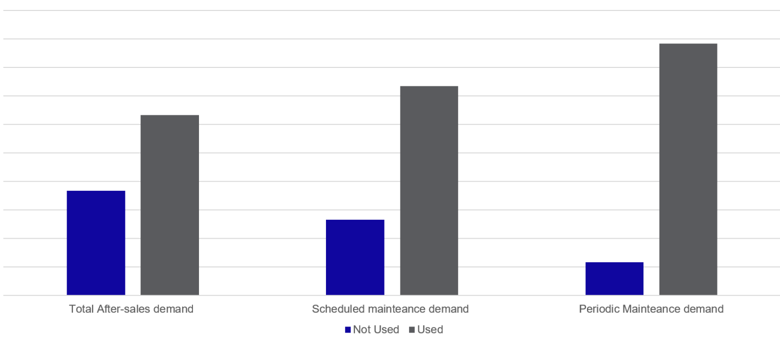

Figure 6.2: Used vs. Not Used analysis

6.5 Detailed Design Local Warehouse Planning

From Section 5.4, it is concluded that the reservations method has the most potential. The potential of the reservations method depends on the quality of the ADI and the characteristics of the reservations. In the following sections, the ADI resources and the characteristics of the reservation will be presented. Subsequently, the detailed design of the local warehouse planning will be explained.

6.5.1 ADI resource for LW planning

In the local warehouse planning, the scheduled demand is distinguished from the unscheduled demand that is included in the SPartAn model. The SPartAn model assumes that the global warehouse has an infinite stock. This assumption is feasible, as the GW plans the parts against WT and CSD objectives. Because the total demand does not change, the LW reservations method can also assume this.

Based on this conclusion, all ADI of type 2 of CS Local can be used. If CS Local provides the information in a service order, the information could be used from two weeks in advance of the maintenance, as there is no processing time required. If CS Local communicates the ADI in an alternative format to CSCM, the information from three weeks in advance can be used to base the reservations on. Additionally, the Fleetplanner project team indicated that the Fleetplanner will be used for the upcoming four weeks. The Fleetplanner events will be linked to a service order, which will contain all the demanded parts. In a service order, the information for the reservation will be complete. Furthermore, the service order for scheduled maintenance (not yet connected to the Fleetplanner), known three weeks in advance can also be utilized.

6.5.2 Characteristic reservation

A part needed for planned maintenance should not solely be stored in the global warehouse because the CS engineers indicated that a maintenance activity is postponed in 80 percent of the cases but can also be brought forward when the machine is standing still due to another issue. Therefore, the part should be stored locally at an interval around the due date. However, the part can be linked to an order of the customer when the part is still at the GW, which results in that the CODP is located in the GW. If the reservation interval is very small, there is a risk that the scheduled demand is demanded and the part is not locally available. In this case, the unscheduled local stock should be used, and there is a possibility that the stock is not available and lateral or emergency shipments are needed. On the other hand, if the interval is too large, the potential in terms of holding cost of the reservations decreases. Additionally, dedicated stock for scheduled events decreases the efficiency of sharing the local stock with all the demand.

Unfortunately, there is no data on the initially planned date of the event and the performed date. Based on the interviews, it is recommended to reserve a part two weeks in advance of the maintenance, as at that moment, preparations for the event have already started. The postponement of an event can be up to a half year or even not performed at all. However, as previously stated in the ADI accuracy Section 6.1, it is assumed that the proposed maintenance will be performed, which makes this last scenario unrealistic. Currently, a part is reserved for a specific service order at the local warehouse for seven days. For example, suppose the initial required date of the service order is the first of December, and the part is still in the local warehouse on the third of December. In that case, the local warehouse will keep that specific part for the corresponding service order until December 8th. Based on this information, it is advised to store the part from two weeks before the maintenance date until a maximum of two weeks after the due date. The reservation is based on service activity, and once the event is completed, the reservation will be consumed.

A calculation can be made to determine the optimal interval for reservations. This calculation involves making a trade-off between the holding cost of stocking globally and locally and the probability that maintenance tasks will be performed on the dates around the planned date. Unfortunately, this probability is currently not available.

This reservation interval method implies that the ADI should be given two weeks of routine shipment plus approximately one week of processing time plus the two weeks one-sided interval around the maintenance. This result in a total of five weeks. The processing time depends on the completeness of the data and the systems the reservations will be managed in. Ideally, this process is performed without manual intervention. Therefore, the reservations method should stimulate the CSCM local engineers to submit the service orders timely for scheduled demand if they already know the maintenance will be performed. This service order information will be useful.

6.5.3 Reservation scenarios

In this section, the characteristics and way of working of the reservations will be discussed using example scenarios.

Scenario 1: A customer plans to perform scheduled maintenance

- First of all, the expected date that the maintenance will be performed should be indicated. This information can be from the CS Local PM list, the Fleetplanner, or early submitted service orders. Ideally, the information is kept in one application. If the Fleetplanner is connected to SAP, and service orders are created based on the PM list information, all the data could be collected in SAP.
- Subsequently, an interval from two weeks before and two weeks after the due date is formulated. Which results in the temporary local warehouse stock point.
- NORA should ensure parts are locally available at the start of the reservation interval. The transshipment should be made by a replenishment/routine shipment.
- The part is temporarily stored at a specific scheduled maintenance storage location. This can be a virtual status and does not have to be a physical status in the warehouse.
- The part is transported to the customer, and maintenance is performed.
- Remove the temporary reservation stock point when the part is used by the customer.

Scenario 2: Unscheduled demand at LW, no local stock, but a reserved part available

In this scenario, the local warehouse experiences a demand from an unscheduled demand and has only scheduled stock available. The parts in the LW can be combined and seen as one stock or kept separate from each other. The advantages of combining the stock are as follows; First, due to combining the inventory, the total inventory should be lower than when the stock is not combined. Furthermore, combining stock is beneficial for warehouse management. As there are no rules regarding which part should be used for a specific demand, the process becomes simpler to execute. When the inventory is kept separately for different demand streams, this can result in conflicting situations. For example, when there is a separate inventory point for corrective and preventive maintenance parts, if a system breaks down, and the part is not available in the corrective inventory parts stock but is available in the preventive parts stock, the machine cannot be repaired in a non-pooling situation. Explaining this situation to the owner of the broken-down system is difficult (R. Basten & van Houtum, 2014). However, a disadvantage of combing stock is that the stocking policy becomes more complex than in the non-pooling situation (R. Basten & van Houtum, 2014).

If the scheduled stock is kept separate from the unscheduled stock, the same principle as the UI&R stock will be used. When the UI&R demand is stored locally, the unscheduled demand cannot use these parts. In warehouses, these parts take additional time to manage. At ASML, customer service is a priority, and it can be difficult to communicate to customers that a specific part cannot be used due to its dedicated use for scheduled events, even when ASML performs above their uptime agreements. In practice, keeping the parts separate will therefore be difficult in practice.

As previously discussed, combining the scheduled and the unscheduled stock has the potential drawback of parts being used for breakdowns instead of the initially planned scheduled demand. ASML wants to stimulate the customer to plan maintenance in advance. As such, they aim to guarantee that if the customer plans scheduled maintenance in advance, ASML can deliver the part with at least the same level of certainty as the unscheduled demanded parts.

To obtain this goal, a solution between combining and not combining stock has to be created. The following process will be used in this scenario.

- Parts are locally stored at the reservation stock position.
- Unscheduled demand arrives at a local warehouse.
- Check order fulfillment sequence. Reserved parts should be restricted for scheduled maintenance and only be used for unscheduled demand purposes if there is no other stock available in the supply chain. The details of the order fulfillment sequence will be explained in Section 6.6.
- When the part is incidentally used for unscheduled demand, the reservation should be replenished again and the owner of the reservation should be made aware of the new expected time of arrival.

Scenario 3: Customer has a part reserved and an unscheduled demand

The temporary scheduled stock levels should be available for unscheduled demand of the same customer but should be locked for other customers served by the local warehouses. In 60 percent of the local warehouses, multiple different customers are served. The rule is based on the customer and not on the fab level. Because service commitments are formulated with the customers. The division of machines over the fabs is out of the scope of the SFP team.

The idea behind this method is that ASML should not have to refuse the delivery when a customer experiences a breakdown when a customer knows the part is available for scheduled maintenance for another goal. The customer and CS in this case can decide whether the part can be used for the unscheduled action. Additionally, if in this situation, ASML is unable to deliver the part needed for scheduled maintenance on time, the customer is aware of the reason. For other customers, combining stock with this scheduled stock from other customers should not be possible. This will encourage active management of scheduled maintenance events. The exact operational effects of this design decision will be described in Section 6.6. The reservation in this situation will work as follows:

- The parts are locally stored at the reservation stock position.
- Unscheduled demand arrives at the local warehouse from the same customer.
- Local CS and the customer can decide which maintenance has priority. The part is assigned to that service order.
- CS gives an indication of when the new expected due date is for the planned maintenance.
- Subsequently the reservation stock point is replenished based on the interval of the reservation.

Scenario 4: Due date has changed while the part is already locally stored

When the due date of a planned maintenance activity is changed the reservation will work as follows:

- Due date change, results in an interval change.
- When the due date is brought forward, the end date of the interval will also be brought forward.
- When the due date is delayed, the interval moves also in time. If the start of the interval is within two weeks the reservation is extended forward.
- If the due date is so that the maintenance is not expected in the upcoming 4 weeks, the restriction is released from the part. The order replenishment system can use the part to fulfill the worldwide demand.
- Local CS is not supposed to postpone the due date multiple times in a row to create additional stock for their own use. Therefore delaying the due date is only possible once. Otherwise, the restriction is released from the part.

Scenario 5: Reservation interval has expired, part is not (yet) used

In this situation, the planned maintenance is not performed at the moment it was expected to be performed.

- Reservation interval is about to end within four days.
- Reminder sent to the planned maintenance activity owner: Do you expect to perform this maintenance within the set reservation interval?
- If CS indicates that the planned maintenance will not be performed at all. The restricted status of the part will disappear and the part can be used for worldwide demand. If the maintenance is delayed, the situation as described in Scenario 4 will be the case.

6.6 DP7: Operational Planning Consequences

In Section 1.4.4, the current different operational processes are explained. The scope of this project is limited to the order fulfillment and allocation decision. Since the order fulfillment is automated by NORA and GESA, the requirements of this input data are also included in this section. The goal of this section is to answer the seventh design parameter; How will the ADI influence the operational order fulfillment and allocation process?

6.6.1 Order fulfillment and Allocation decision

The order fulfillment decision decides which demand will be fulfilled using which SKU. Emergency orders are fulfilled with GESA, while routine and priority service orders are handled using NORA.

NORA

The business rules used by NORA have been developed extensively in the past years. As a result, a complex set of business rules have been made. In summary, the order fulfillment depends on the Storage Location (SLOC), contract type, and service order priority. SLOC's have different categories on the global and local levels. The different SLOCs and their meanings can be found in Figure E.1 in Appendix E. Restricted SLOCs are not used in the NORA automation, they can only be used by manually. The same applies to customer-restricted stock. Contract type can be based on Global Parts Availability (GPA), Central Parts Availability (CPA), or Local Parts Availability (LPA). Almost 90 percent of the install base has an LPA contract. Finally, the service order priority, which is emergency, priority, or routine. When a service order is submitted, the following sequence is completed;

- Local unrestricted stock: Is there unrestricted stock available locally?
- Local semi-restricted stock Is there semi-restricted stock available? Based on the contract type look local or regional.
- Local predecessor/successor: Is there a comparable part locally available?
- Incoming direct shipments (TW31/US60): Are there shipments in the pipeline?
- KR30: Is there stock in the global warehouse in Korea?
- NL10: Is there stock in the global warehouse in the Netherlands?
- KR30 till iron stock: Is there restricted stock globally?
- Local excess within the region: Is there stock regionally?
- Local excess outside the region: Is there stock in another region?
- Continental hubs (NL05, US80, US16): Is there stock in a continental hub?
- Predecessor or successor within and outside the region: Are there comparable parts available in the region or the global warehouse?
- SSL sourcing within the region: Is there safety stock in the region?
- NL10 incoming stock: Is there stock in the pipeline for the global warehouse?
- NL10 lead time: Order a part at the supplier

For the reservations method, an additional temporary local storage location restricted per customer should be created. This storage location should have the same characteristics as the customer SLOC. In the fulfillment sequence, an additional rule should be added: Local customer-restricted scheduled maintenance stock. If there is unrestricted demand from the same customer, the customer can use this part and the stock point should be replenished, with a new customer-restricted scheduled maintenance stock. This step should be added between the incoming direct shipments and global warehouse check for inventory,

The operational planning of the scheduled event will work as follows; the sourcing by the NORA system will start 3 weeks (two weeks replenishment and one-week processing time) before the lower bound of the reservation. The operation process is graphically given in Figure 6.3. In the global warehouse, the parts have an unrestricted status, in the local warehouse, the parts will have the Customer Specific SLOC. If the part is used for another goal, the sourcing of the reservation follows the sequence above.

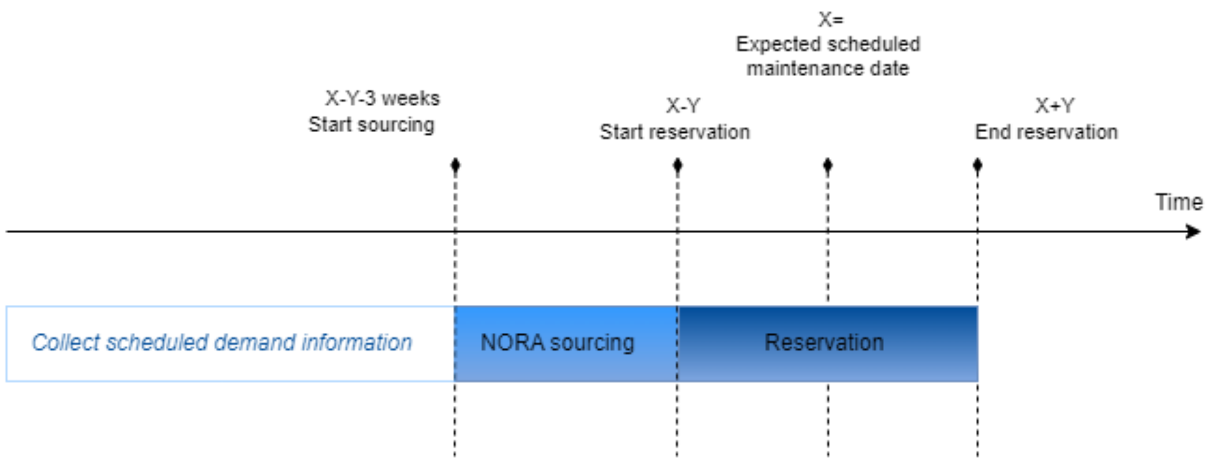

Figure 6.3: Operational planning

HERO

Currently, UI&R service tools have event planning in an application called HERO. When an UI&R event is planned, an expected corresponding planning is made for the tools which will probably be needed. An event item is created, which gives an expected interval when the parts are needed in which location. An event item can be based on multiple events. For example, for two UI&R events, there is a probability that a tool will be used for 10 percent, in this case, only one tool is reserved. Six weeks in advance of the event item, the tool is only available for emergency shipments and will not be actively transshipped to other local warehouses. This is done to prevent unnecessary transport costs. From three weeks in advance, the tool is actively sourced to the local warehouse. One week before the event, the tool changes to a restricted storage location, and the event item will be linked to a service order. The six weeks interval is determined based on two times three weeks, that if the tool is needed five weeks in advance of the maintenance for another maintenance, there is enough time to replenish the tool. The impact of these decided weeks is never calculated. The difference between the HERO method and this detailed design is that in this research scope parts are considered which are used, and parts can not be shared in usage. Thereby, the detailed design aims to store the maturity of the scheduled demand parts in the global warehouse. To conclude, the HERO application can be used to manage the reservation, although this will be in a different way in comparison to which the current UI&R tools are managed.

GESA

If the service order has been indicated with an emergency status, the GESA system will be responsible for the order fulfillment. When an emergency order is submitted, the system will instantaneously source the material. First, the contract type will be checked, and subsequently, the sourcing sequence described in the section above will be followed. And finally, a sourcing trigger will be activated by SAP. The reservation method influences the sourcing sequence described above.

Allocation decision

If there is not enough stock in the supply chain a decision should be made about where the stock should be allocated. This decision is made manually by Demand Allocation Lead or the Global Operations Center, this will result in more manual workload than in the current situation. If the same customer has both scheduled and unscheduled demand for a specific part the customer should choose their priority.

Input and effect on computational time NORA and GESA

As additional input, the NORA system needed the temporary local stock levels (reservations), the corresponding customer, and ideally a service order. This service order can also be an event item. Finally, the order fulfillment sequence should be changed. The seventh functional requirement indicated that the forecast and planning should be able to run in a reasonable amount of time. The operational planning will become more complex due to an increase in restricted storage locations and the expansion of order fulfillment rules, but these changes can be incorporated into the current NORA application. In addition to this, the reservations should be linked to NORA. Ideally, the reservation is made via SAP (and indirectly Fleetplanner) and directly linked with NORA. If this is not possible, a comparable system as HERO should be linked to NORA. All these changes are comparable in terms of computational power with the current applications and models.

6.6.2 Conclusion DP7

The last design parameter is to determine how the ADI will influence the operational order fulfillment and allocation process. The ADI influences the operational order fulfillment and allocation process in the SLOC and order fulfillment sequence. The inclusion of reservations in the operational planning will result in additional tasks for those who manually decide if a restricted part can be used for other purposes.

6.7 Detailed Design Forecast

The current forecast method is described in Section 1.3.1, and the Figure is given in Appendix A. There are three different types of forecasts; weekly, monthly, and bi-annual made forecasts. From the conceptual design can be concluded that combing the historical demand information with the ADI of type 3 has the most potential.

Monthly forecast - Global warehouse planning

The monthly forecast is used for global warehouse planning. Even when the forecast is integrated into current categories of the global warehouse planning calculation, it has multiple advantages to forecasting the scheduled part. Firstly, one of the functional requirements is to be able to indicate the fraction of the forecast that is based on ADI. Secondly, when the scheduled forecast becomes the largest part of the total forecast instead of the unscheduled forecast, another planning strategy may be interesting.

The global warehouse planning described that the forecast of scheduled and unscheduled demand will be combined. Therefore, the forecast should be given with an average usage rate per machine per year. ADI of type 3 can be used in this forecast, given that the ADI will be accurate. The preventive maintenance list per machine should be taken into account. Based on this list the frequency to use a part on a specific machine is known. Subsequently, the last moment the part is used on a specific machine should be considered, this can be a part usage due to a breakdown or due to preventive maintenance. This last moment of usage, plus the proposed frequency leads to an expected preventive maintenance demand moment. Based on this information, an expected demand per part in a period can be determined. In Figure 6.4, the global warehouse forecast, with the scheduled maintenance addition is provided.

For the Forecast, Diagnostic forecast, and Factory forecast, a correction for the growing install base is taken into account. The forecast is made based on the install base over eight months, to correct for the bi-annual local warehouse run. On the other hand, the UI&R forecast for the next month is based on the planned events in the next month. The scheduled maintenance forecast will also look to the install base of the next month, as the parts will only be stored in the global warehouse.

If a machine is already in the field with a PM plan, the demand expectation is known. If a machine already in the field set up a new maintenance plan or includes an additional event on the plan, the ADI should be known a supply lead time plus a one-month global warehouse run in advance. Otherwise, the part will be supplied from the unscheduled demand parts. If the total spare parts demand of the machine stays the same, this will not cause a problem. For machines that are planned to be put into use in the future, ideally, the PM list should be provided with a supply lead time in advance of the first maintenance action. From the interviews, it can be concluded that the CS Local can give the PM list at the moment the machine is put into use. Unfortunately, this will be too late for the first PM moment. As a recommendation for the future, the CS engineers should create the maintenance plan earlier, for example at the time the installation plan is created. An alternative method is that the forecast team will calculate an expected

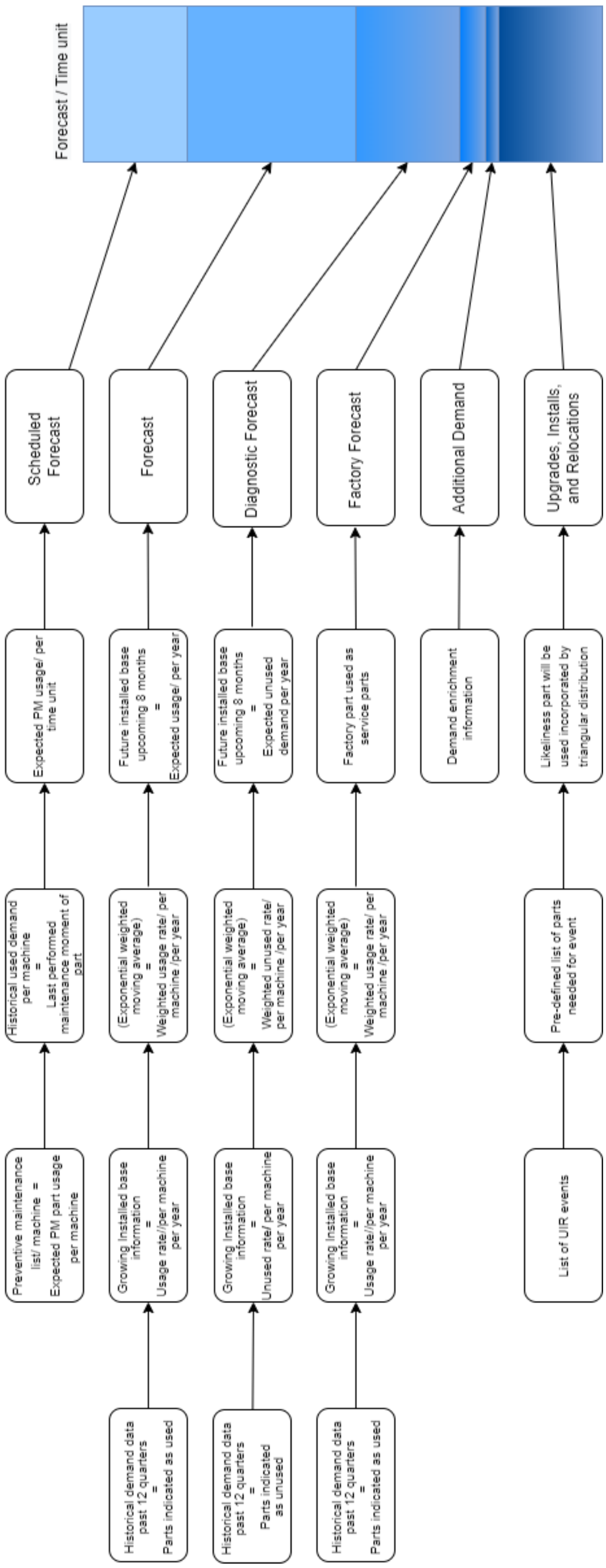

Figure 6.4: Global warehouse forecast

scheduled demand rate based on the PM plans of the same machine for the same customer. Unfortunately, for this correction, the scheduled demand forecast method should be used for some period.

By implementing ADI into the global warehouse forecast, there is an additional category to forecast, which makes the forecast more complex. Transforming the different ADI sources from all the local CS teams to valuable historical demand enrichment data will increase the complexity of the process, which may result in a time increase to run the forecast model.

Bi-annual forecast - Tactical planning local warehouses

The bi-annual made forecast is used for the tactical planning process of the local warehouses. Because the scheduled maintenance stock will not be locally stored, the half-year forecast will not include this category, like the UI&R forecast.

Weekly forecast - Operational planning local warehouses

Lastly, the forecast team creates a weekly forecast. This forecast is per month and for operational planning. This forecast will work with the same method as given in Figure 6.4. Only for the scope of the upcoming month. There will not be a forecast for the temporary local stock level only operational planning.

6.8 Result of Detailed Design on SLA and Cost

According to functional requirements FR1 and FR2 (Section 3.3), the detailed design should ensure the Service Level Agreements are met and the design is beneficial for the cost. The SLA is based on the waiting time (WT) for parts or the fill rate (CSD). When the ADI results in reservations the parts needed will be in the local warehouse when there is customer demand, which results in minimal WT and a higher fill rate than in the current situation.

The holding cost for parts stored in the LW is higher than the holding cost for parts stored in the GW. By mainly storing the parts required for scheduled maintenance in the GW, using the reservations method instead of the LW, holding costs can be saved. The potential of the transportation cost is calculated based on the number of service orders with Z-codes indicating scheduled maintenance (22, 24, 27, and 38) that are sent with an emergency status. From January until June of 2022, approximately 10 percent of this group service orders were indicated with the status of emergency shipment. Additionally, almost 40 percent of the service orders are indicated with the status "routine/prio order < 4" which means that the part is needed within four days. An emergency order is approximately three times more expensive than a routine shipment. Therefore, it is important to ensure that the parts are sent as a routine shipment for the reservation instead of an emergency shipment with last-minute indicated service orders. To conclude, the detailed design is expected to be advantageous for the costs and Service Level Agreements.

6.9 Advantages and Disadvantages

In Chapter 3, five deliverables of the project are given. The last deliverable is an overview of the advantages and disadvantages of including advance scheduled demand information in the forecasting and planning framework in this section the overview will be given. The advantages of the detailed design in comparison with the current forecast and planning method are;

- **Less stock in LW -** The scheduled service parts are mainly stored in the global warehouse instead of the local warehouse. The LW holding cost is higher than the GW holding cost. The reservations method ensures less local holding cost.

- **Fewer emergency shipments -** Due to the ADI, the customer demand is known earlier in advance than in the current situation. The part can be shipped with a routine shipment, instead of an emergency shipment with this information. This is advantageous for the transportation cost.
- **Incentive to communicate ADI -** The priority rules in the order fulfillment process, ensure the indicated scheduled demand gets priority. Including the ADI leads to an incentive for CS Local teams to communicate scheduled maintenance information with the forecast and planning teams.
- **Flexibility in maintenance planning -** CS Local indicated that giving the exact moment the maintenance will be performed is not possible without uncertainty. Working with a reservation interval will ensure that there is still limited flexibility in the maintenance planning.

The disadvantages of the detailed design are:

- **Forecast process becomes more complex -** Including the ADI in the forecast will result in a more complex forecast process than the current process. Translating a PM plan into a forecast will result in an additional manual workload because the locals do not work in a standardized way.
- **Administration operational planning -** Due to the additional restricted storage locations, the GOC gets additional work in allocating parts to the best request.
- **Less pooling of local parts -** Scheduled parts that are stored locally will be locked for a specific customer, this results in less pooling of local stock than in the current situation.
- **Planning depends on accuracy CS -** A weakness in the design is that the ADI depends on the input and communication of CS Local employees. CS Local employees have not proven yet that they will deliver accurate information in the future.

Chapter 7

Conclusions and Recommendations

7.1 Conclusion

The spare parts forecasting and planning model used by ASML considers all after-sales demands as unscheduled demands. This assumption is too generic because CS indicates that there are maintenance events known beforehand. The consequence of considering all demand as unscheduled while part of the service demand is scheduled is stocking against too much uncertainty, too many last-moment shipments, neglecting service performance potential, and too much incident-driven work. The information about these planned maintenance actions in the future could be called advance demand information (ADI). In this study, the available ADI is collected, and based on this result, a method is designed to incorporate the ADI into the currently used spare parts forecasting and planning framework.

Within ASML, there are different perspectives on the term scheduled maintenance. Semi-structured interviews have been conducted to determine what scheduled maintenance means for different stakeholders of the service process. On a tactical planning level, scheduled maintenance is seen as a demand that is known as at least a supply lead time of the part in advance. However, the perspective of CS engineers is that scheduled maintenance actions should be prepared but could already be planned next week. Based on these same interviews, the available ADI has been collected. There is information within the organization about the planned maintenance events. Unfortunately, there is no single source with information that is timely, accurate, available for the SFP team, and complete. To conclude, the ADI about scheduled maintenance events in the ASML teams is imperfect information.

Imperfect ADI can still be valuable compared to a situation where no ADI is considered. Therefore, a method has been designed to include the available imperfect ADI in the current processes. Currently, the CODP of a part is located at the local warehouse. In this research, the aim is to move the CODP upstream to the global warehouse for a fraction of the scheduled demand of that parts with ADI more than three weeks in advance. The CS Local engineers have the most accurate information but are not able to give the exact moment the parts are needed, as the maintenance will often be moved last minute. To deal with this imperfect information, the parts should mainly be stored in the global warehouse. When the maintenance date approaches, they should temporarily be stored in the local warehouse, dedicated to a customer and maintenance activity. In this situation, the imperfect ADI can still be valuable.

Before the detailed design is formulated, the given ADI in the interviews is validated with the historical usage data. Unfortunately, the ADI does not match the usage data. The imperfect ADI available is not accurate enough. As a result, a detailed design is formulated for a situation when the ADI meets the requirements. This solution includes local reservations for the parts. The reservations will be managed on an operational level by the order fulfillment rules and customer-specific storage locations. This reservation method is not only applicable to ASML but could also be used in other industries with a multi-echelon supply chain and ADI from the customer.

The reservations method ensures a reduction in stock at the local warehouse, a decrease in emergency shipments for scheduled maintenance demand, an incentive for CS to communicate their planning, and flexibility for the CS engineers to adjust the planning within a few days. However, the solution also has weaknesses, such as increased complexity of the forecast process, additional administration in operational planning, less pooling of local spare parts, and the planning depends on the accuracy of CS information and performance.

7.2 Recommendation

Based on the results of this project, we would like to make the following recommendations to ASML:

- **ADI quality -** The quality of the ADI available within the ASML teams is not sufficient to include in the service forecast and planning processes. To implement the reservations method in the future, the ADI should improve in accuracy and completion. Additionally, the ADI should actively be communicated to other teams. We recommend ASML to focus on improving the quality of the ADI.
- **Reservations -** As discussed in Chapter 6, when the ADI quality is improved, we recommend ASML to implement a temporary local stock level for the scheduled service demand. This would require changes in the operational fulfillment system and the communication of locally planned scheduled events, but it will reduce the local storage and transportation costs.
- **Link service orders with maintenance events -** Before implementing the local reservations method, it is crucial to have a connection between events and service orders. The operational planning team will introduce this connection at the beginning of 2023. In addition, the Fleetplanner will ensure this connection is made for CS local planners. We recommend that ASML take steps to ensure the customer will create and use this connection. Furthermore, data and interviews have revealed that service orders are not linked to maintenance activity, this results in that the used/ unused and canceled information of service orders can not be linked to an event. The connection of this information could be valuable to evaluate the accuracy of the maintenance event information. Due to a lack of time and prioritization of the CS engineers, communication regarding the accuracy of the PM list to the sequence engineers and D&E engineers is minimal. The confirmation of the used/unused status of the service order by CS is mandatory. Linking the maintenance event information with the service order will enrich the demand information.
- **Lack of distinction between tactical and operational processes -** The local teams check the inventory levels themselves before submitting the service order. This has negative consequences with the automated systems, as the input data is no longer representative due to manual intervention. It is recommended that CS and CSCM local employees be made aware of the effect of the manual intervention.
- **Correct input service order information -** In Section 4.2 service orders are discussed. Service orders are categorized by the Z-codes, with 42 different Z-codes available. However, accurately indicating the service order with the right Z-code can be challenging. It is recommended to simplify this method or to provide clear definitions for all the Z-codes.
- **Planners in the field -** The employees responsible for field planning are often experienced field engineers. These employees are not educated as a planner. Therefore the local CS and CSCM workers must be made aware of the advantage of actively communicating the maintenance planning to other teams. In a future project of ASML, the planners in the field should be made aware of the influence of their decisions. If they decide to submit a service order at the last moment the planner should be aware of what the influences are on the supply chain.

7.2.1 Future research

For future research it is recommended to look deeper into the following topics:

- **Testing effect on local warehouse planning -** The effect on local warehouse planning should be tested by integrating the concept of reservations in NORA. For future research, it is recommended to test the detailed design.

- **Calculating the optimal reservations interval -** The optimal duration of the reservation depends on the holding cost and on how accurate the moment of the maintenance is in the ADI. When there is more data about the accuracy of the performed maintenance date in the ADI. Fur future research, it is recommended to calculate the optimal interval of the reservations.
- **Collect all local preventive maintenance plans -** In this research, only the PM list of one local is checked with the usage data. For future research is recommended to look into the PM list of other locals and compare their plans with the historical usage data.
- **Extend the scope to tools -** During this master thesis, the focus has been on service parts. An in-depth analysis is performed on the resources needed for preventive maintenance activities. The majority of the maintenance action is calibrations, checks, and tests. For these maintenance activities, only service tools are needed. The number of PM activities becomes larger if the tools are also considered. Furthermore, the service tools are used and will come back in inventory, while the parts are consumed. Therefore we recommend ASML to perform further research on how ADI could be used for tools.
- **The multiplicity and correlation of parts -** In Appendix D, it is noted that in some activities multiple of the same parts are required. Currently, the information that certain parts are always exchanged in pairs (or other multiples) is not reflected in service forecast and planning. The same for two different parts which should always together been swapped. For future research is recommended to look into the correlation and multiplicity of parts.
- **Condition monitoring -** In the interviews D&E indicated that they plan to perform more condition-based monitoring in the future. For future research, it is recommended to look into a method to communicate and include this information in the service forecast and planning.

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Appendix A

Forecast Type

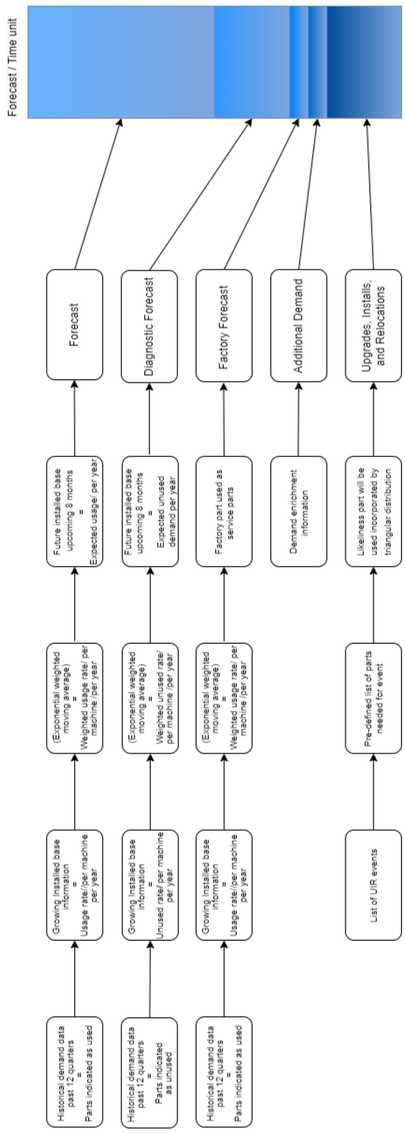


Figure A.1: Forecast types

Appendix B

Interviews

B.1 List of Interviewed ASML Employees

The employees with the following responsibilities are interviewed for this research:

- Forecast Analyst
- Tactical Planner EUV
- Tactical Planner DUV
- System Sequence Engineer EUV
- System Engineer EUV
- System Engineer DUV
- CSCM-FMA-BL-DUV MPS performance
- CSCM-FMA-BL-EUV performance
- CSCM-FMA-DAL PM EUV
- CSCM MRP Coordinator
- CSCM Service Excellence- Demand and supply consolidation project
- CSCM FMA Operations/ Scheduled maintenance project
- CS Chief product owner ONE field execution
- CSCM local major account DUV Region A
- CSCM local DUV after-sales Region B
- CS CG SBD Service Operations, preventive maintenance team
- CS EUV Configuration Management
- CS EUV Region B
- CS CA DUV TS Region B
- CS CU EUV Region A EUV Operations Planning
- CS Service Coordinator

B.2 Interview Questions

At the start of each interview. The interviewee is thanked for his/her time. Subsequently, the cause and the aim of the interview are explained. As the last step of the introduction, a confirmation is asked to use the name and answers for the study. Subsequently, a semi-structured interview is performed. The questions formulated beforehand of the interview are summed in this appendix. The interview answers and names of the interviewee have not been added due to confidential information.

B.3 Tactical level - Service Forecast

B.3.1 CSCM - Forecast team

Questions

- How does your department define planned/ scheduled maintenance?
- How is the information currently handled?
- If there is a planned action now, what is the time interval between communication, update in

the forecast, increased planning, and increased stock levels now?
- How is the forecast accuracy measured? (U&I) and after-sales?
- Which forecast details are communicated to planning? (used/unused/ unscheduled/scheduled/machine specific)

- In an ideal situation, when do you want to receive the demand information?
- What are the requirements for the information, so that the forecast accuracy increases?
- What are the requirements for the data so that the total inventory value decreases?

- What are the problems with the UI&R input data?
- Why should this data be enriched?
- What are the essential enrichment steps?

B.4 Tactical level - Service Planning

B.4.1 CSCM Service Planning

Questions

- How does your department define planned/ scheduled maintenance?
- How does your department define preventive maintenance?
- How do you define emergency shipments?
- How do you define priority shipments?
- How do you define routine shipments?
- How do you define replenishment shipments?
- What are the lead times you take into account?
- How do planned actions work now?
- How do you get the information? (forecast? mail?)
- In an ideal situation, when do you want to receive the demand information?
- What are the requirements for the information, so that the planning accuracy increases? (Exact date? Exact content?)(Region-specific, location-specific, machine specific?)
- Which data is used from the monthly forecast file?
- Which data is used from the biyearly forecast file?, What do you do with this data?

- Which information about scheduled events do you receive?
- From which departments do you receive this information?
- How detailed do you get this information?

Additional question later in the project
- Is there a link between planned actions and reservations?
- How are the different forecast categories incorporated into the local and global warehouse planning?

B.5 Operational level - Service Planning

B.5.1 D&E

Questions

- What was the goal of the project you did together with the service forecast?
- Is this a recurring task or a one-time project?
- What is your role?

- Who are your stakeholders?
- Which potential advance demand information do you have for the planning of spare parts?

B.5.2 CS - Service Engineering

Questions

- How does your department define planned/ scheduled maintenance?
- What is the preventive maintenance (PM) list?
- How accurate is the PM list?
- How far before the maintenance action is performed is the PM list known?

Questions

- Is there any data on the specific parts needed for a planned DUV maintenance event? (PM-list?)
- How far upfront of the maintenance activity is this information known?
- Is there a standard way of working for communicating the planned events to CS local?

B.5.3 CSCM-FMA- Demand and Allocation Lead

Questions

- How does your department define planned/ scheduled maintenance? (in terms of timing and content)
- What is the role of DAL with scheduled events?

- How do you obtain Advance Demand Information?
- How far in advance do you obtain this information?
- How is this information connected with a Service Order?
- Which details does your department have about ADI?
- How accurate is this information in your opinion?
- How often do you receive this information?

- To who are you communicating this information?
- How accurate is this information?
- How timely is this information provided?
- Which details could you give of this information?
- How often is this information communicated?

- In a dream situation how would you like to have the communication flow?
- What are the advantages of scheduled event information for DAL?
- Are there differences in the way of working of a EUV and DUV DAL?

B.5.4 CSCM-FMA-MRP Coordinator

Questions

- Which input information do you use?
- Do you receive information about scheduled maintenance? (Which, When, How, and from who, do you receive ADI?)
- Do you communicate information about scheduled maintenance to other teams? (Which, When, How, and To who, do you communicate this information?)

B.5.5 CSCM projects

Questions

- Which information did you find that is available on the demand side of the project?

Questions

- Which information about scheduled events did you find during the project?
- How timely could you receive this information?
- How reliable was this information?

- Which ADI do FMA operations receive?
- When do you want to receive ADI from an FMA operations perspective?

Questions

- What is your role?
- How does your department define planned/ scheduled maintenance?
- Could the Fleet planner be used as a reliable resource of ADI?
- Is it possible to connect the service parts to an event?
- How far before an event is the Fleetplanner filled in? And the service order added on average?
- What are your plans for the Fleetplanner in the future?
- Do you plan to connect the Fleetplanner to a spare part availability program?

B.5.6 CSCM- Field Operations

Questions

- How does your department define planned/ scheduled maintenance?
- Which information do you receive about expected spare part demand ?
- Who are your stakeholders for receiving the information?
- Do you use the PM list?
- Do you use Coach?
- How are these actions communicated to you?
- How reliable is this information?
- How often do you receive this information?
- Are you familiar with the Fleetplanner? Do you fill in the information?
- Who are your stakeholders for communicating ADI?
- In your dream situation how would you arrange scheduled maintenance information?

Questions

- What is your role?
- How does your department define planned/ scheduled maintenance?
- Which information do you receive about expected spare part demand ?
- From which teams do you receive this information?
- Do you know the PM list?
- How are these actions communicated to you?
- How reliable is this information?
- How often do you receive this information?
- In a dream situation, how would you arrange scheduled maintenance?

B.5.7 CS - Central

Questions

- How does your department define planned/ scheduled maintenance?
- Which data does CS Central receive about a scheduled event?
- From which teams does CS Central receive this information?
- How reliable is the received information?
- How far in advance of the activity does CS receive that data?

- What is the role of CS Central in scheduled events?
- Which data does CS Central have about the scheduled events?

- How does CS communicate this to other teams? Which teams?
- Does CS share this information with the planning or forecasting team?
- How far in advance of the activity could CS Central provide the data?
- How reliable is the data?

- Who gives the input of the Fleetplanner?
- How far upfront of the event should the Fleetplanner be filled?
- What are the differences and similarities between the EUV and DUV processes?

B.5.8 CS - Local

Questions

- What was your role in scheduled maintenance?
- How does your department define planned/ scheduled maintenance?

- Which information do you receive about expected spare part demand?
- From which teams do you receive this information?
- How reliable is the information in the Coach file?
- Do you use the PM file?
- Do you use the Fleetplanner?
- To whom do you communicate the ADI?

Questions

- How does your department define planned/ scheduled maintenance?
- Which information do you receive about expected spare part demand?
- From which teams do you receive this information?
- Do you know the PM list?
- How are these actions communicated to you?
- How reliable is this information?
- How often do you receive this information?
- Are you familiar with the Fleetplanner? do you fill in the information?
- To who do you communicate the ADI, and who is your stakeholder?

Questions

- How does your department define planned/ scheduled maintenance?
- Which information do you receive about expected spare part demand?
- From which teams do you receive this information?
- Is the information in the Coach file complete?
- Do you know/use the PM list?

- Which information do you communicate to other stakeholders? which ones?
- How would you design your ADI dream situation?
- What are the ADI information details?

Questions

- What is your role?
- How does your department define planned/ scheduled maintenance?
- Do you use a PM list?
- Do you used the Fleetplanner?
- Which information do you receive and provide?

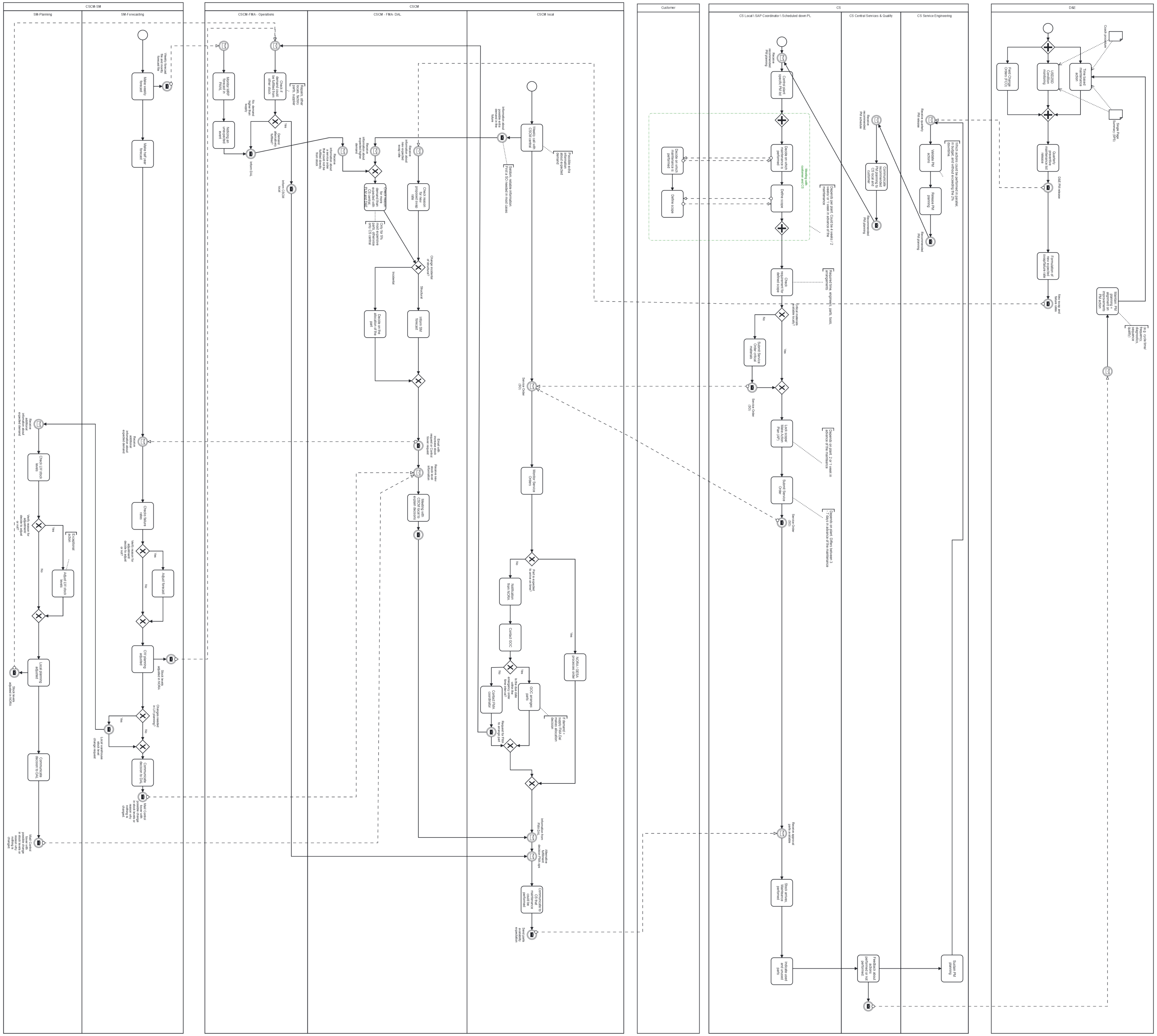
Questions

- What is your role as an SAP Coordinator?
- What is your interaction with CSCM local?
- Which information do you receive?
- Which information do you provide?

- Who is responsible for the service order?
- How do you decide on the right Z-code?
- How often are activities postponed?

Appendix C

BPMN Model ADI


CSCM-SM
SM-Planning
SM-Forecasting
CSCM
CSCM-FMA - Operations
CSCM - FMA- DAL
CSCM local
Customer
CS
CS Local \ SAP Coordinator \ Scheduled down PL
CS Central Services & Quality
CS Service Engineering
D&E

Appendix D

Event Based Forecast

In the interviews was indicated that for some maintenance activities, multiple of the same parts are needed. Combining historical demand information and information about maintenance activities could be valuable. For example, in 2016, the NXE 3400 was introduced. For this machine, preventive maintenance actions are formulated, with, among other things, two tri-yearly activities. For these maintenance activities, a procedure is created with recommended parts. For the first activity, multiple parts are needed one time, and part SERV.671.xxxxx is needed four times. In the historical usage of this part could be seen that the part is more frequently demanded in 2019 and 2022. In Figure D.1, the demand of SERV.671.xxxxx from January until September 2022 per machine is given. From the figure can be concluded that the total ordered demand per machine is often four parts or the used number of parts is four. There is an exception for two machines, one that only used three parts and one that only used one. The machine that only uses three parts had an order with four parts in February but did not use these parts. Potentially, the maintenance was postponed. Later in July three parts were ordered, and these parts were used. For the machine with only one part usage, there is a probability that the demand was not scheduled maintenance but breakdown maintenance. From this figure can be concluded that if there is demand for this part on a machine, this will often be in multiples of four.

For another tri-yearly maintenance action, the procedure recommended five units of SERV.502.xxxxx. Figure D.2 shows the demand for that part from January until September 2022 per machine. From this figure could be concluded that there are often one or a multiple of five parts ordered. Based on the multiplicity of the part usage, the last moment the specific scheduled maintenance is performed could be concluded.

The service orders submitted are currently not linked to an event. The forecast is currently part-based. If the forecast will be made event-based, this could give additional insight. For example, the parts used for the specific events could be compared with the recommended parts, but also the multiplicity and the correlation between parts. The link between the events and the service order is not yet available. The operational planning team indicated that there is a project to link the service order and events for tools for UI&R events. The rollout of this project will start in February 2023. Potentially this project could be extended in scope to the after-sales parts. Thereby, the Fleet planner 2.0 will have the event part connection. The method of including event-based forecasting and planning instead of part-based forecasting and planning is a design study on its own, this topic is out of scope. Although, a recommendation will be made to investigate the opportunities in the future.

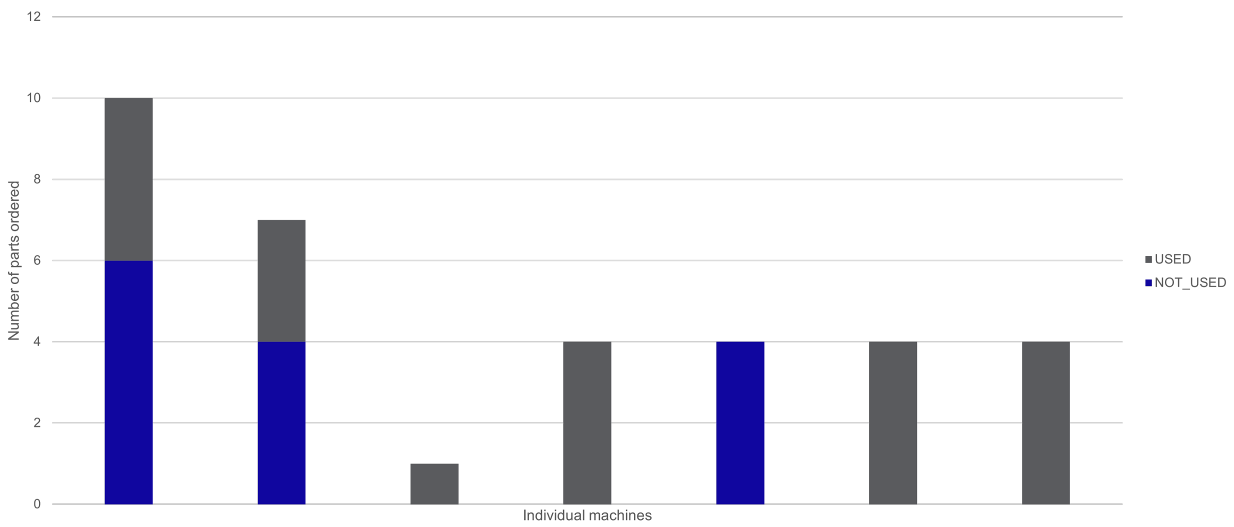


Figure D.1: SERV.671.xxxxx multiplicity of 4

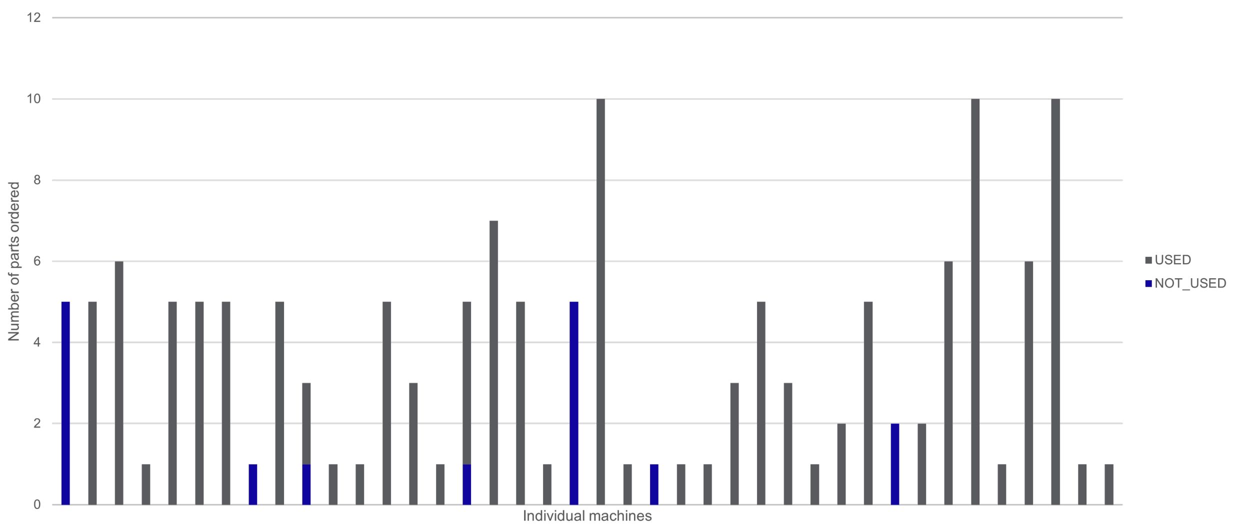


Figure D.2: SERV.502.xxxxx multiplicity of 5

Appendix E

Storage Location Categories

Global SLOC type	Local SLOC type	Meaning
U	U	• Unrestricted stock
R	R	• Restricted stock
R	A	• Semi-restricted stock - can potentially be used by local and region
R	B	• Semi-restricted stock - can potentially be used by local only
R	C	• C = customer SLOC • Restricted stock • Use: serve as ship-to SLOC for direct deliveries
R	D	• Semi-restricted stock - can potentially be used by region only)

Figure E.1: Storage location categories