Inventory management with orders without usage

ASML
University of Twente

Final report

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March 6, 2015

Inventory management with orders without usage

Executed commissioned by: ASML

UNIVERSITY OF TWENTE.

Date: March 6, 2015

Version: Final Concept

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DOA ATTS CSD
Demand SAP
RCT Requalification
availability
KPI Method Inventory
SKU Rush
logistics
parts
ROP
Scrap
method
Simulation Sales
Multi-echelon
SPOC Serviceable
Continental DTWP
VOCABULARY Order
Usage
CS
order
Repack SLA
CL
Replenishment Local Global
centre Forecast Plant
Critical Init
MyQ
Model Control model

VOCABULARY

Abbreviation	Description
ATTS	Average time to shortage; Measurement to divide the stock, when there is not enough stock for the outstanding orders
CL	Customer Logistics; Planners and forecasters are employers in this department. Inventory Control is a sub-department
Critical parts	Parts of which there are too little on stock to fulfil the demand within lead time from the supplier
Continental parts availability	These customers have a CSD contract and are delivered from the hub warehouse in their continent; This is out-of-scope in this research, because the current inventory management optimization does not take this into account.
CS	Customer Service; Engineers are employers in this department. Local Logistics Centre is a sub-department
CSD	Customer Satisfaction Degree; Percentage of demand which you can pick immediately from the region of the customer or at global level (is included in some contracts)
Demand	All parts ordered; Include usage, scrapped parts and returned parts, like serviceable, repack and requalification
DOA	Death on Arrival; Parts, which the engineer wanted to use, but got a failure before they arrived at the customer
DTWP	Down Time Waiting for Parts; Percentage of time a machine is down and the customer has to wait for a part for this machine
Global parts availability	These customers have a CSD contract and are delivered from the central warehouse
Init order	The order to fill the safety stocks, when the safety stocks have been changed
Inventory Control	Sub-department of Customer Logistics; The objective is to control the inventory level and ordering activities, to improve the forecast of inventory and to check the quality of ordering and forecasting
KPI	Key Performance Indicator
Local logistics centre	Sub-department of Customer Logistics; Located at the Local Warehouse
Local parts availability	These customers have a DTWP contract and are delivered from the local warehouses
Multi-echelon model	Model to optimize the amount of stock in the local warehouses and central warehouse
MyQ	Portal, where the local logistics centre and the operational planning department create there purchase orders; Coupled to SAP
Plant Simulation	Tool for discrete-event simulation, which can model processes and measure their performance
Replenishment Cycle Time	RCT; Lead time of orders, which is the time between placing the order at the local warehouse to the central warehouse and the arrival of the order at the local warehouse
Repack	Parts which are returned and unpacked, but which are not tried in the machine. They have to be repacked at the local warehouse
Replenishment order	The order driven by the SAP-system; This order is requested when the inventory level is lower than the safety stock
Requalification	Parts, which are returned and tried in the machine, but became not the solution. In this case the old part is set back in the machine and the part to requalify has to be checked if it is still working properly. The parts, which have to be requalified, are sent via the hub or central warehouse to the supplier to be tested and eventually repaired

ROP	Reorder Point
Rush order	The order, driven by a manual order of parts
Sales Order	The order, what is on beforehand sold to the customer
SAP	ERP-system of ASML
Scrap	Parts, which are returned and to inexpensive that it is more cost-effective to scrap these parts and order new parts
Serviceable	Parts, which are returned and not even unpacked, but only taken to the customer
SKU	Stock Keeping Unit, which has at ASML a personal SKU-code
SLA	Service Logistic Agreements; Maintenance contracts with customers of the machines ASML delivers with targets DTWP and CSD
SPOC	Single Person of Contact; Contact person from central to local warehouse
Usage	Parts, which are used and will not return at the local warehouse

MANAGEMENT SUMMARY

Currently ASML determines the safety stock levels by having the usage as main input in the model, Spartan, to determine the safety stock levels. However at ASML the orders of parts are not all used parts, but returned: [redacted]% of the orders from the local warehouse to the customer are not used and will be returned. Next to that, [redacted]% of the emergency transportation costs are due to orders without usage. Also the replenishment cycle time is higher for orders without usage.

Thereby the problem in this research is: "ASML is facing higher emergency transportation costs, longer replenishment cycle time and higher risk of not satisfying the customer contracts due to not incorporating orders without usage in the inventory level determination.". Hereby the core question becomes:

*"How should ASML respond to **orders without usage** into the inventory level calculations?*

What would be the impact of this incorporation in terms of:

- *Emergency transportation costs;*
- *Inventory holding costs;*
- *Replenishment cycle time;*
- *Risk of not satisfying the customer contracts?"*

In this research first **the current process** and forecast is explained. A new part only will be send to the local warehouse of a customer, when a part is needed and not on stock, or when the inventory level is lower than the safety stock, which is a result of a usage of a part. The inventory level only changes when a part is used and not when a part is sent to the customer. This is the policy at ASML. Then the part is allocated. When returning a part, it can be used ([redacted]%), serviceable ([redacted]%), requalified ([redacted]%), repacked ([redacted]%) and other returns ([redacted]%). The other returns are out-of-scope in this research. This means that [redacted]% of the orders from the local warehouse to the customer is not taken into account in the forecast, because they are not used. This has the consequence of lower safety stocks than needed, which result in higher emergency transportation costs.

The forecast at ASML is determined by the exponential smoothing of usage. In the optimization the local safety stock levels are determined by Spartan, whereby the down time waiting for parts is the constraint and the holding and emergency transportation costs are minimized. The forecast of the central demand is the usage during lead time. In the optimization of the central inventory the reorder points are set by minimizing the holding costs with the constraint of the customer satisfaction degree. The limitation in this research is that the current inventory model and current measurement of the usage may not be changed. Only a change in the input of the inventory model may be the result of this research. The optimizations of the central and local inventory systems are not coupled, whereby a higher inventory value for the local inventory system does not result in a lower inventory value for the central inventory system to keep the same targets.

The impact of not including the orders without usage is measured. The impact of orders without usage on the emergency transportation costs is €[redacted] million in 2013, which is [redacted]% of the total cost.

The impact on the replenishment cycle time is that the cycle time for a SKU with a high number of orders without usage is higher than a SKU with a low number of orders without usage.

Next **the forecast methods** following literature are presented and the best method is chosen. The suitable forecast methods in literature including return demand are developed by the authors Kelle and

Silver. They present four forecast methods. Method 2 of Kelle and Silver is found to be the most appropriate method, because of his high robustness and low number of calculations in the method. Next to that, the method performs almost as good as the best method. The forecast of method 2 decreases the demand (usage and returns) with the parts which return during lead time.

Method 2 of Kelle and Silver has the drawback that negative demand may arise for SKUs having many subsequent periods with zero demand, which have a high number of requalification orders returning in the coming period. Also this method has still extra calculations than the current forecast. Thereby a new method is developed. This method is simpler than method 2 of Kelle and Silver and the forecast is the demand (usage and returns) minus the average number of orders returned.

These **methods are applied** to the inventory optimization methods of ASML and the most appropriate method is chosen. The best method is chosen based on the smallest difference in outcome of the simulation of the reality at ASML and the optimization per method. In the simulation of the local inventory the developed method has the closest results to the optimization of the local inventory.

Implementing the developed method results in the annual savings of €[redacted] million worldwide, which includes the annual holding and emergency transportation costs. Next to that, implementing the developed method results in the reduction in out-of-stocks of [redacted] parts annually, which is 33% of the planned out-of-stocks. The costs of these out-of-stocks are not taken into account in the annual savings and thereby there can be more costs reduction. The method needs an investment in inventory value of €[redacted] million. The risk and annual costs of the extra inventory value is taken into account in the annual savings.

In reality the current method results in an underperformance in DTWP, RCT and CSD, because not all demand is taken into account. The DTWP and CSD are in reality 1% lower than in the current method (with not taking the returns into account). There is no significant difference in the RCT.

A qualitative result of adding the returns to the forecast, is a better planning, which results in more satisfied suppliers and a better reaction of the suppliers on the demand of ASML. A better reaction on the demand, results in less critical parts. Next to that, the emergency transportations will be reduced, which results in more efficiency and a better consolidation of orders.

The recommendations, based on this research, are as follows:

- Include the return flow in the optimization of the local safety stock levels and the central ROP by determining the forecast with developed method.
- In the next years ASML will implement a new multi-echelon inventory model, whereby the optimizations of the central and local inventory costs are combined. The advice is to implement this multi-echelon inventory model including the developed method. The current prototype is not yet fully developed, whereby the results are not yet comparable to the current situation. The recommendation is to calculate the methods with the correct CSDs, when the software is available and check if the expectation is correct.

Further research is required for the following topics:

- A reverse logistics multi-echelon multi-item inventory model, whereby the multi-echelon model is combined with the full return flow.
- The reduction of orders without usage, to reduce to core problem of having orders without usage.

PREFACE

After a fantastic time in Enschede and at the University of Twente, I hereby present my master thesis. This thesis is the last delivery of the master program Industrial Engineering and Management with the specialization Production & Logistics Management. The research for this thesis was executed at ASML in Veldhoven.

First of all I want to thank all people with whom I worked together, lived together, had nice evenings and nights and who motivates me in my whole student life. I really liked my time with my study colleagues, my roommates of the Borstelweg and Bentinckstraat, at Rowing Club Euros, at Study association Stress, with my sorority Nefertiti, in my Student Union board and with my company PIP Advice.

With a lot of energy I worked on this research. It was fun to learn how to implement a theoretical model in a real, dynamic environment. Besides that it was a good learning experience making all stakeholders of this research clear what the goal was, methods were and results were.

I would like to thank my supervisors within ASML, K. Oner and R. van Sommeren, for their insights in the problem and methods at ASML. I appreciated the time they spent in my research and their trust in me to give me the full freedom and responsibility in my research. I also would like to thank my colleagues for their critical input and their help for gathering information and getting contacts within the company.

Next to that, I also would like to thank my first supervisor of the University of Twente, M.C. van der Heijden, for his contribution, critical reviews and enthusiasm for this research. Also thanks to my second supervisor, A. Al Hanbali, for his support and also critical review. It is really motivating when both supervisors really read your thesis report and give clear feedback.

I would like to thank all readers for their time to review my thesis report: Sophie, Jelco, Elieke, Tabea, Tim and Irene. Next to that, I would like to thank my boyfriend Jelco for his positive support during my study and master thesis. At last I would like to thank my parents, Gerard and Carla, for their support during my entire study.

Veldhoven, March 6, 2015

H.E. van der Horst

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1. ASSIGNMENT DESCRIPTION

1.1. Company description ASML

Figure 1.1: Twinscan NXE - one of ASML's machines for producing chips (ASML, 2013).

ASML is founded in the Netherlands in 1984 and is located nowadays on more than seventy locations in sixteen countries. This 30-year old company is a world leader in the production of lithography systems for the semiconductor industry. ASML designs, develops, integrates, markets and services complex machines for the production of integrated circuits or chips. These chips are used in electronic, communication and information technology products, which everyone uses in daily life. The headquarter of ASML is in Veldhoven, where also the main part of the research and development activities takes place. ASML is traded on Euronext Amsterdam and NASDAQ (ASML, 2013). The strategy of ASML is: "Technology leadership combined with customer and supplier intimacy, highly efficient processes and entrepreneurial people" (ASML, 2014).

ASML is divided in three business units: Business Segments, Business Operations and Business Support. Within the business unit Business Operations, the inventory control of service parts and improvement of service logistics take place in the department Customer Logistics. The sub-department for these activities is Inventory Control. In the Inventory Control department the objective is to control the inventory level and ordering activities, to improve the forecasting of the central inventory and to check the quality of ordering and forecasting. This project falls within the Inventory Control department.

1.2. Motivation of the research

ASML has service logistic agreements (SLAs) with customers buying ASML machines. Based on these SLAs ASML has to obtain service targets with the following performance indicators:

- DTWP: Down Time Waiting for Parts: Percentage of time a machine is down and the customer has to wait for a part.
- CSD: Customer satisfaction degree: Percentage of demand which you can pick immediately from the hub warehouse in the region of the customer or which you can pick globally. In literature called fill rate.

Because of these SLAs, inventory is needed in the local warehouses, hubs and central warehouse to obtain these service targets.

Three different service logistic agreements are possible for customers:

1. Local parts availability: These customers have a DTWP contract and are delivered from the local warehouses.
2. Continental parts availability: These customers have a CSD contract for the region of that customer and are delivered from the hub warehouse in their continent.
3. Global parts availability: These customers have a CSD contract for the global inventory and are delivered from the central warehouse.

For all customers the engineer will decide which parts to order when he receives a failure notification.

The engineers at customers with a DTWP contract contact the logistic employees at the nearest local warehouse, who will order a part from their local warehouse ((1) in Figure 1.2). When the part is not available in the local warehouse, they order the part from the local warehouses in the neighbourhood (2) or from the hub in the neighbourhood (3). When there is no part available at these warehouses they will ask the central warehouse to look for that part globally: so at the central warehouse (4) or at hubs or local warehouses (5) globally (in other regions). When the parts are located, these will be sent to the engineer (1-5).

The engineer will repair the machine with the parts and all parts which are not used will be sent back to the local warehouse (R1). Parts to repack are parts which are unpacked, but which are not tried in the machine. Parts which have to be repacked and not used are repacked at the local warehouse. Parts to requalify are parts which are tried in the machine, but became not the solution. In this case the old part is set back in the machine and the part to requalify has to be checked if it is still working properly. The parts, which have to be requalified, are sent via the hub or central warehouse (R2) to the supplier (R3). Serviceable parts are parts which are not even unpacked, but only taken to the customer.

Engineers for the continental customers contact the logistic employees at the nearest hub warehouse, who will order a part from their hub warehouse. When the part is not available the part is asked at the central warehouse. They will return their parts to the hub warehouse.

The same for global customers, then the engineer contacts the logistic employees at the central warehouse, who will order a part from their central warehouse. They will return their parts to the central warehouse.

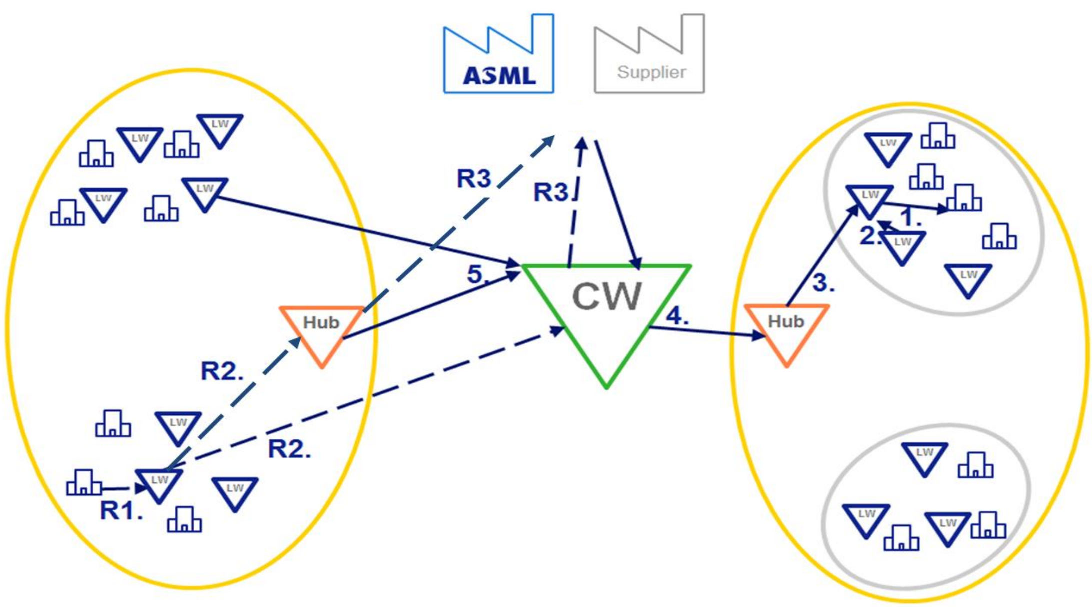


Figure 1.2: Current Service Process.
Figure based on a presentation of TacticalPlanning1 (TacticalPlanning1, 2014)**. The figure is changed to the situation, which is described above.**

The start of this research is due to a signal from the engineers, who reported that the lead time of orders, which came from other local, central or hub warehouses, was high and that they have to wait long for spare parts. (InventoryControl3, 2014)

To find out the root cause for these complaints the lead time of orders was measured (called: replenishment cycle time (RCT)). The RCT is the time between placing the order and the arrival of the order at the local warehouse. The percentage of order lines replenished within fourteen days to the local warehouse was lower than the targeted 86%. To figure out the gap between the actual RCT and the planned RCT the department Customer Logistics wrote down twenty-three possible causes (InventoryControl3, 2014). One of these possible causes, namely orders without usage are not taken into account in planning, is the start of this research. In the remainder of this section, further information about this research is given. In the next section the problem statement is given.

In Figure 1.3 the horizontal axis is scaled by the percentage of parts used per order. 0% used means that all parts in that order are not used, but returned. The vertical axis is the average replenishment cycle time, as mentioned above.

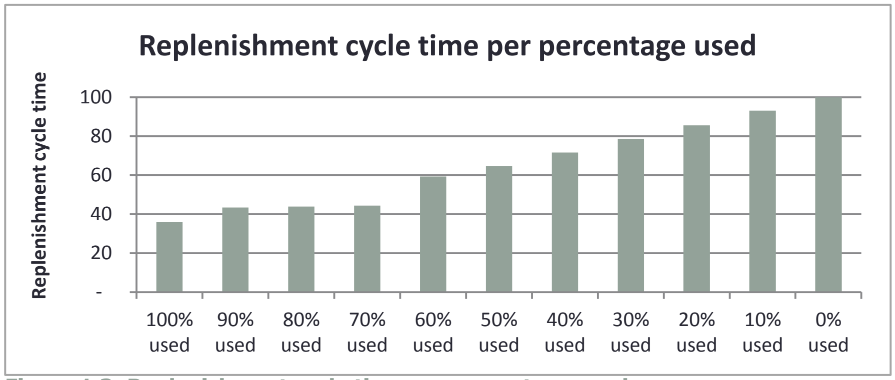


Figure 1.3: Replenishment cycle time per percentage used. Based on data of 2013. Normalized to 0% used is RCT of 100.

As you can see in Figure 1.3, the average cycle time is doubled between full usage and no usage. There could be multiple reasons for the higher RCT for parts with low usage:

- Parts, which are ordered but less/not used, have a low safety stock, because there is not the expectation that these parts will be ordered. This could result in a higher lead time (as result of fewer parts in the field).
- Next to that, parts, which are ordered without usage, but need to be requalified, have to be sent to the supplier and are an amount of time not available as inventory. There is no planning on this demand and thereby this could result in higher cycle times.

1.3. Objective & research questions

Based on interviews with the head Inventory Control, four employees of Inventory Control, the manager Customer Logistics and an employee of Customer Logistics, a problem cluster is set up as in Figure 1.4.

The upper part of the problem cluster (Figure 1.4) contains the root problems. The results of these root problems are in the lower part of the figure.

The root problem is that it is unknown why engineers order parts, which won't be used. This results in the following:

- First, it is unknown if engineers always order the same parts, when receiving the same errors. Not having this knowledge leads to not taking the correlation of parts into account in the forecast of the failure rates and thereby the determination of the safety stocks.
- Second, it results in not using the information of orders in the determination of the base stock levels. This means that the determination of the base stock levels is only based on used orders and not on orders without usage.

The lack in taking into account the correlation and orders without usage results in having stock out of parts in the central warehouse, when it was expected that they were on stock. This has the effect that also in local warehouses there could be out-of-stocks.

Another result of not taking into account the orders is the longer lead time of replenishments of orders without usage or with less usage. This is explained in Figure 1.3 in section 1.2.

Finally this results in:

- Higher personnel, transportation and order costs;
- Higher replenishment cycle time;
- Higher risk of not satisfying the DTWP and CSD in the contract; and
- Lower satisfaction on the collaboration of Customer Service and Customer Logistics.

The engineers are employees of the Customer Service (CS) department. The planners and forecasters are employees of the Customer Logistics (CL) department.

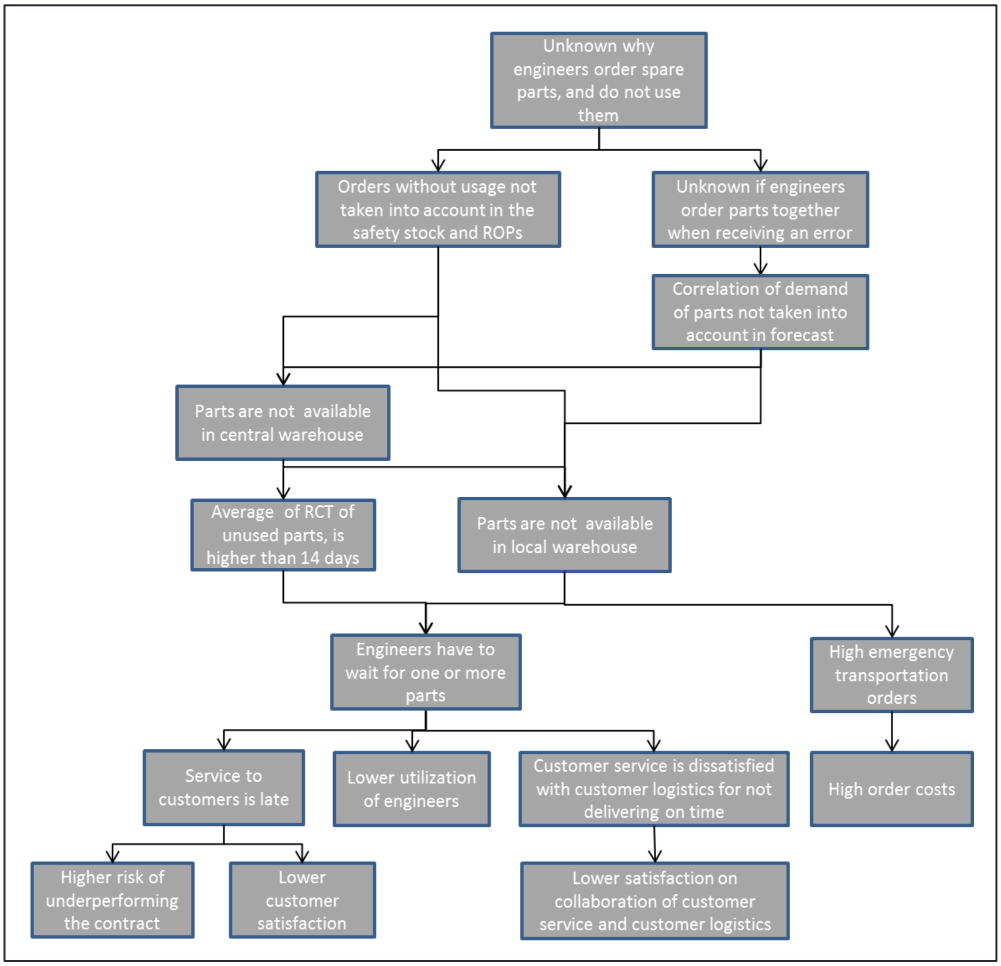


Figure 1.4: Problem cluster of the unavailable parts at the local warehouse.

Because it costs too much time to take both the correlation of parts and the determination of safety stocks into account, the research is limited to the determination of safety stocks based on orders without usage.

Hereby the problem can be defined as follows:

"ASML is facing higher emergency transportation costs, longer replenishment cycle time and higher risk of not satisfying the customer contracts due to not incorporating orders without usage in the inventory level determination."

The purpose of the research is to give advice to ASML about determining the base stock level based on the orders and the return flow, by:

- Analysing the process of ordering and returning;
- Analysing the current forecasting method and current method of determination of the safety stocks and reorder points;
- Analysing the impact of orders without usage;
- Reviewing literature to find forecast methods;
- Developing the forecast which incorporates the order and return flow of orders without usage;
- Comparing the results of the current method and the new method;
- Giving an implementation plan of the new method.

Hereby the core question becomes:

"How should ASML respond to ***orders without usage*** *into the inventory level calculations?*

What would be the impact of this incorporation in terms of:

- *Emergency transportation costs;*
- *Inventory holding costs;*
- *Replenishment cycle time;*
- *Risk of not satisfying the customer contracts?"*

The current model for determining the safety stocks and reorder points is the basis in this research. The new forecast will be the input in this model.

This core question can be divided in different research questions; the so called knowledge questions (Heerkens, 2005). These questions can be answered by reviewing the related literature, interviews at ASML and data from ASML. The research questions are as follows.

1. What is the current way of working in the order and return process and how does ASML forecast and determine the base stock levels?
    a. How does the ordering process perform at the local warehouse?
    b. How does the process of returning parts perform?
    c. How does the current forecast method of the used parts perform?
    d. How does the current determination of reorder points perform at the local warehouse?
    e. How does the current determination of reorder points perform at the central warehouse?
2. What is the impact of not including orders without usage in the determination of base stock levels?
    a. In which segments of ASML is the number of orders without usage the highest?
    b. What is the impact of orders without usage on the emergency transportation costs and replenishment cycle time?
    c. How long is the return lead time of orders without usage?
3. Following the literature, what forecast method can be used to determine the demand and return flow?
    a. Which methods are possible to forecast the demand and return orders?
    b. What are the criteria to select the forecast method?
    c. Which method is following the criteria the best to be added to the forecast of ASML?

4. How can the chosen method be added to the current determination of the base stock level?
    a. How can the method be applied to ASML to forecast the order and return flow?
    b. What are the disadvantages of the method and how can these disadvantages be covered?
5. What is the impact of the new methods compared to the current method?
    a. Which forecast of the methods is the most correct in the optimization compared to the reality?
    b. What is the cost impact by adding the forecast of the new method to the current inventory model?
    c. What is the impact on DTWP by adding the forecast of the new method to the current inventory model?
    d. What is the impact on CSD by adding the forecast of the new method to the current inventory model?
    e. What is the impact on replenishment cycle time by adding the forecast of the new method to the current inventory model?
    f. What are other effects at ASML by adding the forecast of the new method to the current inventory model?
6. How can the new forecast method be implemented at ASML?
    a. What is the plan to implement the forecast method?
    b. What are the risks and drawbacks of the implementation and how can ASML handle these?

1.4. Scope

The scope in this research is the following:

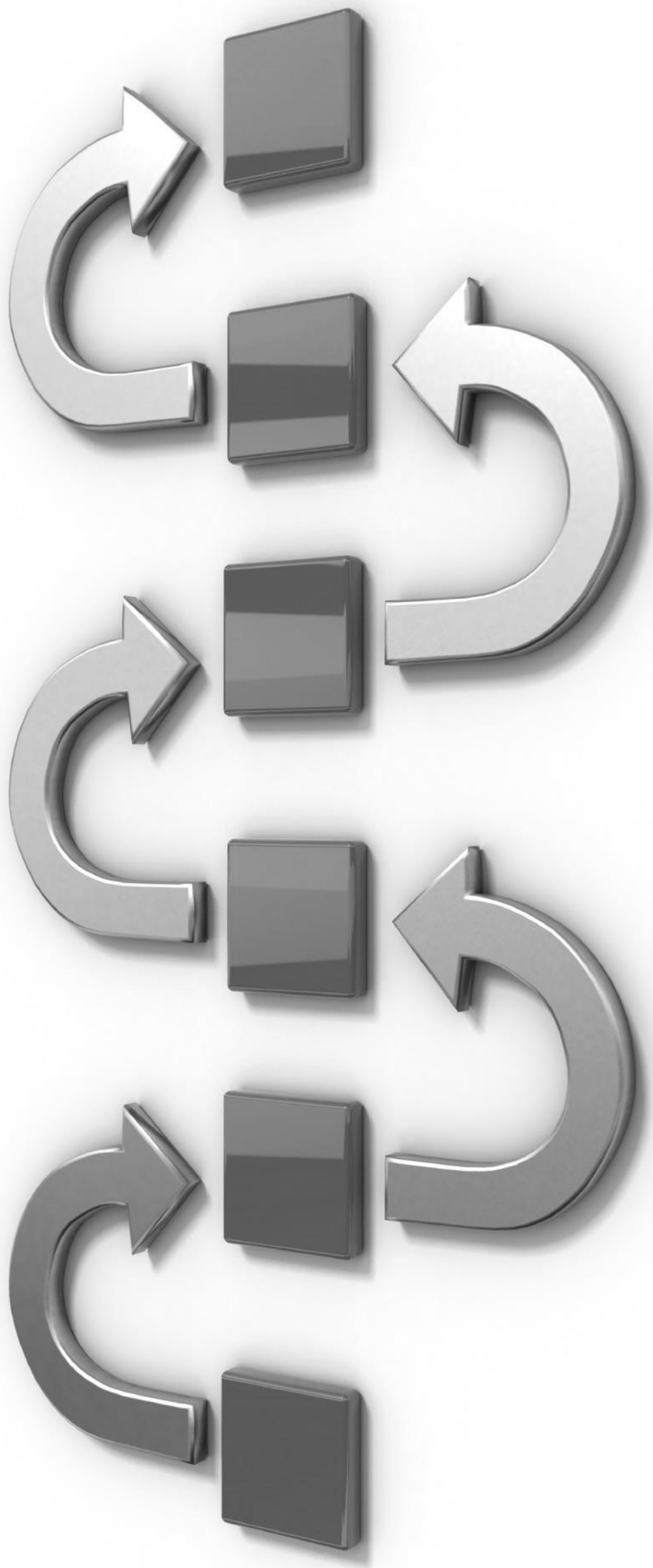
- The description of the process in this research starts when the error in the machine has occurred.
- The description of the process in this research ends when the parts are used or returned to the local or central warehouse and added to the inventory level.
- The current forecast method and translation to the safety stock model will not be changed, because this is not reasonable to obtain in six months. The forecast will be added to this model.
- The customers with continental parts availability are not taken into account in this research, because they are currently also not taken into account in the inventory management optimization.
- The research is done for service parts.
    - The tools are out of scope.
    - Service parts for planned service are out of scope, because these will not have orders without usage.

1.5. Planning

The planning in this research is as in Table 1.1.

Start	Deadline	Subject	Result
4 Aug	12 Sept	Research proposal	End version research proposal
11 Aug	14 Sept	Research question 1 *Current situation*	Answer on research question 1 *Current situation*
11 Aug	21 Oct	Research question 2 *Impact of orders without usage*	Answer on research question 2 *Impact of orders without usage*
2 Oct	7 Nov	Research question 3 *Method from literature*	Answer on research question 3 *Method from literature*
7 Nov	25 Nov	Research question 4 *Applied method*	Answer on research question 4 *Applied method*
17 Nov	24 Dec	Research question 5 *Impact method*	Answer on research question 5 *Impact method*
24 Dec	4 Jan	Complete Master Thesis	First concept Master Thesis
4 Jan	11 Feb	End Master Thesis ASML	Presentation Master Thesis at ASML Final concept Master Thesis
11 Feb	6 March		Final Version Report at ASML & UT
	13 March	Master Colloquium UT	Presentation Master Thesis at UT

Table 1.1: Planning of master thesis.



2. CURRENT WAY OF WORKING

This chapter answers the research question that is formulated in section 1.3: "What is the current way of working in the order and return process and how does ASML forecast and determine the base stock levels?". First the changes in inventory level are described. Then the current forecast methods and inventory models for determining safety stocks and ROPs are declared.

2.1. Ordering process at the local warehouse

This section answers the sub-question: "How does the ordering process perform at the local warehouse?". This section is divided in order types and transportation types.

2.1.1. Order types

The orders can be divided in different types: Init, sales, replenishment and rush (HeadInterfaceTeam1, 2014).

The init orders are the orders to fill the safety stocks, when the safety stocks have been changed. This order type is out of scope, because it is not possible to forecast these orders. These orders are one-time changes. Next to that, the delivery lead time of init orders is the length of the lead time of delivering new parts from the supplier to the central warehouse.

The sales orders are orders which are sold to the customer beforehand, when the customer maintains the machine by himself. The sales orders are out of scope of this research, because these orders also cannot be forecasted and have also the lead time of the supplier (HeadInterfaceTeam1, 2014).

Replenishment orders, as typology at ASML, are orders driven by the SAP-system. These orders are requested when the inventory level is lower than the safety stock. The parts of the replenishment orders can be shipped from another local warehouse, when there is overstock at that local warehouse. When there is no overstock at the local warehouse the parts will be shipped from the central warehouse. The process is visualised in Figure 2.1 (HeadInterfaceTeam1, 2014).

Rush orders, as typology at ASML, are orders which are driven by manual orders of parts in SAP. Rush orders are requested by the local logistic centre within the local warehouse. The rush orders are needed for the parts, which don't have a safety stock or where the inventory level is too low for the number of parts needed. Rush orders are in most cases orders which have to be delivered very fast. It is also possible to have a rush order which is planned on a specific time in the future, while it is still manual set (HeadInterfaceTeam1, 2014).

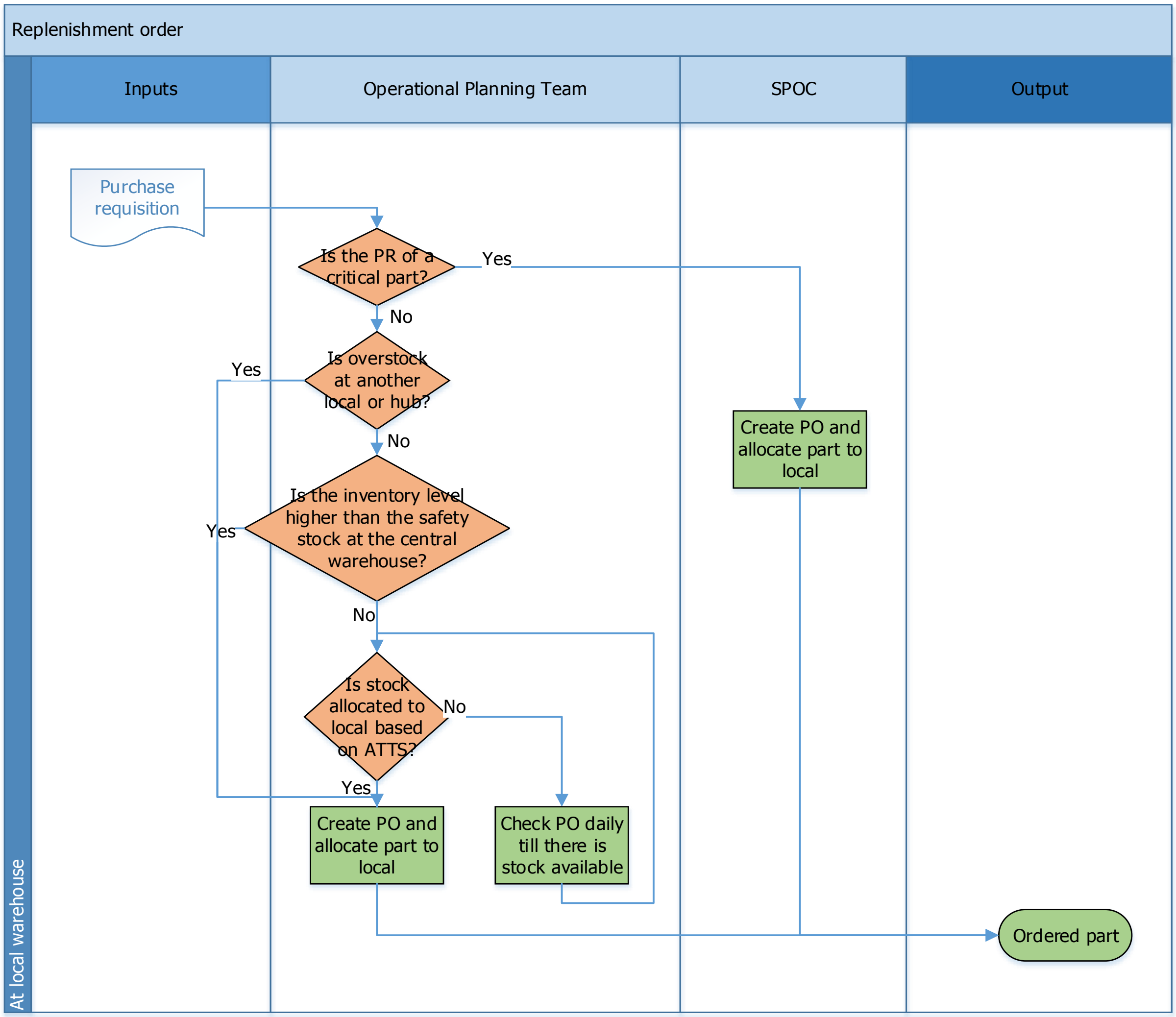


Figure 2.1: Process of replenishment order.

The rush order process is as follows (in Figure 2.2) (HeadInterfaceTeam1, 2014):

1. The engineers receive a failure notification from the system or by phone from the customer. They download the root error, root causes, solutions and possible parts to order in different systems.
2. The engineers decide if and what to order and make a reservation in MyQ. MyQ is the portal to reserve the parts, which is connected to SAP.
3. The Local Customer Logistics department checks if the part is available in their local warehouse or in the local warehouses in the neighbourhood and creates a purchase order in MyQ when the part is available.
   When the part isn't available in their local warehouse or in the local warehouses in the neighbourhood, the local customer logistics department fills in and sends a Part Request Form to the Operational Planning Team.
4. The Operational Planning Team allocates the most nearby part and creates a purchase order in MyQ.

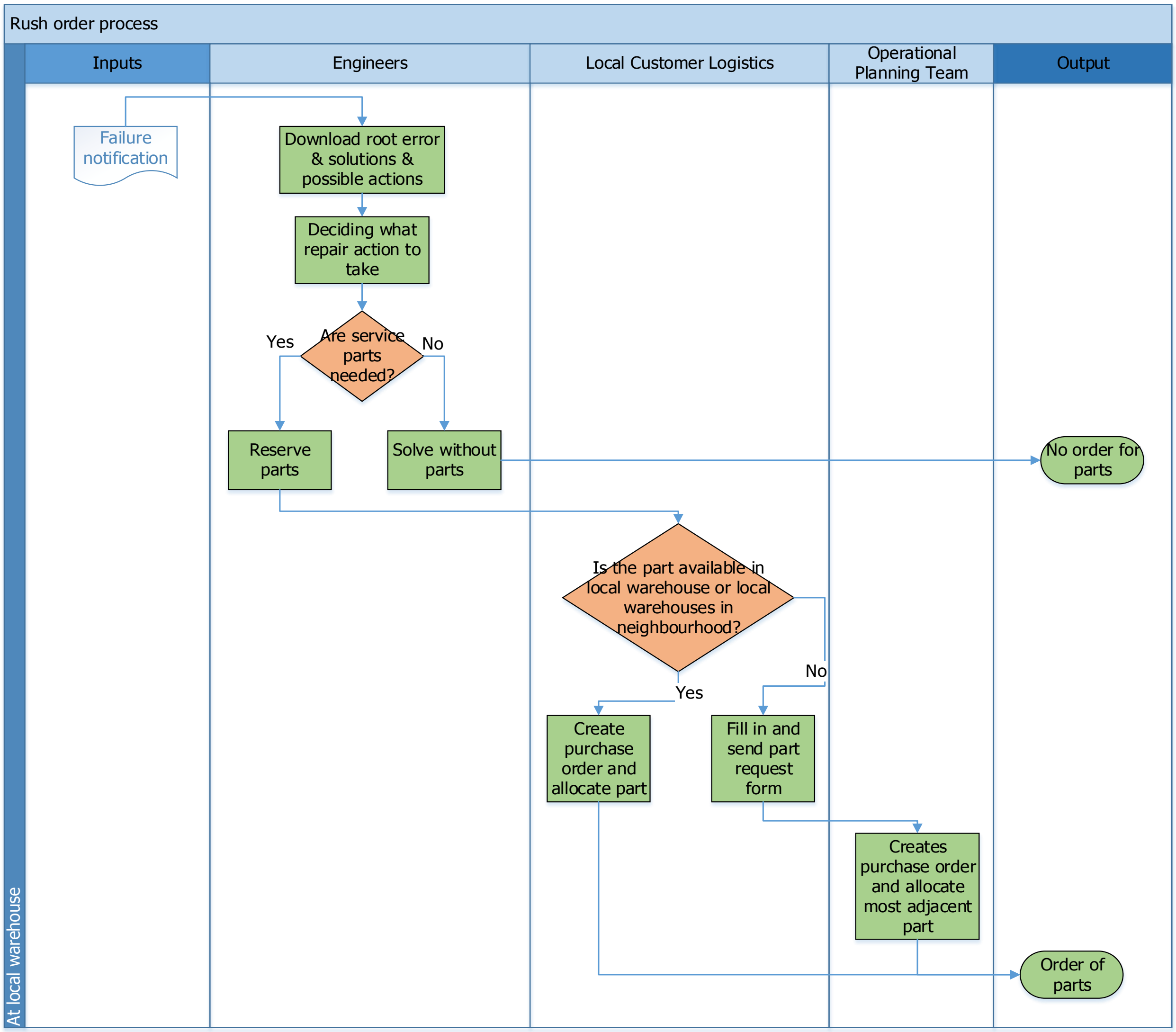


Figure 2.2: Process of rush order.

Concluding, a new part only will be ordered when a part is needed and not on stock or when the inventory level is lower than the safety stock, which is a result of a usage of a part. When a part is picked and sent to a customer, the part is allocated. This means that the inventory level only changes when a part is used and not when a part is sent to the customer.

2.1.2. Transportation types

The replenishment and rush orders can be transported in three types: emergency, priority and routine.

Emergency deliveries will be delivered as fast as possible. This results in a delivery time of a few hours within a country and a few days between countries (TransportController1, 2014).

Priority deliveries will be picked at the same day and will be transported in the next delivery. This results in a delivery time of half a day within a country and three to five days between countries (TransportController1, 2014).

Routine deliveries will be picked on the next day and will be transported when possible. This results in a delivery time of one day within a country and six to nine days between countries (TransportController1, 2014).

Per order type and per transportation type an overview of the differences is given in Table 2.1. The choice of priority and emergency of a replenishment order is how fast a planner wants to have the critical part on stock (TransportController1, 2014).

Order type	**Replenishment**			**Rush**		
Transportation type	Routine	Priority	Emergency	Routine	Priority	Emergency
Is the order manual made in SAP?				Yes	Yes	Yes
Is the order requested automatically by SAP?	Yes	Yes	Yes			
Is the machine down?						Yes
Are the parts needed for a planned action within 14 days?					Yes	
Is the part a critical part?		Yes	Yes			

Table 2.1: Overview of differences in order and transportation types.

2.2. Process of returning parts

This section answers the sub-question: "How does the process of returning parts perform?".

When a part is used, the inventory level decreases. When a part is not used and is returned, the local customer logistics department fills in the material notification and adds the reason of returning in the material notification. In table 2.2 the different reasons of returning parts are given following the material notification.

The data of the return flow are gathered in two phases: the used parts and the returned parts. The data of the used parts are gathered at August 15, 2014 and contains all order lines of goods received between January 1, 2013 and December 31, 2013. The data are gathered by Analyst3, responsible for forecasting, in SAP. The data of the returned parts are gathered at August 20, 2014 and contains all order lines of goods receipt between January 1, 2013 and December 31, 2013. The data are gathered by TacticalPlanning2, responsible to determine safety stocks, in SAP. All incomplete order lines are out of scope, because incomplete order lines cannot be analysed. For verification the data of returned parts are gathered at August 27, 2014 by CriticalParts1, member of the critical parts team. The data for verification of used parts are gathered by OperationalPlanner2, member of the critical parts team, at August 21, 2014.

In Table 2.2 you can see that 21% of all parts ordered at the local warehouse are returned and are still serviceable. Another 12% of all parts ordered are also sent back, but need a handling to add the parts on stock again. The detailed table can be found in appendix D, because of confidentiality.

Reasons for sending back	Percentage of total ordered parts	Percentage of returning parts
Death on arrival	2%	5%
Repacked	3%	10%
Requalified	7%	21%
Serviceable	21%	64%
Used	67%	-

Table 2.2: Return of parts.

The process of returning the parts is given in Figure 2.3. The parts labelled as "DOA" are out of scope of this project. The reason for this is that when these parts would not have a failure when they arrived or when they were installed, they would be used.

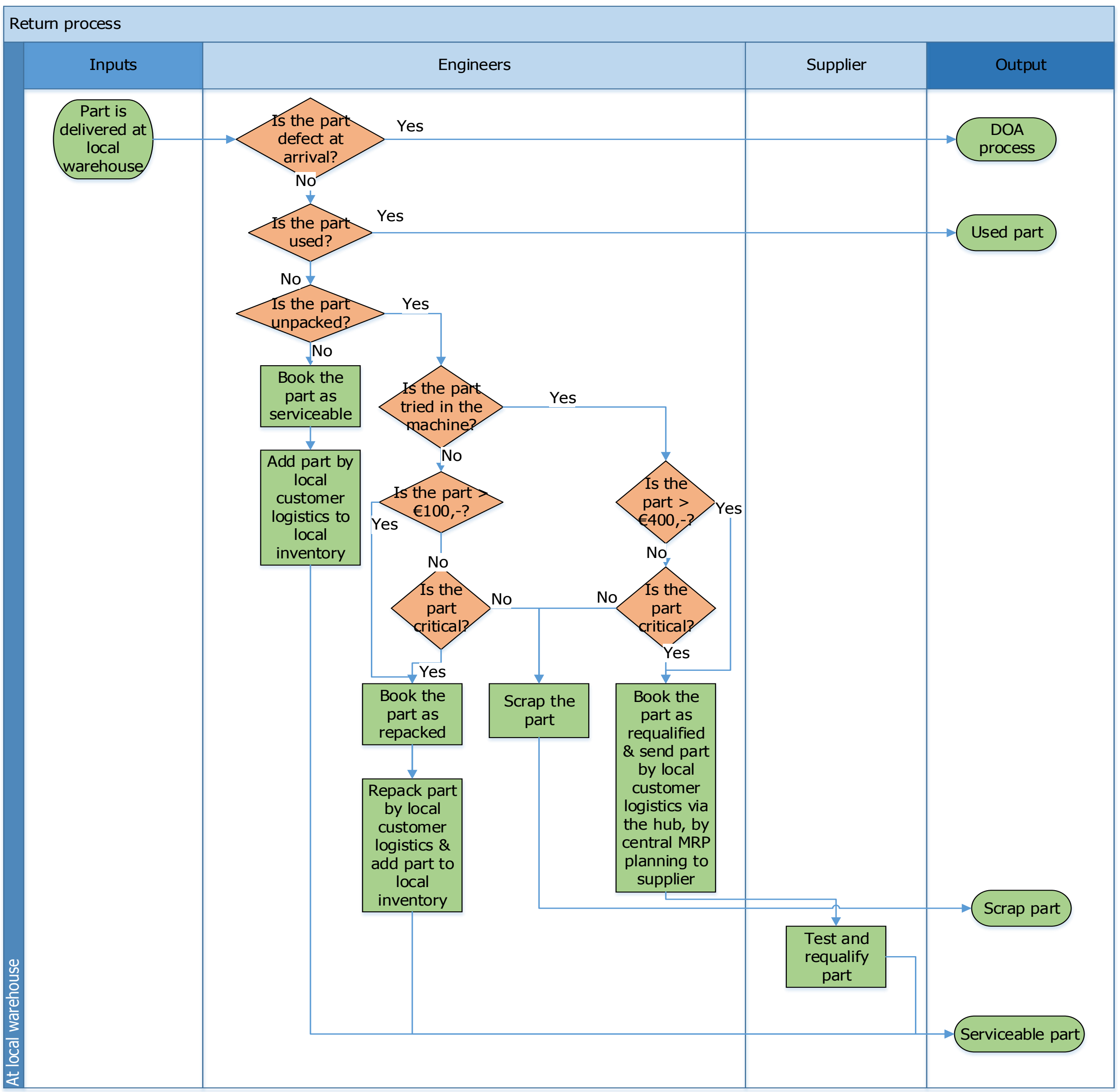


Figure 2.3: Process of return order.

The parts, which returned with the label "Requalification", were sent back by the local logistics centre to the hub. The hub sent them back to the supplier, who tested the parts and sent them back to the hub. In the hub the parts are added to the stock of the hub. When the part to be requalified has a price lower than €400,- and is not a critical part, the part is scrapped before going to the supplier. Critical parts are parts, of which there are too little on stock to fulfil the demand within lead time from the supplier. If a part to be requalified cannot be repaired, the part is scrapped. In total 15% of the parts to requalify is scrapped. The lead times are given in section 3.3 (Criticalparts1, 2014).

The parts to be repacked are sent to the local warehouse, then repacked and added to the stock at the local warehouse. When the parts to be repacked have a price lower than €100,- and they are not critical parts, then the part is scrapped, before repacking. In total 16% of the parts to repack is scrapped. The lead times are given in section 3.3 (Criticalparts1, 2014).

The serviceable are added to the stock in the local warehouse immediately. The lead times are given in section 3.3 (Criticalparts1, 2014).

2.2.1. Reasons of returned parts from interview

To answer the question why parts are ordered without usage, interviews were hold with stakeholders of the returning process. The results can be found in Table 2.3.

Category	Reason for ordering parts without usage	No. of references
System	Different possible root causes for the failure mentioned in the system	5
System	New machine, which means less knowledge about the possible failures	3
System	Unknown failure mode	1
Customer	High pressure of customer to solve as soon as possible	3
Customer	Customer demand for an extra part	1
Customer	Customer situation: Previous maintenance cost a lot of time or signing a new contract with the customer	1
Customer	Political situation: Management promised specific parts on stock	1
Contract	Limited time to diagnose, because of DTWP	3
Contract	Preparation for worst case scenario: certainty of repair at once	2
Engineer	Low expertise of engineer: Less knowledge about errors and less knowledge about diagnoses tools	2
Engineer	Gut feeling of engineer that extra parts are needed	1
Other	Often a DOA on that part: So more of the same SKUs ordered	1
Other	Part was not delivered on time and the engineers forgot to cancel the part when repair the failure	1

References:

- **Analyst of the process (Analyst1, 2014);**
- **One employee of the operational planning team (HeadInterfaceTeam1, 2014);**
- **Two service engineers, responsible of repair the ASML machines (Engineer2, 2014), (Engineer1, 2014);**
- **One employee from the global support centre (ServiceLogistics1, 2014);**
- **One single point of contact to the local warehouse (OperationalPlanner1, 2014).**

Table 2.3: Reasons for ordering without usage from interviews.

As you can see the reason which is mentioned by five out of six interviewees is 'different possible root causes for the failure mentioned in the system'. The reasons can be divided into five categories, which are explained more detailed as follows:

- System: When an engineer looks in the system for the problem, he finds a possible problem. Subsequently, this possible problem is the input for getting the solution out of another system. The output of that system is a list of ten different solutions, which were mentioned by an engineer at least once. Based on that information the decision of what part to order is made (CompetencyEngineer1, 2014).
- Customer: The machines of ASML are the bottleneck machines in the production process at the customer, because these are the most expensive machines and thereby the bottlenecks (ToolPlanning1, 2014). So when a machine is down, the whole flow is down. This results in high costs, which could lead to more than $500.000,- per hour for the newest machine of ASML (InventoryControl1, 2014). This situation at the customer results in high pressure of the customer and high dependency on each other.
- Contract: In the contract with the customer the down time has to be limited. Thereby there is limited time to diagnose and the repair has to be all at once to avoid losing time.
- Engineer: Because of the difficulties in the system, the engineer has to make decisions based on his experience and knowledge. Thereby it depends on the engineer, how much parts he will order.

The next sections present: Current forecast method, current determination of safety stocks at the local warehouse and current determination of reorder points at the central warehouse.

2.3. Current forecast method

This section answers the sub-question: "How does the current forecast method of the used parts perform?". This question is used to understand the current forecast method, which can be used later in determining the new forecast method. First the forecast method of the failure rates at local warehouses is described. Then the translation of this forecast is made to the central forecast.

2.3.1. Local forecast method

The current forecast of the failure rates is determined monthly. In the local warehouse all SKUs are stocked according safety stock levels, with as input the expected failure rates.

In Figure 2.4 the process of forecasting and reviewing of the failure rates is given. The process is divided in the demand forecasting and the control tower. In the demand forecasting the forecast is executed and reviewed. In the control tower the changes in the forecast, discussed in the demand forecasting, are decided. Per stage the process is explained in the next paragraphs.

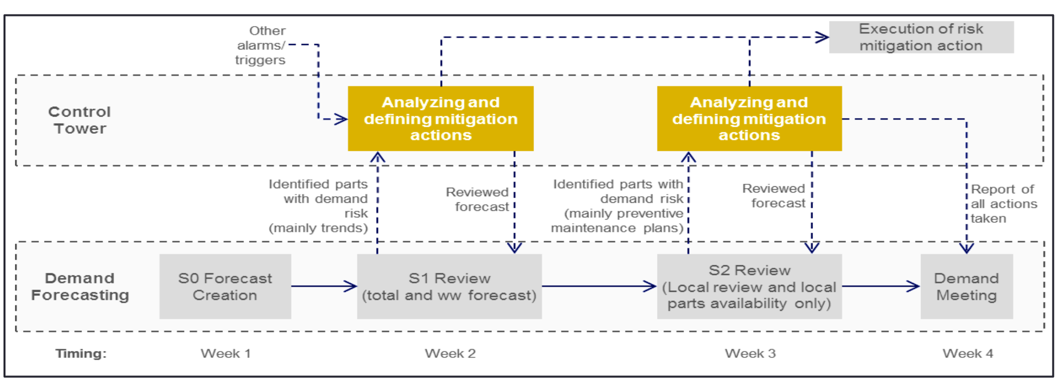


Figure 2.4: Monthly forecasting of failure rates.
Based on (Analyst3, 2014); Changed for this project to clarify the process.

In S0 the forecast is created. The input is as follows:

1. Usage per SKU per machine per quarter;
2. The number of SKUs per machine;
3. The number of machines per local warehouse.

The failure rate per quarter t is calculated by formula (2.1), as specified by ASML. $IBL_{i,t}$ is the install base life. This is the number of installed machines times the number of parts of that SKU in that machine in quarter t. $Usage_{i,t}$ is the average usage per day of SKU i in quarter t. The usage contains the preventive and corrective replacement of parts (Analyst3, 2014).

$$X_{i,t} = \frac{Usage_{i,t}}{IBL_{i,t}} \tag{2.1}$$

The forecast is determined at ASML by formula (2.2). Hereby w_t is the weight percentage. The weight percentage is measured by formula (2.3). The forecast is the average usage per day of SKU i during the last three years.

$$F_i = \sum_{t=1}^{12} X_{i,t} * w_t \tag{2.2}$$

$$w_t = \frac{\alpha^{t-1}}{\sum_{t=1}^{12} \alpha^{t-1}} \tag{2.3}$$

α is the decrease of exponentially weight and is 1.4 at ASML. α is determined by checking different weights and thereby 1.4 became a good mix of stiffness and flexibility (Analyst3, 2014). From my own calculations there is no difference in forecast with different weights. Changing this is out of scope of this research.

The time taken in the creation of the expected failure rate is three years and every time step is one quarter of a year. Thereby there are twelve periods. ASML choose for twelve periods because in the simulation study this amount of time resulted in the best performance of the forecast in terms of forecast errors (Analyst3, 2014). A t of 12 is the most recent period of the data sample.

The forecasts are reviewed on central and local level for specific SKUs. The criteria are stated in Appendix A.1. The results of S0 are the forecast of the failure rates per SKU and a list of SKUs to be discussed. The selected SKUs are discussed in S1 and S2.

In S1 the worldwide forecast of failure rates of the selected SKUs is discussed by the Inventory Control team and tactical planners per SKU. In this meeting the adjustments can be made per SKU per machine.

In S2 the regional review will take place with the SPOCs: contact persons to the local warehouse. Here the focus is on regional trends. Adjustments are made per local warehouse.

In the demand meeting (week 4 in Figure 2.4) the decision is made what changes are necessary to make. The forecast is the input for the determination of the reorder points as explained in section 2.4.

2.3.2. Central forecast method

In the central warehouse, SKUs are forecasted if they have a usage of more than six parts in half a year. A usage less than six parts in six months results in having a reorder point. The reason for this is that the forecast is reviewed monthly and thereby it is more cost efficient to only forecast SKUs which are used at least once per month.

The central planners check every month the forecast and they order per month the forecasted amount. There is no safety stock level or reorder point for the forecasted parts. The forecast is monthly reviewed.

In calculating the ROP the forecast, which is based on the formula (2.4), is needed (InventoryControl2, 2014). Hereby S_i is the forecast worldwide per day for SKU i. $F_{i,j}$ is the forecast per day of local warehouse j for SKU i. J is the number of local warehouses.

$$S_i = \sum_{j=1}^{J} F_{i,j} \tag{2.4}$$

2.4. Current determination of reorder points at the local warehouse

This section answers the sub-question: "How does the current determination of reorder points perform at the local warehouse?". In the half-yearly forecast of the local reorder points Spartan is used to determine the reorder points with a greedy algorithm (Kranenburg, 2006). A greedy algorithm is an algorithm that goes through all stages in a problem solving heuristic, whereby at each stage the local optimum is chosen. It is possible to find the global optimum, but the result could also be a local optimum (Hazewinkel, 2011).

The inputs for Spartan are as follows (TacticalPlanning2, 2014) (Kranenburg, 2006):

- Failure rates occurring following a Poisson process with constant rate $m_{i,n}$; whereby i is the SKU and n is a machine. These failures are determined following section 2.3.1;
- Number of machines of type n per customer linked to local warehouse j;
- Average time for an emergency transportation from the central warehouse to the local warehouse per SKU t_i^{em};
- Average cost for an emergency transportation from the central warehouse to the local warehouse C^{em};
- Average time for a lateral shipment from another local warehouse to the local warehouse per SKU t_i^{lat};
- Average cost for a lateral shipment from another local warehouse to the local warehouse per SKU C_i^{lat};
- Holding costs per time unit per SKU C_i^h.

The objective in Spartan is to minimize the total costs by determining the base stock level of SKU i at local warehouse j $S_{i,j}$.

The constraints are defined as follows (Kranenburg, 2006):

- Maximum average waiting time per local warehouse $\hat{W}_j^{obj}$: DTWP as specified in section 1.2;
- Lead time to deliver the parts with a routine transportation to the local warehouse (from the central warehouse) is fixed on 14 days.

In this method inventory pooling is applicable, which implies using the same inventory at one local warehouse of a SKU for several machines. Next to that, pooling is applicable to the lateral transhipment between local warehouses. In this case when a part is needed, the part also can be ordered from another local warehouse (and central warehouse). In this case all local warehouses can have lateral transhipments and thereby this method is full pooling. The greedy method contains three steps (Kranenburg, 2006).

Step 1: In step one the parameters are initiated, which includes setting zero stock levels: $S_{i,j} = 0$.

Step 2: In step two the base stock levels $S_{i,j}$ increase as long as the costs do not increase. Thereby $\Delta C(i,j)$, the cost difference of SKU i at local warehouse j, is measured to determine if the cost difference is equal or positive.

Step 3: In step three the stock level $S_{i,j}$ increases of the SKU that provides the largest decrease in waiting time ($\Delta W(i,j)$) per unit costs increase $\Delta C(i,j)$, as long as the current solution is not feasible. The current solution is feasible when the constraints as set above are achieved.

The written out formulas and procedure in detail can be found in Appendix A.2. Some SKUs need an extra review following the list in Appendix A.3. The review of the output of Spartan is also described in Appendix A.3.

When the failure rates are changed a lot in a month, the reorder points are changed based on the approach in section 2.3.1. The safety stock is one month of usage on top of the forecast. For SKUs with a high fluctuation, this amount can be higher. This amount is based on gut feeling (InventoryControl1, 2014).

2.5. Current determination of ROPs at the central warehouse

This section answers the sub-question: "How does the current determination of reorder points perform at the central warehouse?" When the usage is less than six in the last six months, the SKU has a reorder point and is ordered based on the reorder point. The reorder points are monthly reviewed and are reviewed when an SKU is ordered at the supplier (InventoryControl2, 2014).

The expected usage during lead time (DDLT) is calculated by including the expected demand (as in formula (2.4)) during lead time, including the scrapped parts of the returns in the demand and including the parts to repair (of the failed parts) of the returns. Please notice that the returns in formula (2.5) are the result of the usage. So because of a usage the failed parts in the machine are sent back. This is another flow than the orders without usage. The demand during lead time for SKU i is as follows formula (2.5) (InventoryControl2, 2014).

$$DDLT_i = Usage_i * Lead\ time_i * \left((1 - Return_i) + Return_i * (1 - Scrapped_i)\right) \\ + Usage_i * Return\ Lead\ time_i * Return_i * Scrapped_i \tag{2.5}$$

The ROP is calculated to fulfil the CSD, Customer Satisfaction Degree. The assumption is made that the demand during lead time is Poisson distributed. This is measured in August by checking the data with the distributions (InventoryControl1, 2014). In a Macro in Excel the calculation is made that the ROP will increase as long as the service level is not yet fulfilled, as in the cumulative function in formula (2.6) (InventoryControl2, 2014). In formula (2.6) the ROP has to be high enough to fulfil the change of not going out-of-stock ($1 - P(ROP \leq Usage)$), which has to be higher than the CSD.

$$1 - P(ROP \leq Usage) \geq CSD \tag{2.6}$$

When the demand is zero during lead time or when the demand is one in the last two months, the reorder point is two.

These SKUs have a safety stock. The safety stock is the difference between the ROP and the demand during lead time. So when the ROP is 3 and the demand during lead time is 0.71, then the SSL is 2 (3-0.71 rounded). For SKUs with a high fluctuation, this amount can be higher. This amount is based on gut feeling (InventoryControl1, 2014).

2.6. Conclusion

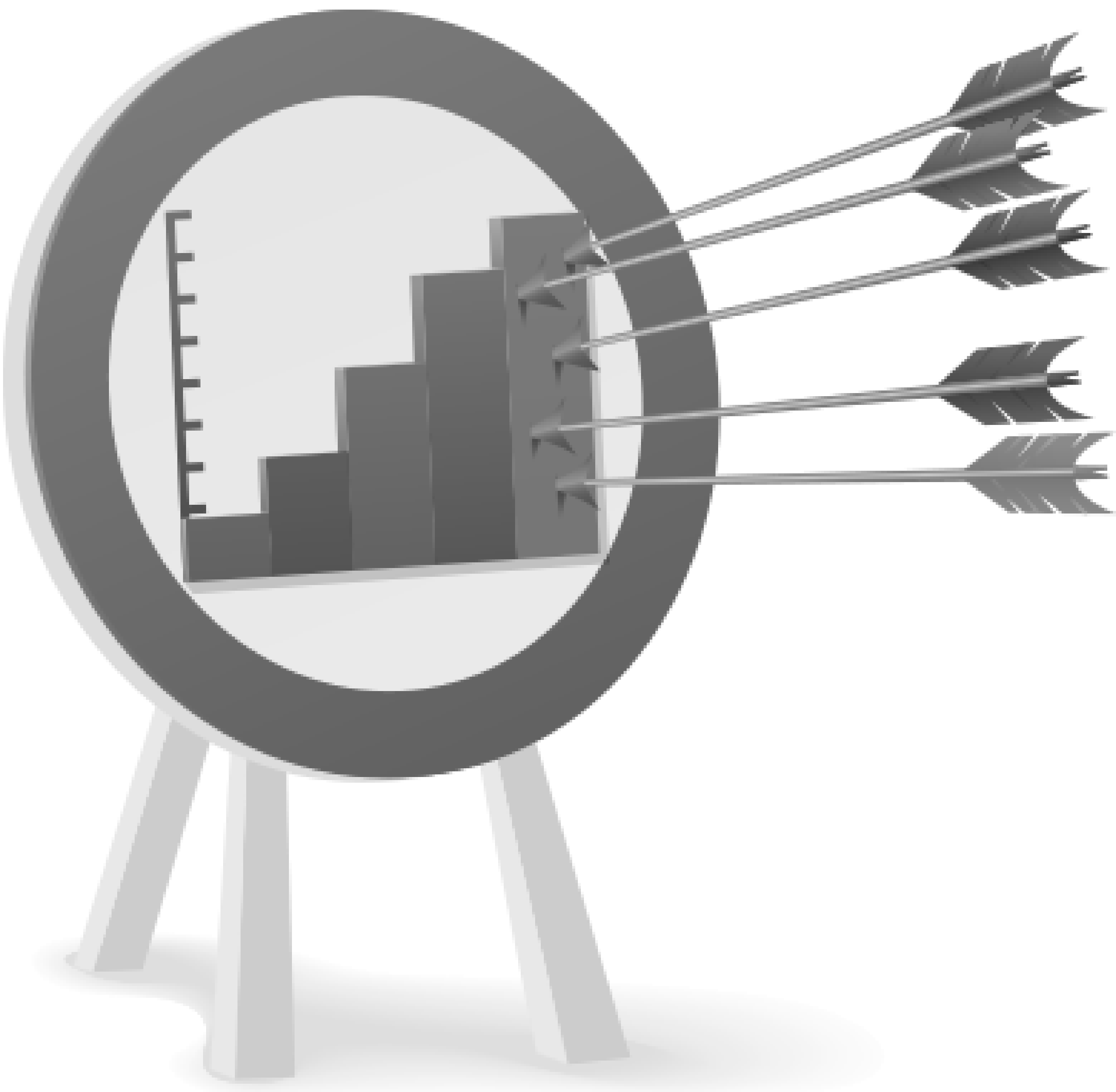
This chapter answers the question "What is the current way of working in the order and return process and how does ASML forecast and determine the base stock levels?". The conclusions are as follows:

- A new part only will be ordered when a part is needed and not on stock or when the inventory level is lower than the safety stock, which is a result of a usage of a part. The inventory level only changes when a part is used and not when a part is sent to the customer. Then the part is allocated.

- When returning a part, it can be used (67%), serviceable (21%) or labelled as requalified (7%) and repacked (3%). This means 33% of the orders from the local warehouse to the customer is not taken into account in the forecast. The orders without usage are handled different per order type. The serviceable parts and parts to repack are added to the inventory of the local warehouse. The parts to requalify are sent to the supplier and added to the inventory of the hub warehouse.

- The forecasted failure rate per local warehouse depends on the usage of a SKU per quarter, the installed base of machines for that SKU per quarter and the weight factor. The forecast of the usage per month for the central warehouse is dependent on the usage, the amount to repair and the lead times from the supplier. Thereby, in the local and central warehouse forecast the orders without usage are not taken into account.

- The reorder points at the local warehouse are constrained by the replenishment lead time and the constraints in the contract with the customer: the down time waiting for parts and the fill rate of a SKU. The reorder point at the central warehouse is impacted by the lead time of receiving new parts and repair parts from the supplier.



3. CURRENT PERFORMANCE ON ORDERS WITHOUT USAGE

This chapter answers the research question that is formulated in section 1.3: "What is the impact of not including orders without usage in the determination of base stock levels?" First the segments, with a high number of orders without usage, are determined. Then the effect of the orders without usage on the emergency transportation costs and replenishment cycle time is made clear. At the end it is made clear what the demand impact is on the availability in the supply chain.

3.1. The segments with high number of orders without usage

This section answers the sub-question: "In which segments of ASML is the number of orders without usage the highest?". Per segment the analysis on orders without usage is executed and the causes for the outcomes are made clear. The characterization of the orders without usage can be found in the conclusion of this chapter.

The data used for the orders at the customer are the data as mentioned in section 2.2. The data of the shipments are gathered at January 23, 2014 and contains all order lines of goods received between January 23, 2013 and January 22, 2014. The data are gathered by InventoryControl3 in SAP. For verification the data of the emergency and priority orders and returns of January 1, 2013 to December 31, 2013 are gathered at October 8, 2014 by Researcher1 in SAP.

3.1.1. Overall results

As given in section 2.2 orders without usage as percentage of all orders at the customer to the local warehouse is 33%. Orders without usage shipped as percentage of all parts shipped from other local warehouses and central warehouse to the local warehouses is 44%. A reason for a higher percentage when shipped, is that ASML does not plan on orders without usage and thereby the availability of orders without usage could be lower at a local warehouse. The total parts shipped include replenishment and rush orders. This means that also the replenishment of the stocks at the local warehouse is included. The parts in the orders based on safety stock are a result of usage, whereby the manual ordered parts still have to be used. Thereby the percentage of 44% is only an indication of orders without usage shipped.

The price per SKU does not differ between the mean of used orders and orders without usage. This is applicable for orders to the customer and shipments to the local warehouse.

When you check globally where the highest percentage of orders without usage is, you find out that there is a difference in continents (see appendix D). In Continent1 (28%) the percentage of orders without usage is lower than in Continent2 (35%) and Continent3 (35%). A reason for this could be the stable and thereby experienced workforce in Continent1. Another reason could be that the customers of Continent3 give the most pressure on the engineers and thereby this continent has a high percentage of orders without usage (HeadLogistics1, 2014). Going more into detail concerning the percentage of orders without usage per country, you see that in Continent3 Region1 has the lowest percentage of orders without usage. Although Region1 has the lowest percentage of orders without usage, the region still has the most orders without usage. The reason for this is that Region1 has the highest number of orders. Changing the work force is out of scope, but it is a good observation for ASML to take actions on.

3.1.2. A select number of SKUs causes most orders without usage

The Pareto principle states that a high number of events are caused by a small number of causes. The Pareto rule is known as the 80-20 rule, which means for the case of orders without usage, that 80% of the orders without usage is resulted by 20% of the SKUs (Chen, Chong, & Tong, 1991). As you can see in Figures 3.1 and 3.2 this is the case for ASML. In Figure 3.1 you can see that 17% of all SKUs ordered by the customer at the local warehouse results in 80% of orders without usage. In Figure 3.2 you can see that 28% of all SKUs shipped to a local warehouse results in 80% of orders without usage shipments. These shipments could come from the central warehouse, but also from other local warehouses or hub warehouses. Further in the research the method could be scoped by using only these high-impact SKUs.

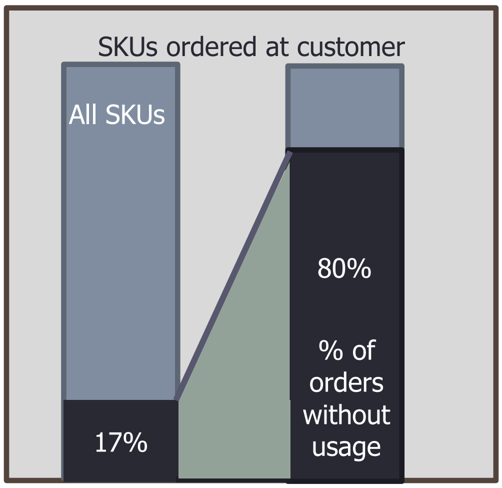


Figure 3.2: A select number of SKUs causes most orders without usage at the customer.

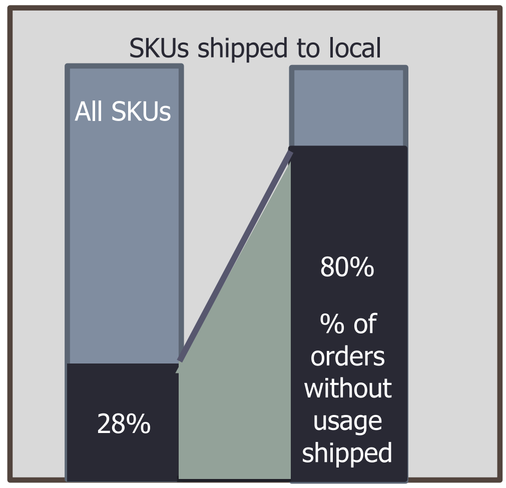


Figure 3.1: A select number of SKUs causes most shipments without usage to the local warehouse

3.1.3. Increase of orders without usage

In Figure 3.3 the number of parts returned per month can be found. This is the only data set in this chapter which is gathered for two-and-a-half years. As you can see the number of parts to requalify is equal over time. The number of serviceable returned parts is also increased in the last five months. The number of parts to be repacked is increased in the last year. An explanation for this is that the number of the machines is increasing. The overall demand is increasing and thereby the number of orders without usage is increasing. Consequently, planning on the orders without usage will have even bigger impact in the future.

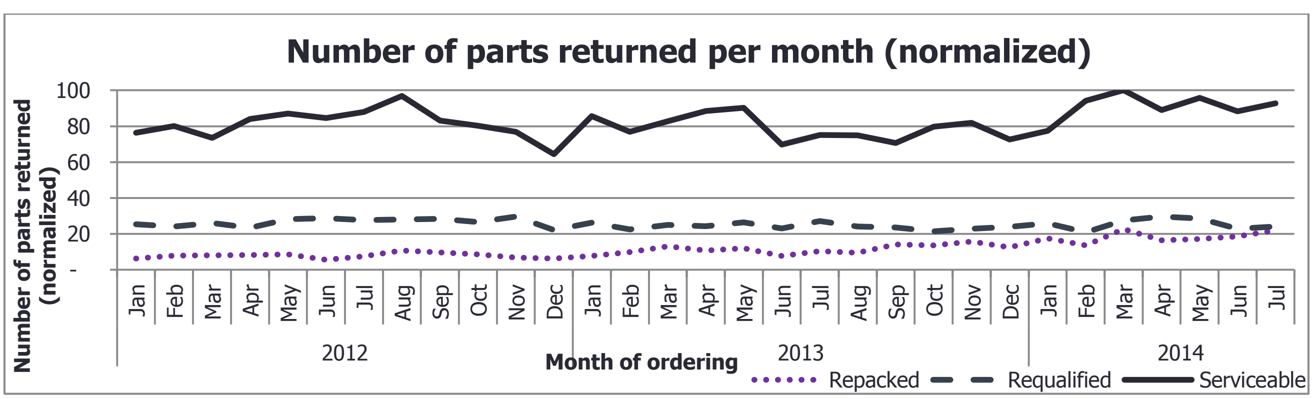


Figure 3.3: Number of parts returned per month.

3.1.4. Newest machines have the highest number of orders without usage

In Figure 3.4 the percentage orders without usage per machine type can be found. As you can see in Figure 3.4, Machine 1, Machine 3 and Machine 8 has the highest percentage of orders without usage. Machine 1, Machine 3 and Machine 8 are the newest machines of ASML. The reason for the high percentage of orders without usage for new machines could be the missing experience and knowledge of the engineers with the machines. Also the increase of complexity of machines could be a reason for having a higher percentage orders without usage for the newest machines. The outlier in this figure is Machine 4. This machine is the oldest machine of ASML and thereby has the lowest percentage of orders without usage. There is no correlation between the newest machines and the continents or countries with a high percentage of orders without usage.

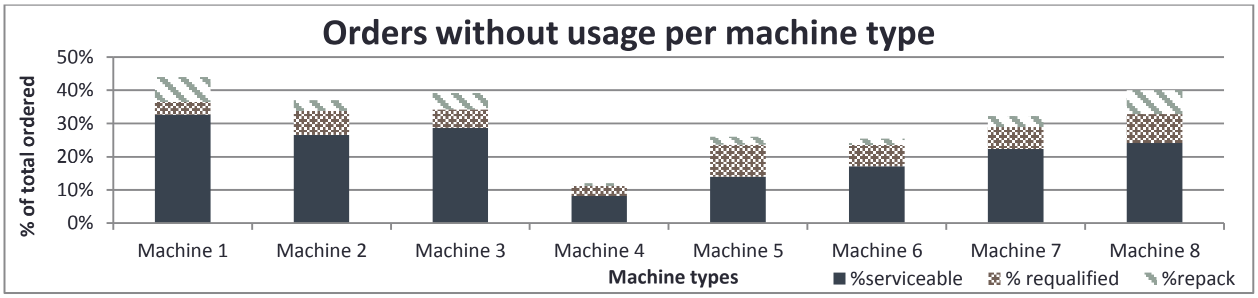


Figure 3.4: Orders without usage per machine type.

3.1.5. Higher percentage emergency transportations for orders without usage

In Figure 3.5 the transportation type per usage bucket can be found. The SKUs in full usage are the SKUs with no orders without usage. The SKUs in the bucket partly used have some orders which are used and some orders which are not used. The bucket no usage contains SKUs with all orders not used. As you can see an SKU with no usage has more emergency transportations than a SKU with full usage. When you go in detail with this the data, the percentage of emergency transportations for SKUs with no usage is higher for shipments between continents than within continents. This can be explained by the fact that most parts that were ordered were ordered in Continent1 and Continent3 and that the central warehouse is stated in Continent2, which delivers most parts. This information is useful for the explanation of the emergency transportation costs in section 3.2.1.

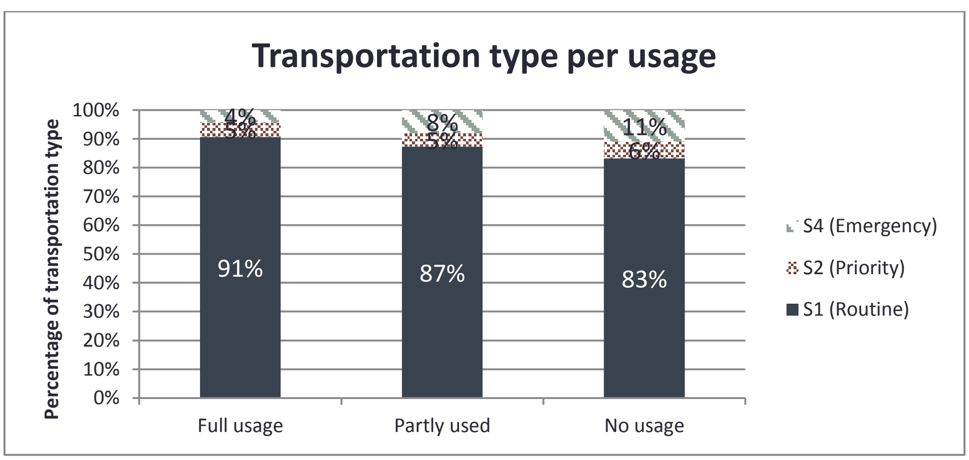


Figure 3.5: Transportation type per usage bucket.

3.2. Impact of orders without usage

This section answers the sub-question: "What is the impact of orders without usage on the emergency transportation costs and replenishment cycle time?". The impact of orders without usage on the holding costs is not possible to measure before calculating the safety stocks with the new forecast method. The DTWP is not directly possible to link to usage, because ASML does not measure the down time linked to the exact orders.

3.2.1. Emergency transportation costs

As explained in section 2.4 the holding and transportation costs of SKUs are minimized in the determination of the safety stocks. The transportation costs in the determination of the safety stocks are the emergency and lateral transportation costs. In this section these costs are combined to emergency transportation costs.

As was already shown in Figure 3.5 in section 3.1.5 the number of emergency transportations is higher for partly used and not used SKUs. The transportation costs are calculated by measuring the number of emergency orders from a supplying local warehouse to a receiving local warehouse. Per transportation between a supplying and receiving local warehouse, transportation costs are looked up in the input parameters of Spartan and checked with the Infrastructure & Transportation department of ASML (Analyst2, 2014) (TransportController1, 2014). The costs per transportation and the number of transportations per supplying and receiving warehouse are multiplied and all costs are summed.

Based on the data of 2013, the emergency transportation costs of the shipments without usage are in total €[redacted] million. This is 55% of all emergency transportation costs. €[redacted] million is related to lateral shipments.

Emergency transportation costs per type of planning

In Figure 3.6 the emergency transportation costs are explained per type of planning: "Having reorder point/safety stock level, but no stock available" and "Having no reorder point/safety stock level".

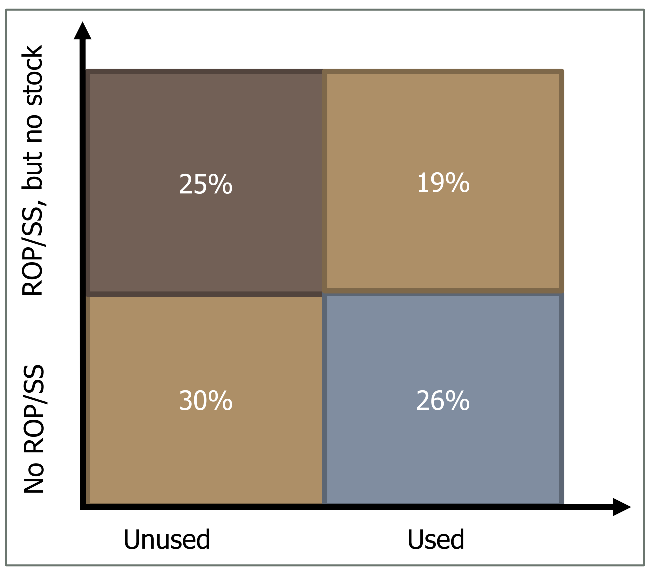


Figure 3.6: Emergency transportation costs per usage and (no) ROP/SSL

As you can see in Figure 3.6, 44% of the emergency transportation costs are made when a SKU has a reorder point or safety stock at a local warehouse, but when there is no stock. Two reasons are possible to clarify this: supply chain issues and orders without usage. Supply chain issues could be made quantified by measuring the number of critical parts. In the buckets of "ROP/SS, but no stock" is the improvement expected, because here the unused parts have effect on the planned safety stock level (HeadLogistics1, 2014).

Emergency transportation costs if machine is down

In Figure 3.7 the emergency transportation costs are divided in "Machine down" and "Machine not down". Remarkable is that 43% of the emergency transportation costs is caused by orders when the machine is not down. These transportation costs, when the machine is not down, are mainly caused in Region1 (58%) and Region2 (25%). This means that in these regions the engineers also order emergency shipments although it is not allowed when the machine is not down. Although Continent2, Region2 and Region3 are the regions with the highest percentage emergency transportations, the emergency transportations costs based on orders without usage are mainly caused by Region1 and Region2. This is because Region1 and Region2 have the highest number of orders. Based on Figure 3.7 can be concluded that orders without usage are also ordered because of a down machine. So there is an effect of no usage on having a machine down. In this research the reduction in costs can be gained in all buckets.

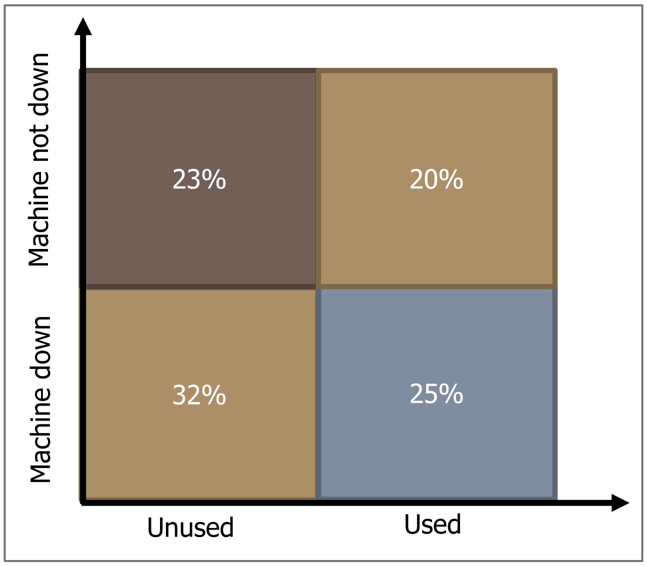


Figure 3.7: Emergency transportation costs per usage and machine down

3.2.2. Replenishment cycle time

The expectation is that the replenishment cycle time (RCT) (measured per day) is higher for a high percentage orders without usage, because of not planning on that demand. In Table 3.1 the comparison is made between a high, medium or low usage and the percentage orders without usage of the total number of orders per SKU. As you can see the replenishment cycle time is higher for low usage SKUs and for high percentage of orders without usage. The high replenishment cycle time for low usage SKUs could be because the safety stock model planned on this. The high replenishment cycle time for high percentage of orders without usage is because there is not planned on these orders.

Replenishment Cycle Time per Usage - % Orders without usage		**Percentage of orders without usage of total orders per SKU at customer**		
		Low	Medium	High
Usage per SKU	Low	77	94	100
	Medium	65	67	73
	High	67	74	74

Table 3.1: Replenishment cycle time per usage and percentage orders without usage per SKU.
Usage per SKU is in equal buckets: Low (max 1 order in 2013), Medium (between 2 and 5 orders in 2013) and High (6 or more orders in 2013). Percentage orders without usage of total orders per SKU in equal buckets: Low (Full usage), Medium (Max half of the orders is without usage) and High (More than half of orders without usage).

3.3. Returning time of orders without usage

This section answers the sub-question: "How long is the return lead time of orders without usage?". The return time is divided in: time from customer to local, time at local and to hub, time at hub and time from hub to supplier and back on stock in the hub.

3.3.1. Time from customer to local

The maximum time of parts at the customer is fixed. Engineers have to send the orders without usage with material notification within fourteen days to the local warehouse (InventoryControl2, 2014). After those fourteen days the serviceable parts are put on stock. The parts to repack are scrapped, replenished or repacked and then put on stock (see Figure 3.8). Parts could be scrapped because it is too expensive to repack these parts. These data are gathered by CriticalParts1 and CriticalParts2 on weekly basis from SAP. Data of 2013 are used for analysis. The time to repack is not measured separate, because the parts to repack are booked at the moment that the parts are already repacked. Because ASML cannot connect the orders and returns, the difference in return time of serviceable and repack parts is unknown. Engineers report that the time to repack is small and will not result in delay in adding the part to the inventory (Engineer1, 2014).

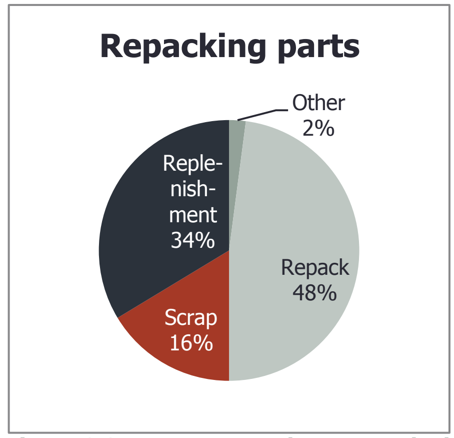


Figure 3.8: Parts to repack are repacked, scrapped or replenished. Data from 2013; Gathered by CriticalParts1 every two weeks from SAP.

In these fourteen days the serviceable and repack parts were allocated. When parts are allocated, the parts still can be used in another machine at the same customer, if not used at the requesting machine. Also when another customer in the same region needs an allocated part (at a customer), the engineer calls for the part if it is available. Thereby the availability will not be lower by repack or serviceable parts. This means that in the forecast of inventory these parts don't have to be taken into account (InventoryControl1, 2014).

3.3.2. Time at local warehouse and to hub

The parts to be requalified have to be sent once a week from the local warehouse to the hub (InventoryControl2, 2014). On average, it takes 8.9 days for requalification parts, with a standard deviation of 10.3 days. This is based on data of 2013 gathered by OperationalPlanner1 at September 22, 2014 in SAP. The results are verified with employees of the central planning team.

3.3.3. Time at hub

Next the central planners have to decide within fourteen days what the action will be on those parts: scrap, replenishment or requalify (see Figure 3.9). These data are gathered by CriticalParts1 and CriticalParts2 on weekly basis from SAP. Data of 2013 are used for analysis. Also this time is not exactly measured, because the order numbers change between local warehouse and hub.

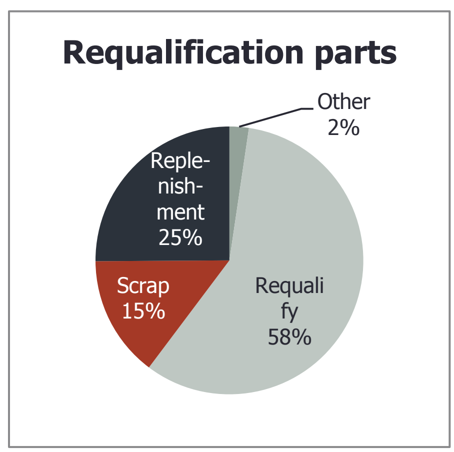


Figure 3.9: Parts to requalify are requalified, scrapped or replenished. Same data source as Figure 3.9.

3.3.4. Repair at supplier

The repair (including shipping) takes on average 49 days with a standard deviation of 31 days. These data are gathered by Researcher1 at November 13, 2014 in SAP. The data are of the quarters two and three in 2014, because since 2014 they have a new approach in sending returned parts to the supplier. The result is verified with the central planning team. Then the part is booked on stock in the hub.

3.3.5. Total return time

When measuring the total time starting from the material notification till the return of requalification parts to the hub, the total time is on average 71 days with a standard deviation of 43 days. The data is the same as the repair data in the paragraph above. The 71 days contain the time at the local warehouse (max 7 days), transportation form local warehouse to hub (9 days), the time at hub (max 14 days) and the time to the supplier (49 days). Next to that, the parts to requalify are already maximal 14 days out of stock before adding them to the local stock.

Concluding the serviceable parts and parts to repack are within fourteen days back on stock at the local warehouse. The parts to requalify are back on stock at the hub within 85 days (when decided to repair at the hub).

3.4. Conclusion

This section gave answer to the question "What is the impact of not including orders without usage in the determination of base stock levels?". The conclusions are as follows:

- The orders without usage as percentage of all orders at the customer are 33%. Shipments without usage as percentage of all shipments are 44%. The overall demand is increased in the last year and also the number of orders without usage is increased in last year. Therefore planning on the orders without usage will give even bigger impact in the future.

- Characteristics of orders without usage are the following:
  - Mostly ordered for the newest machines;
  - Mostly ordered for Region1 or Region2;
  - 64% of the orders without usage is serviceable, 21% has to be requalified and 10% has to be repacked;
  - A select number of SKUs causes most orders without usage: 17% of all SKUs ordered by the customer at the local warehouse results in 80% of orders without usage.

- A SKU with no usage has more emergency transportations than a SKU with full usage. This results in emergency transportation costs of the shipments without usage of €[redacted] million in 2013. This is 55% of all emergency transportation costs. 42% of the emergency transportation costs are while the machine is not down, which is mainly caused by Region1 (58%) and Region2 (25%). These regions also have overall the highest emergency transportation costs.

- The replenishment cycle time is higher of a SKU with a high number of orders without usage compared to a SKU with a low number of orders without usage.

- The serviceable parts and parts to repack are within fourteen days back on stock at the local warehouse. There is no difference in return time, because the engineer books the parts in one time as inventory. There will be additional costs for repacking. These costs will not be taken into account in this research.

- The parts to requalify are within 85 days back on stock at the hub (when decided to repair at the hub). These parts are in this time not available and thereby have to be taken into account in the new forecast method. There will be additional costs for the requalification. These costs will not be taken into account in this research.

4. LITERATURE REVIEW FORECAST METHOD

This chapter answers the research question that is formulated in section 1.3: "Following the literature, what forecast method can be used to determine the demand and return flow?". First the forecast methods from literature are given. Then the criteria are made clear and next the method is chosen.

4.1. Forecast methods from literature

This section answers the sub-question: "Which methods are possible to forecast the demand and return orders?".

Web of Science, Scopus and the University Library catalogue were used to find all articles and books. Keywords, like 'reverse logistics', 'forecast', 'stock', 'inventory control', 'internet sales', 'lost sales', 'sales with rejection', 'return parts', 'reverse logistics', 'remanufacturing', 'reuse', 'recovery' and 'demand forecasting', were used to find literature. Also forward and backward search is used to check related articles to already found articles.

Kelle and Silver (1989) developed four different methods of forecasting demand, which include different amounts of return information. These authors are the most suitable authors who take the returns into account in the forecast of demand. Most authors take the returns in to account in the inventory optimization model. Because of the restriction of no changes in the inventory model at ASML, these articles are not adaptable to ASML.

Method 1 only takes the failure rates of the SKUs into account. **Hereby the forecast is the demand during lead time multiplied with a fixed probability that a part is never returned.** The demand is all orders transported to the customer, so including usage and all return types.

Method 2 is more exact than method 1 and includes all returns (expected) during replenishment lead time. Hereby the total returns are combining the expected returns during lead time of demand before the current period and the expected returns during lead time of demand during lead time. **The forecast is the demand during lead time minus the total returns during lead time.**

Method 3 includes even more information than method 2, by including the return information per order per period. This means that each order is separately tracked and information have to be saved of the demand and returns per period. Hereby the total returns per order are combining the expected returns per order during lead time. The returns are of demand before the current period and of demand during lead time. **The forecast is the demand during lead time minus the sum of the total returns during lead time per order.** This method requires the most information of all methods.

To reduce the time needed to track the orders separately like in method 3, method 4 is developed. In method 4 the information of method 2 is used including the correlation of the returns. Hereby the correlation is taken into account of the returns before current period with the returns during lead time of demand before current period. The correlation of returns is based on the total amount of returns per period without identification which order is issued. This means that if there are a high number of returns before the current period, there will be a lower number of returns during lead time of the demand in the same period. The total number of returns cannot be higher than the demand of that period. This results then in a negative correlation and in a higher forecast. **The forecast is the demand during lead time minus the returns during lead time (method 2) plus the correlation of returns** (Kelle & Silver, 1989).

4.2. Criteria forecast method

This section answers the sub-question: "What are the criteria for the forecast method?". The methods of Kelle and Silver (1989) are measured on three criteria in literature:

- Relative error of the forecast of the method compared to the most-informed method:
  Kelle and Silver (1989) and De Brito and van der Laan (2009) reason that the method with the most information is the most realistic method. Thereby method 3 is the most appropriate method. The second and third best method, relatively method 4 and 2, don't differ more than 1% from method 3. Method 1 performs very poorly overall and it is not recommended by de Brito and van der Laan to use this method in practice (Kelle & Silver, 1989) (De Brito & Van der Laan, 2009).
- Robustness of the method when the return rate is over- or underestimated:
  The robustness is measured by De Brito and van der Laan (2009) to find the effect of imperfect information. The most robust method is method 2. Method 3 is less robust than method 2, but the gap is at maximum 2% cost difference with relation to method 2 in case of over- and underestimation. Method 4 is of these three the least robust, with a maximum of 26% difference in costs compared to method 2. Method 1 is not measured on robustness, because De Brito and Van der Laan rejected this method based on the forecast errors (De Brito & Van der Laan, 2009).
- Amount of data required as input for the method:
  Method 2 needs the individual tracked returns and demand per period. This information is available at ASML, but not yet sorted. Method 3 needs individual tracked returns and demand per period. ASML has this information not yet available. Method 4 needs the demand, return rate per period and the returns of the demand from one period linked to each other. ASML has this information not yet available. (De Brito & Van der Laan, 2009)

4.3. Choice of method

This section answers the sub-question: "Which method is following the criteria the best to be added to the forecast of ASML?"

The result of the research of Kelle and Silver is that the relative errors of the forecast of method 1 are considerable, whereby this method is rejected. The improvements of method 2 and 4 are obtainable and are quite big improvements compared to method 1. Method 3 got the biggest improvement, but it is difficult and time expensive to obtain all data (Kelle & Silver, 1989). They conclude to implement method 2 or 4.

De Brito and van der Laan advise to use method 2, because this method is the most robust, the performance difference with the best method is rather small and the investments in recording the data are not high.

From the overview of the results from literature and the amount of data available at ASML, the conclusion can be made that method 2 is the best method to implement at ASML. The reason for this is that ASML already has this information available, this method is the most robust and the performance on forecast error is rather small compared to method 3 and 4.

In the next section Method 2 of Kelle and Silver is explained in detail. In this section first an example is given to calculate the forecast with the method of Kelle and Silver. Then the method is explained in the form of formulas.

4.3.1. Formulas of method 2 of Kelle and Silver

In method 2 of Kelle and Silver the realized demand is measured at the end of each period i. Returns arrive at the beginning of an interval i. The current time is at the end of period t. The forecast of method 2 is calculated for the time between the current time t and the current time plus the lead time $t + L$.

In Table 4.1 an overview is given of the notation used in method 2 of Kelle and Silver.

Notation	Description
$\boldsymbol{t}$	Current period
$\boldsymbol{L}$	Lead time; In the case of the local inventory system this is the replenishment lead time; In the case of the central inventory system this is the supplier lead time
$\boldsymbol{F[t+1,t+L]}$	Forecast during (supplier/replenishment) lead time after period t; This is calculated in method 2
$\boldsymbol{ED[t+1,t+L]}$	Expected demand during (supplier/replenishment) lead time after period t; The demand includes items that will be classified as usage, requalification, repack and serviceable returns later on
$\boldsymbol{ER[t+1,t+L]}$	Expected returns during (supplier/replenishment) lead time after period t; The returns include items that will be classified as repack and serviceable returns later on
$\boldsymbol{Y_i[t+1,t+L]}$	The success probability of getting back the demand in period i during (supplier/replenishment) lead time after period t, whereby $i < L$
$\boldsymbol{m[t+1,t+L]}$	Amount of periods of the earliest demand, with returns during (supplier/replenishment) lead time after period t
$\boldsymbol{q[t+1,t+L]}$	Amount of periods of the latest return during (supplier/replenishment) lead time after period t
$\boldsymbol{n[t+1,t+L]}$	Amount of periods before t of the first demand with returns during (supplier/replenishment) lead time after period t
$\boldsymbol{\mu_i}$	Expected demand in period i, whereby $i > t$; The demand includes items that will be classified as usage, requalification, repack and serviceable returns later on
$\boldsymbol{u_i}$	Realized demand in period i, whereby $i < t$; The demand includes items that will be classified as usage, requalification, repack and serviceable returns later on
$\boldsymbol{p_i}$	Probability that a demand returns in period i

Table 4.1: Notation in method 2 of Kelle and Silver and their descriptions.

The forecast of method 2 of Kelle and Silver is the forecast during the lead time. The forecast during lead time, $F[t+1,t+L]$ of method 2 of Kelle and Silver is calculated as expressed in formula (4.1). This formula includes the expected demand during lead time, $ED[t+1,t+L]$ and the expected returns during lead time, $ER[t+1,t+L]$. The demand includes the usage and requalification, repack and serviceable returns.

$$F[t+1,t+L] = ED[t+1,t+L] - ER[t+1,t+L] \tag{4.1}$$

The expected demand during lead time, $ED[t+1,t+L]$, is the sum of the expected demand, μ_i, during each period between current period t (so $t+1$) and current period t plus lead time L (so $t+L$).

$$ED[t+1,t+L] = \sum_{i=t+1}^{t+L} \mu_i \tag{4.2}$$

The expected returns during lead time, $ER[t+1,t+L]$, is the sum of the expected returns during lead time of realized demand before current period t and of expected demand during the lead time after period t. This calculation is stated in formula (4.3).

The first side of formula (4.3), $\sum_{i=t-n[t+1,t+L]}^{t} u_i Y_i[t+1,t+L]$, is the expected returns during lead time of realized demand before current period t: sum of the realized demand in period i, u_i, times the success probability of getting the demand back during lead time, $Y_i[t+1,t+L]$. The realized demand is the measured demand in the periods before current period t. Here per demand in period i the amount of returns is calculated. The earliest period, $t-n[t+1,t+L]$, is the earliest period of demand that has returns during lead time.

The second side of formula (4.3), $\sum_{i=t+1}^{t+L-1} \mu_i Y_i[t+1,t+L]$, is the expected returns during lead time of demand during lead time after period t: sum of the expected demand, μ_i, times the success probability of getting the demand of period i back during lead time, $Y_i[t+1,t+L]$. The time is taken from next period (first period of returns; $t+1$) till the last period of possible returns before lead time $(t+L-1)$. This is because at $t+L$ the ordered parts will be delivered.

$$ER[t+1,t+L] = \sum_{i=t-n[t+1,t+L]}^{t} u_i Y_i[t+1,t+L] + \sum_{i=t+1}^{t+L-1} \mu_i Y_i[t+1,t+L] \qquad (4.3)$$

The last question is how to calculate the success probability, $Y_i[t+1,t+L]$. <u>The success probability is the sum of the chances that the parts of demand i return over different periods during the lead time.</u>

The success probability is calculated differently for each time period:

1. The periods before the earliest demand, with returns during lead time, are the time periods without returns during lead times. This means that the success probability is zero.
2. The period between the earliest demand, with returns during lead time, and the current period is the second time bucket. In this time bucket the success probability of returns during lead time of demand in time i is the sum of the chances the parts will be returned during lead time, p_{t-i+j}. The chance that a demand of period i will return during lead time after period t is the sum of the chances the returns from t to $t+L$. When j is 1 in p_{t-i+j}, this is the chance of returns in period $t+1$. The j will increase to the minimum of the lead time, L, and the last chance of return of that demand, n. This results in the following formula: $m[t+1,t+L] = \min\{L, n[t+1,t+L]+i-t\}$.
3. The period between the current period and the current period plus the lead time is the third time bucket. In this time bucket the success probability of returns during lead time of demand in time i is the sum of the chances the parts will be returned during lead time, p_j. These returns are from the first chance of return of that demand, j is 1, and till the minimum of the first return before t and the lead time. This results in the following formula: $q[t+1,t+L] = \min\{n[t+1,t+l], t-i+L\}$.

The success probability can thereby be given as formula (4.4). The timing of the returns is between current period t and the lead time L. The chance that demand i returns in that time frame is measured as the sum of the chances per period i.

$$Y_i[t+1,t+L] = \begin{cases} 0, \; for\; i < t-n[t+1,t+L] \\ \sum_{j=1}^{m[t+1,t+L]} p_{t-i+j}, \; for\; t-n[t+1,t+L] \le i \le t \\ \sum_{j=1}^{q[t+1,t+L]} p_j, \; for\; t < i < t+L \end{cases} \qquad (4.4)$$

In the next section an example is given to illustrate the method.

4.3.2. Example of method 2 of Kelle and Silver

In this example the current time t is 3. This means that we are currently at the end of period 3. The replenishment lead time of the SKU, L, is 3 periods in this example.

First we need to know the input parameters in this example: the realized demand in period i, u_i, the expected demand in next period i, μ_i, and the chance of return in period j per demand in period i, p_j. This information is given in Table 4.2.

As can be seen in Table 4.2 the demand in period 1 was 3 parts. One of these parts is returned in period 2, one of these parts is retuned in period 3 and one of these parts is expected to return in period 4. The periods are counted in Table 4.2 as period i plus j periods later. This means that all parts return, which were ordered in period 1, whereby one part is expected to return during lead time (after t=3). This means that the demand of period 1 is fully returned after three periods. When the sum of the probabilities is lower than 1, then a fraction of the demand is used. This means that one minus the sum of the probabilities of demand in period i is the probability of usage. The realized demand is the sum of all demand of a SKU in period i. The p_i's of realized demand are different for each period because these are known based on the data of ASML.

In the article of Kelle and Silver (1989) it is not mentioned how the expected demand has to be calculated. In this example in Table 4.2 the expected demand is 4. So on average 4 parts are ordered in every period.

Period	**Realized demand in period i**	**Expected demand in period i**	**Expected probability of return in period i+j**			
i	u_i	μ_i	p_1	p_2	p_3	p_4
1	3		0.333	0.333	0.333	-
2	6		0.167	0.333	0.167	-
3	2		-	0.5	-	-
4		4	0.25	0.5	-	-
5		4	0.25	0.5	-	-
6		4	0.25	0.5	-	-

Table 4.2: Input parameters in example of method 2 of Kelle and Silver.

The question is how to calculate the expected returns during lead time. The expected returns during lead time can be divided in the expected returns of demand before t and expected returns of expected demand after t.

The expected returns of demand before t are the realized demand multiplied with the chance of returns in period i. p_j is the chance of returns after j periods starting in period i of the demand. For example for period 5 the expected returns of previous demand are the realized demand of period 1, 2 and 3 multiplied with the expected percentage returned in period 5 of demand in period 1, 2 and 3: $u_1 * p_4 + u_2 * p_3 + u_3 * p_2 = 3 * 0 + 6 * 0.167 + 2 * 0.5 = 2$. The expected number of returns in period 5 of demand before current period t =3 is 2.

The expected returns of expected demand after t is the expected demand multiplied with the expected chance of returns in period i. For example for period 5 the expected returns of demand during lead time are the expected demand of period 4, μ_4, times the expected percentage returned in period 5 of demand in period 4, p_4, (4*0.25). The expected number of returns of demand during lead time for period 5 is 1.

This means that in this example, based on Method 2, the demand minus the returns in period 5: 4 – 2 – 1 = 1. The forecast is thereby 1 for period 5. The forecast in this example is an integer. This doesn't have to be the case.

4.4. Conclusion

This section gave answer to the question: "Following the literature, what forecast method can be used to determine the demand and return flow?". The conclusions are as follows:

- The suitable literature of forecast methods with returns is the article of Kelle and Silver (1989). They present four forecast methods, which are compared to each other and measured based on the articles of Kelle and Silver (1989) and De Brito and Van der Laan (2009). In these articles the criteria are relative forecast error, robustness and amount of data.

- Based on these criteria method 2 of Kelle and Silver is chosen. This method is the most robust, can be calculated with available data of ASML and has a rather small forecast error compared to the two methods of Kelle and Silver with less forecast errors.

- Method 2 includes all returns (expected) during replenishment lead time. Hereby the total returns are combining the expected returns during lead time of demand before the current period and the expected returns during lead time of demand during lead time. The forecast is the demand minus the total returns during lead time.

5. Applied method

This chapter answers the research question that is formulated in section 1.3: "How can the chosen method be added to the current determination of the base stock level?". First the chosen method 2 of Kelle and Silver (1989) is applied to ASML. Then, because of some disadvantages of this method, a new method is developed. At last the tests of the methods for the optimization of the central and local inventory are explained.

5.1. Applied forecast method to ASML

This section answers the sub-question: "How can the method be applied to ASML to forecast the order and return flow?". First the applied inventory model is presented. Then Method 2 of Kelle and Silver (1989) is applied to ASML and the new developed method is presented.

5.1.1. Inventory model applied to ASML

Based on the Figures A to D in Appendix C, an applied model is designed. In Figure 5.1 the applied inventory model at ASML can be found. This model is based on the process descriptions in chapter 2. In Figure 5.1 you see that the serviceable, repack and requalification returns are separated in the inventory model. The number of parts in the system decreases by used or scrapped parts. The parts to requalify are scrapped when the price of these parts is lower than €400,- and these parts are not critical. The parts to repack are scrapped when the price of these parts is lower than €100,- and these parts are not critical. For these scrapped parts it is more cost-effective to buy a new part, than to requalify or repack these parts. (Criticalparts1, 2014)

As can be seen in Figure 5.1 the parts to requalify are returned on stock at the hub. This means that they are out of the system for the local warehouse. The serviceable parts and parts to repack are stocked at the local warehouse.

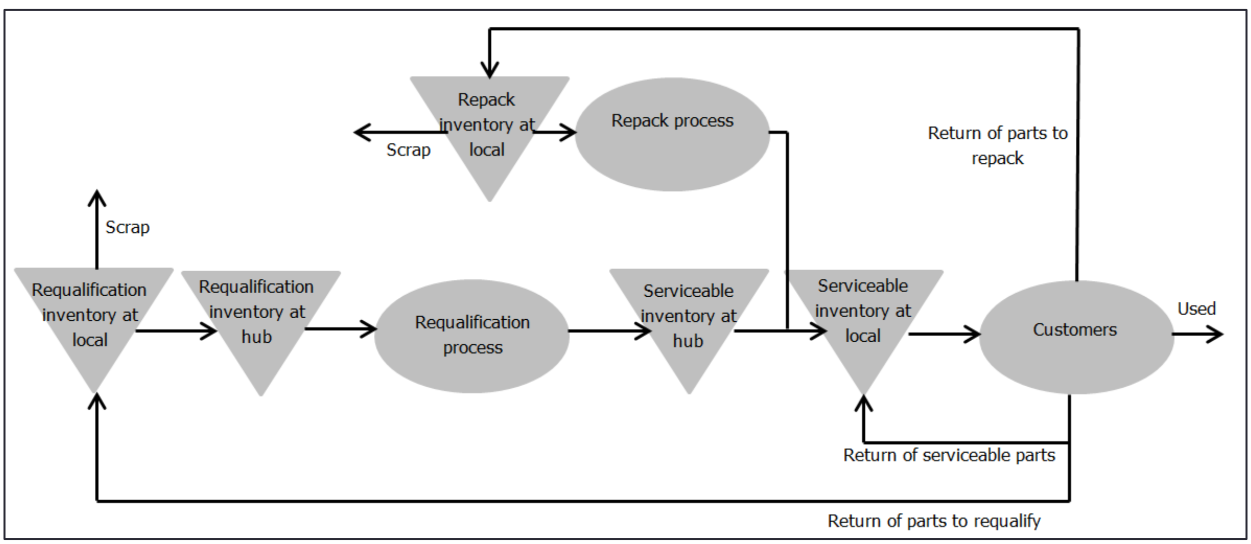


Figure 5.1: Applied inventory model of the reverse logistics at ASML.

5.1.2. Method 2 of Kelle and Silver applied to ASML

In this section method 2 of Kelle and Silver is applied to the situation at ASML. The method is modified in a way that it is possible to implement this method. These changes are as follows:

- In the current forecast method the usage is **exponential smoothed over twelve quarters** for the **local inventory model**.[1] To make the tests of the methods in the inventory model comparable, method 2 also will have exponential smoothed input for the local inventory model. The demand for the local method will be calculated as in formula (5.1). The demand is the usage plus the relevant returns: scrap and requalification. Hereby u_m is the demand for SKU i at customer j in period m measured per day. The exponential smoothed factor, w_m, is calculated per period as explained in section 2.3.1 in formula (2.3). In this formula period m=t-11 is the earliest period and period m=t is current period.

$$\mu_t = \sum_{m=t-11}^{t} u_m * w_{m+11} \tag{5.1}$$

- In the current forecast method the usage is calculated **on average over the last year or half year** for the **central inventory model**. To make the tests of the methods for the inventory model comparable, method 2 also will have the demand on average over the last year or half year for the central inventory model. There is difference in the methods, because the local and central inventory optimizations are executed by two different departments. The demand for the central method will be calculated as in formula (5.2). Hereby u_m is the demand per SKU i in period m measured per month. In this formula period m=t-5 is the earliest period and period m=t is the last period.

$$\mu_t = \frac{\sum_{m=t-5}^{t} u_m}{6} \tag{5.2}$$

- The forecast per day is the input for **the local inventory model**. Thereby the method has to be changed from forecast during lead time to **forecast per day**. Therefore, as in formula (5.3), the demand is calculated as demand per day, $F[t]$, as calculated in formula (5.1) (instead of during lead time) and the returns are per day, $\frac{ER[t+1,t+L]}{L}$ (instead of during lead time). Here the lead time, L, is measured in days.

$$F[t] = \mu_t - \frac{ER[t+1,t+L]}{L} \tag{5.3}$$

- The forecast for the local inventory model has to be zero or a positive number. Thereby when the **forecast is negative**, the **forecast is changed to zero**. The forecast could be negative if the expected returns during lead time are higher than the expected demand. This is possible when there is a high number of returns in the last period, t-1, compared to the mean numbers of the returns and demand. Spartan, the local optimization method, cannot handle negative forecasts. Thereby this forecast is changed to zero, if negative. To make this case more clear an example is given in the next paragraph.

[1] As mentioned in 2.3.1: From my own calculations there is no difference in forecast with different weights, as is calculated in section 2.3.1. Changing this is out of scope of this research.

In this example the lead time, L, is 3. In table 5.1 the expected demand during lead time, $ED[t+1,t+L]=\sum_{i=t+1}^{t+L}\mu_i$, is (by using exponential smoothing): 2.9 per period.
The expected return demand of demand after current period, $\sum_{i=t+1}^{t+L-1}\mu_i R_i[t+1,t+L]$, is 0.20*2=0.4. Here two periods are taken, because in the first period after the current period there has to be demand. Next period there can be returns. The return demand during lead time of demand before current time, $\sum_{i=t-n[t+1,t+L]}^{t}u_i R_i[t+1,t+L]$, is: 3 (see in the table the fourth row 'Return during lead time' with period 12). The total return demand during lead time is thereby, $ER[t+1,t+L]=\sum_{i=t-n[t+1,t+L]}^{t}u_i R_i[t+1,t+L]+\sum_{i=t+1}^{t+L-1}\mu_i R_i[t+1,t+L]$, 3+0.4=3.4.
Overall this gives as demand during lead time, $F[t+1,t+L]=ED[t+1,t+L]-ER[t+1,t+L]$: 2.9-3.4=-0.5. A negative value cannot be input in Spartan and thereby the demand is set to zero.

Period	1	2	3	4	5	6	7	8	9	10	11	12
Demand	0	1	2	0	0	1	2	1	0	0	2	1
Return before lead time	0	0	0	1	0	0	0	1	1	0	0	0
Return during lead time	0	0	0	0	0	0	0	0	0	0	0	3

Table 5.1: Example of the negative values of Method 2 of Kelle and Silver.

5.2. Disadvantages of method 2

This section answers the sub-question: "What are the disadvantages of the method and how can these disadvantages be covered?". Based on the previous sections, some disadvantages are formulated. These are as follows:

- As in the previous section is described, the forecast is changed to zero if the forecast is negative. This means that the method cannot be exact copied to the case of ASML. The reason for these negative values is that ASML works in the service logistics with a very small demand per SKU. The question is therefore if the method is still correct.
- Measuring which returns come back in the periods during lead time results in extra calculations. These calculations could be reduced by making the calculations easier.

Therefore a new method is developed. This method has fewer calculations and cannot have negative values by only using the average/exponential smoothed usage and returns in the forecast. This method is made clear in the next section.

5.2.1. Developed method

The developed method is an easier method than method 2 of Kelle and Silver, by calculating the forecast, $F[t]$, as the expected demand, $\mu[t]$, minus the expected returns, $ER[t]$, as in formula (5.4). The forecast is calculated per SKU i per customer j and measured per day.

$$F[t]=\mu[t]-ER[t] \tag{5.4}$$

$\mu[t]$ is calculated in the same way as in previous section in formula (5.1) for the local inventory optimization and in formula (5.2) for the central inventory optimization.

For every SKU the expected returns, $ER[t]$, are calculated by taking the exponential smoothing as in formula (5.5). Hereby Ret_m are the amount returned in period m and w_m is the exponential smoothing factor. From data analysis in this research can be concluded that the smoothing factor has no influence on the expected returns, because there is less than 1% difference in expected demand when taking a smoothing factor between 1, average demand, and 2.2, full focus on last year. Thereby also an average could be taken. Although the smoothing factor will be chosen as 1.4, even as the demand. The reason for this is that the results are then comparable. Twelve periods is chosen because this is also taken in the current forecast determination. Thereby the methods are comparable.

$$ER[t] = \sum_{m=t-11}^{t} Ret_m * w_m \qquad (5.5)$$

The difference with Method 2 of Kelle and Silver is that only the expected demand and returns are taken into account and not the extra returns of demand before current period. This results in less calculations and always positive numbers. The difference between the developed method and Method 1 of Kelle and Silver is that in the developed method the amount of return is not fixed, but depends on the previous data per SKU.

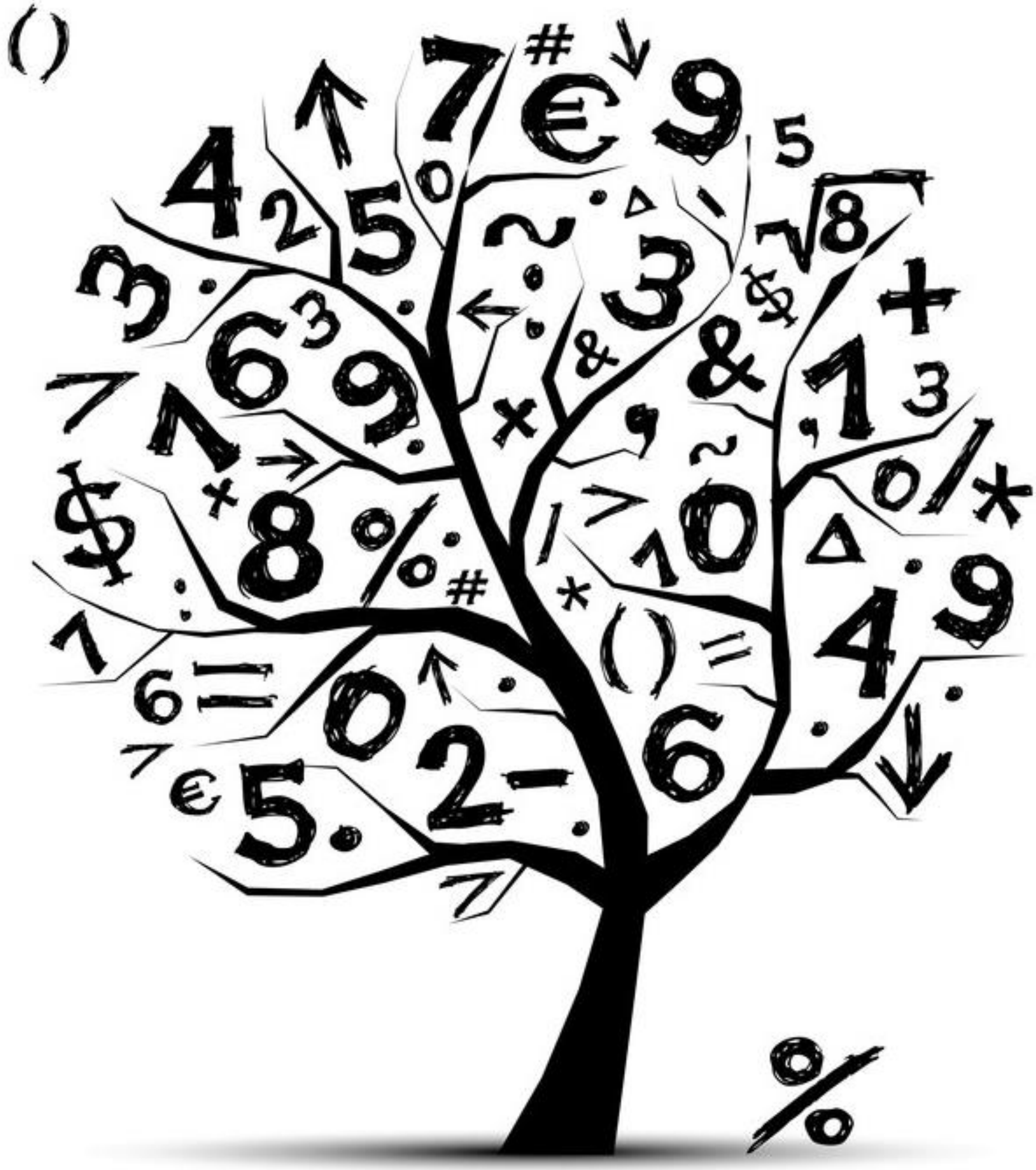
To give an example of the calculations of the developed method, the data of Table 5.1 in section 5.1.2 is used. The forecast is thereby the expected demand (exponential smoothed) minus the expected returns (exponential smoothed). This is 0.97 minus 0.2 per period: 0.77 per period. As can be seen, the expectation is that the forecast of the developed method is higher than the forecast of Method 2.

5.3. Conclusion

This section gave answer to the question "How can the chosen method be added to the current determination of the base stock level?". The conclusions are as follows:

- The parts to requalify and the scrapped parts go out of the system in the local inventory system, next to the used parts. The reason for this is that they will be scrapped or will be tested at the supplier and will return back at the hub warehouse. These parts are taken into account in the tests of the methods as demand but will not return. The serviceable and repack demand, which is not scrapped, will be taken into account in the methods as return demand.

- Method 2 of Kelle and Silver is modified for four elements when applying the method to the case of ASML. Hereby disadvantages came across: changing the output of the method when having a negative demand and extra calculations compared to the current method. Therefore a new method is developed. The developed method is simpler and only includes the expected returns instead of the expected returns and the returns of previous demand.



6. IMPACT METHODS

This chapter answers the research question that is formulated in section 1.3: "What is the impact of the new methods compared to the current method?".

First the methods are tested on correctness. The most correct method will be measured in the further sections on the impact. Section 6.2 gives the impact on the costs for the local and central inventory. The impact on the DTWP at the local warehouse is given in section 6.3. Section 6.4 gives the impact on the CSD at the central warehouse and section 6.5 the impact on the RCT at the central warehouse. Finally the qualitative effects of the new method are given in section 6.6.

The three methods tested in these analyses are:

1. The current method including only usage;
2. Method 2 of Kelle and Silver (1989) including full demand and returns.
3. Developed method including full demand and returns.

In the case of method 2 and the developed method, this means that the demand includes usage, scrap, requalification, repack and serviceable orders. The returns are the serviceable and repack demand. The demand which does not return is the usage and scraps. The requalification demand returns in the central inventory system after a repair lead time. The requalification demand doesn't return in the local inventory system, because this demand goes to the hub warehouse and is out of the system.

The data are gathered for the period November 2011 till November 2014 and have the source as given in Table 6.1 (except for the scrap percentage: this is data from 2013). All data are checked on correctness with other data from another source in SAP.

Data	Date gathered	Gathered by
Usage, repair lead times and production lead times of global customers	December 8, 2014	InventoryControl1
Usage and DTWP of DTWP customers	November 13, 2014	TacticalPlanning1
Requalification and repack demand	November 24, 2014	H.E. van der Horst
Scrap percentage	Every week in 2013	CriticalParts1 and CriticalParts2
Price of SKUs	November 26, 2014	H.E. van der Horst

Table 6.1: Source of data in results.

6.1. Test methods on correctness

This section answers the sub-question: "Which forecast of the methods is the most correct in the optimization compared to the reality?". In this section each method is tested based on their correctness compared to the reality. The reality is given by a simulation model with all demand included. This is made clear in section 6.1.1. The result of the optimization is gathered by optimizing in Spartan. This is explained in section 6.1.2. Section 6.1.3 gives the differences between the reality and the optimization.

The test on correctness is done for one region, because with one region there is enough evidence that a method has the smallest gap between the reality and the optimization. The choice is made to have Region2 as region for the test, because this is a region with three locations, which have low and high demand SKUs. Next to that, this region has enough returns to see difference in costs between the methods.

6.1.1. Simulation of methods

Next to the optimization of the local inventory in Spartan, a simulation model is designed to measure which method provides the best results. The simulation model is designed in Plant Simulation and includes the full demand: usage, scrap, requalification, repack and serviceable orders. Thereby the real emergency transportation costs will be made clear, by having demand and returns.

The inventory model in the simulation is given in Figure 6.1. The central warehouse has an infinite amount of parts and replenishes the local warehouse based on the safety stock level and the number of parts at the local warehouse and customer (1 in Figure 6.1). The replenishment lead time is exponentially distributed with an average of fourteen days, which is the input in Spartan. The customer generates demand based on a Poisson distribution with the average demand per SKU. The demand will be gathered when available based on the following priority of locations (3 in Figure 6.1):

1. Most nearby local warehouse;
2. Second nearby local warehouse (2 in Figure 6.1) (via most nearby local warehouse);
3. Third nearby local warehouse (2 in Figure 6.1) (via most nearby local warehouse);
4. Emergency shipment from central warehouse (1 in Figure 6.1) (via most nearby local warehouse).

The serviceable and repack parts are sent back to the local warehouse (4 in Figure 6.1). Based on interviews with engineers the serviceable and repack parts are available when they are allocated for other machines. This means that when the serviceable and repack part is allocated for one machine, another machine in that region can use it. Thereby the lead time is zero. When there is overstock at one local warehouse, the part will be shipped to a local warehouse with under stock. The simulation model is explained in detail in appendix E.

To verify the simulation model a simulation is done for the current method with only usage and the developed method with usage, scrap and requalification as demand. The results in Appendix E give that the simulation model has almost the same outcome than the optimization and thereby can be used to verify which method is the best.

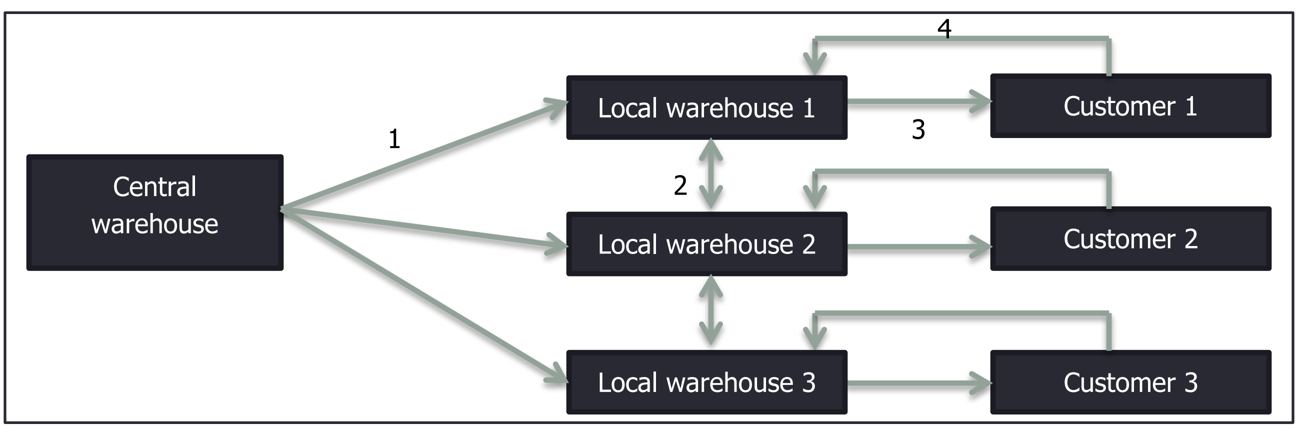


Figure 6.1: Inventory model in simulation.

The inputs of the methods are the safety stock levels of the optimization of the methods. The results per method are the emergency transportation and holding costs and DTWP per method.

Table 6.2 gives the results in costs of the simulation, with in the first two columns the methods, which are tested. The third column gives the emergency transportation costs as output of the simulation. The fourth column gives the annual total costs of the simulation: the emergency transportation and holding costs. The values in the third and fourth column are higher than the values in the optimization. The reason for this is that the optimization doesn't take into account the repack and serviceable demand and in the simulation these are taken into account. Therefore the annual emergency transportation costs and annual total costs without serviceable and repack demand are given in the fifth and sixth columns.

As can be seen in Table 6.2 the developed method has the lowest annual emergency transportation costs. This is because this method has the highest safety stock levels. Overall the developed method has the lowest annual costs. The difference between the optimization and simulation are given in next section. These results will be compared to the optimization in section 6.1.3.

Test	Method	Annual emergency transportation costs	Annual total costs	Annual emergency transportation costs	Net annual costs
		All demand in simulation		Usage, scrap and requalification demand in simulation	
1	Current method	58	140	27	109
2	Method 2	44	132	20	108
3	Developed method	41	130	18	107

Table 6.2: Results in costs of simulation model of region 2 per method.
Normalized with the annual costs of the developed method in the optimization in Table 6.3.

Table 6.5 in section 6.1.3 gives the results in DTWP of the optimization and simulation.

In next section the optimization of the methods, to compare with the simulation can be found.

6.1.2. Optimization of methods

In the optimization of the local inventory the goal is to determine the method with the lowest holding and emergency transport costs and the lowest DTWP.

In Figure 6.2 the optimization per test is made clear. Hereby the forecast per method is the input and the constraint is the current target DTWP. The usage in each test is influencing the DTWP, while the demand of the scraps and requalifications don't influence the DTWP directly, but only by getting lower availability with extra demand. This means that the scrap and requalification demand is added in the inventory optimization model as extra "dummy" customer, so it doesn't affect the DTWP directly, but it requires parts from the local warehouse. At this moment the scraps and requalification demand are not taken into account in the optimization, whereby this is a new way of adding demand to Spartan. The outputs are the safety stock levels (SSL) and the holding and emergency transportation costs.

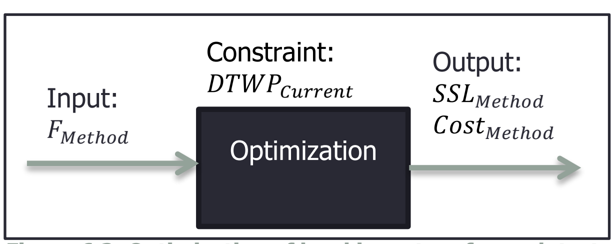


Figure 6.2: Optimization of local inventory for each test.

The results in costs of the optimization are given in Table 6.3 as normalized numbers compared to the annual total costs of the optimization of the developed method. The annual total costs include the annual emergency transportation costs and the annual holding costs. The annual holding costs are factor 0.17 of the inventory value. This factor is based on the stocking risks and costs. The real costs can be found in appendix F.

As can be seen in Table 6.3, the emergency transportation costs and inventory value increase, when the demand increases. The demand per method increases, because scrap and requalification demand is added. These results will be compared to the simulation in section 6.1.3.

Test	Method	Annual emergency transportation costs in optimization	Annual holding costs in optimization	Annual costs in optimization
1	Current method	6	82	87
2	Method 2	10	86	95
3	Developed method	12	88	100

Table 6.3: Optimization of Region 2.
Normalized with the annual costs of the developed method in the optimization.

Table 6.5 in section 6.1.3 gives the results in DTWP of the optimization and simulation.

6.1.3. Choice of method

As can be seen in Table 6.4 the developed method is in the optimization of the costs the closest to the simulation of the costs. This means that the developed method is the closest to the reality, but there is still a small gap between the optimization and simulation.

These costs are related to the effect of the transportation time of serviceable and repack demand on the other demand. This means that when a serviceable or repack is ordered from a local warehouse, there is transportation time to transport the part. This time has effect on the availability of the parts.

Next to that there is effect of the fourteen days of demand on consignment stock on the availability of the parts. This means that booking the parts on average after fourteen days to usage, scrap or requalification gives the effect of waiting longer for a new part. This has effect on the availability of the parts.

Test	Method	Difference in annual total costs of optimization including usage, scrap and requalification
1	Current method	25%
2	Method 2	13%
3	Developed method	7%

Table 6.4: Optimization of Region 2 in Chapter 6.

As can be seen in Table 6.5 the developed method and Method 2 is in the optimization of the DTWP the closest to the simulation. This means that the developed method is the closest to the reality, but there is still a small gap between the optimization and simulation. This gap can be found by the unavailability of parts due to the fourteen days on consignment stock. This is not taken into account in the optimization, but is the case in the reality. Because of confidentiality the result in DTWP can be found in appendix F.

Test	Method	Difference in DTWP
1	Current method	25%
2	Method 2	5%
3	Developed method	5%

Table 6.5: Results in costs of simulation model of region 2 per method.

In the next sections the difference of the developed method will be made clear for the full local and central inventory optimization.

6.2. Impact on costs

This section answers the sub-question: "What is the cost impact by adding the forecast of the new method to the current inventory model?". First the costs of the local warehouse are presented and then the costs of the central warehouse are presented. Finally the summed costs are given.

6.2.1. Costs in local warehouse

The costs are in the optimization of the local inventory the holding and emergency transportation costs as calculated in section 2.4. First the same optimizations as in 6.1.1 are done for the current method and the developed method, but then for all regions.

In addition, the extra emergency transportation costs have to be determined when the demand of scrapped and requalification parts is not taken into account in the current forecast. These are determined by the evaluation method in Spartan, as given in Figure 6.3. In the evaluation method the extra emergency transportation costs and DTWP are determined when ASML has the current safety stock levels with the demand of the developed method. Hereby the input is the forecast of the developed method. The constraints are the current safety stock levels. The outputs are the DTWP and the holding and emergency transportation costs. The holding costs are equal as in the current situation, because this is based on the safety stock levels. The result of the DTWP is given in section 6.3.

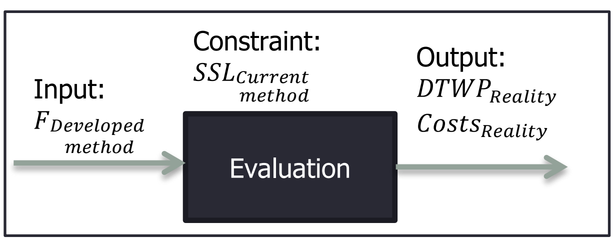


Figure 6.3: Reality of using the SSLs of the current method and the real demand.

Table 6.5 gives the results of the optimizations of the methods and the real emergency transportation costs. The real emergency transportation costs are gathered by the method as above. In Table 6.5 the first column gives the methods. The second column gives the normalized emergency transportation costs and the third column gives the normalized holding costs. In appendix F the table is given with the real numbers, which are confidential.

As can be seen in Table 6.5, the emergency transportation costs and inventory value increase, when the demand increases. The demand per method increases, because scrap and requalification demand is added.

In the evaluation can be seen that the holding costs are equal. This is because the safety stock levels are the constraint and thereby the holding costs are equal as in the current method. The emergency transportation costs are in reality a lot higher, than calculating the forecast in current situation.

	Emergency transportation costs	Holding costs
Current method - optimization	8	98
Developed method - optimization	10	100
Current method - evaluation	18	98

Table 6.6: Optimization and evaluation, normalized with holding costs of developed method.

The implementation of the developed method results in a reduction of almost €[redacted] million annual costs. This is a costs difference of 6%. The inventory value will be increased with a bit more than €[redacted] million. With an investment of this 3% in inventory value, after two years the profit can be gained. The full results can be found in appendix F.

6.2.2. Costs in central warehouse

The goal of the optimization of the central inventory is to determine the lowest costs, the highest customer satisfaction degree (CSD) and the lowest replenishment cycle time from central warehouse to local warehouse. The optimization of the central inventory contains the same tests as the optimization of the local inventory, as explained in the next sections.

In the optimization of the central inventory the inventory holding costs are minimized with the constraints of the customer satisfaction degree (CSD) per pilot. In Figure 6.4 the tests are made clear. Hereby the forecast during lead time is the input and the constraint is the CSD. The outputs are the ROP, replenishment cycle time and the holding costs. The ROP is calculated as in section 2.5.

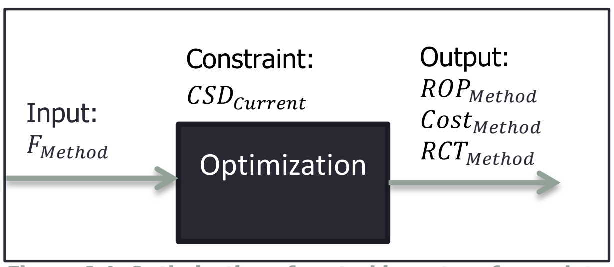


Figure 6.4: Optimization of central inventory for each test.

The inventory holding costs are calculated by multiplying the expected number on stock (NOS) with the price of the SKU and the holding cost factor, as in formula (6.1). The holding cost factor is 17%, because this includes the risk, rental and location costs of holding the part on stock (Analyst3, 2014). The price of the SKU i, c_i, is the price as mentioned in SAP. The average number of parts on stock, NOS is the reorder point minus half of the expected demand during replenishment lead time.

$$Inventory\ holding\ costs = \sum_{i=1}^{I}(c_i * NOS_i * hf) \tag{6.1}$$

The increase in annual holding costs is around €[redacted] million by using the developed method compared to the current method. This is an increase of 0.7% of the total annual holding costs. The increase in costs is as expected, because in this calculation no out-of-stock costs are included. The number of out-of-stocks is calculated in section 6.4. The full results can be found in appendix F.

6.2.3. Impact of developed method on total costs

The impact of the developed method on the total costs can be divided in annual costs and inventory value. By combining the annual emergency transportation and holding costs of the local inventory and the annual holding costs of the central inventory there is a reduction of €[redacted] million annual costs by implementing the developed method. This is an annual costs difference of 1%. Next to that, there is an increase of €[redacted] million in inventory value, which is 1% of the total inventory value. The risk and the costs of the extra inventory value are already taken into account in the annual costs. The pay-back-period is thereby nine year. This pay-back-period will be a lot smaller, based on the results in the section 6.4 and 6.6.

6.3. Impact on DTWP

This section answers the sub-question: "What is the impact on DTWP by adding the forecast of the new method to the current inventory model?". The DTWP is calculated with Spartan. The optimization is explained in 6.1.1 and the evaluation is calculated as explained in 6.2.1. The impact on DTWP is given per region in table 6.7. The full table is given in appendix F because of confidentiality.

Region	Difference in DTWP
Region 1	1%
Region 2	3%
Region 3	2%
Region 4	0%
Region 5	0%
Region 6	0%
Region 7	2%

Table 6.7: Difference in DTWP per region.

The impact per method on the DTWP is insignificant, because the DTWP will be decreased with a maximum of 0.02 per region by implementing the developed method. This is 3% for one region as maximum. On average the DTWP does not even decrease with 1%. This 1% is as expected, because currently ASML satisfies the DTWP and thereby satisfies the contract at most customers.

6.4. Impact on CSD

This section answers the sub-question: "What is the impact on CSD by adding the forecast of the new method to the current inventory model?". In the optimization of the central inventory the CSD is the constraint.

Next to that, the impact on the CSD and RCT have to be determined when the demand of scrapped and requalification parts is not taken into account in the forecasts. These are determined by the evaluation method, as in Figure 6.5. In the evaluation method the CSD and RCT are determined when ASML has the current base stock policy with the demand of the developed method. Hereby the input is the forecast of the developed method. The constraint is the current base stock policy. The outputs are the CSD and RCT. The holding costs are equal as in the current situation, because this is based on the ROP.

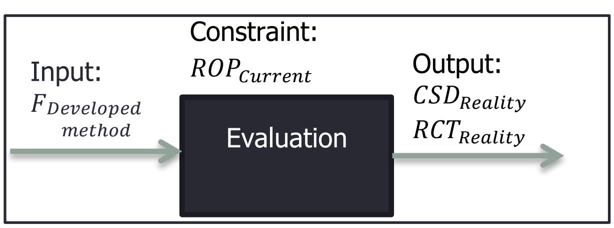


Figure 6.5: Reality of using the ROPs of the current method and the real demand.

The result of the evaluation is that there is an increase in CSD by applying the developed method of 0.01. This is only 1% of the CSD. Next to that, the CSD is still within the boundaries of ASML, because the requested 0.95 CSD is kept.

Although there is no big impact on the performance of ASML in CSD, this small change results in a high number of out-of-stock parts. There is a decrease of 33% in out-of-stocks when the developed method calculates the correct forecast, which is a reduction of 383 planned out-of-stocks annually. The costs of these out-of-stocks cannot be exactly measured, but there will also be a cost reduction based on the reduction of out-of-stocks. This means that the CSD is 1% lower and the number of out-of-stocks increase with 33% in reality than in the optimization with the current method.

6.5. Impact on replenishment cycle time in central warehouse

This section answers the sub-question: "What is the impact on replenishment cycle time by adding the forecast of the new method to the current inventory model?". The RCT is the fourteen days of the agreed lead time plus the waiting time.

The replenishment cycle time is based on the fixed replenishment lead time of fourteen days and the waiting time per SKU. The expected waiting time is determined by the expected backorders at the end of the cycle divided by the demand. The expected backorders at the end of the cycle is the sum of the each demand more than the calculated ROP multiplied with the chance that the demand exists, as in formula (6.2). In this formula the chance of having x parts ordered during lead time, $DDLT$, is $P(DDLT = x)$. This is a Poisson probability, because based on analyses of ASML the demand is Poisson distributed (Analyst3, 2014). The chance is multiplied with the number of demand more than the ROP: $ROP + 1$. For each SKU the expected amount of backorders is calculated by summing all chances times the number of extra SKUs.

$$EBO = \sum_{x=ROP+1}^{\infty} P(DDLT = x) * (ROP - x) \tag{6.2}$$

The difference in waiting time can be found by the optimized situation as given in 6.2.2 and the situation in reality as in 6.3.

The result of adding extra demand to the optimization of the central inventory results in a small increase in waiting time of 0.01 days. The increase of 0.01 is the increase of 15 minutes waiting time on average. This is that small amount that can be conclude that it won't give effect on the emergency shipment costs in the optimization of the local inventory.

6.6. Other effects of developed method

This section answers the sub-question: "What are other effects at ASML by adding the forecast of the new method to the current inventory model?".

Next to the effects of the decrease in annual costs, there are qualitative effects of adding the returns to the local forecast:

- Having a higher safety stock level at the local warehouse results in less transportation of parts. This is because when a part is put on stock at a local warehouse with a safety stock for that part, the parts don't have to be transported to that local warehouse when necessary and don't have to be transported to other local warehouses after that trial. Less transportations results in less logistic death on arrivals, because every transport gives a risk of a defect by transporting parts. Also less transportations results in a more sustainable environment.

- Another advantage in the reduction of emergency transportations is a more efficient consolidation. When an order is transported with emergency this part cannot be consolidated with other orders, because of the high priority of that order. When the order is transported as routine, the order can be consolidated with other orders, whereby extra cost reductions can be gained.

Next to the effects of the decrease in annual costs there are qualitative effects of adding the returns to the central forecast:

- Less workload is gained when having a realistic planning. When a SKU has a high number of returned requalification orders, a lot of extra demand is not taken into account in the current planning. This means that this part has a higher risk to become critical. When a part becomes critical extra time has to be invested to get extra parts from the supplier. In the worst situation the part becomes out-of-stock (383 orders more) and extra pressure to the supplier has to be given.

- A more realistic planning results in a better forecast to the supplier, which increase the satisfaction of the supplier.

6.7. Conclusion

This section gave answer to the question "What is the impact of the new methods compared to the current method". The conclusion is as follows:

- The recommendation is to implement the developed method, because this method is the closest to the reality. Thereby the developed method is most suitable for forecasting the demand at ASML.

- Implementing the developed method results in an annual cost reduction of [redacted] million (1%), combining local and central inventory optimization. The investment is around €[redacted] million (1%). Next to that the costs will be even more reduced through the following reasons:
    - A reduction in out-of-stocks of 33%;
    - Less emergency transportations, this results in less extra handling costs and more efficient consolidation of orders.

- The impact of the developed method on the DTWP is maximum 1% improvement worldwide. For one region this is 3%. In this region the developed method will improve the DTWP significant.
  The impact on the CSD gives a performance improvement of 1%. This doesn't give a high impact on the overall performance of ASML.
  The impact on the RCP is limited.

7. IMPLEMENTATION PLAN

This chapter answers the research question that is formulated in section 1.3: "How can the new forecast method be implemented at ASML?". First the implementation plan is presented and then the drawbacks and risks are made clear, even as how to handle these drawbacks and risks.

7.1. Implementation plan of developed method

This section answers the sub-question: "What is the plan to implement the forecast method?". The goal of the implementation plan is to implement the developed method. Hereby the planning is as in Figure 7.1. Each step is explained in the next sections.

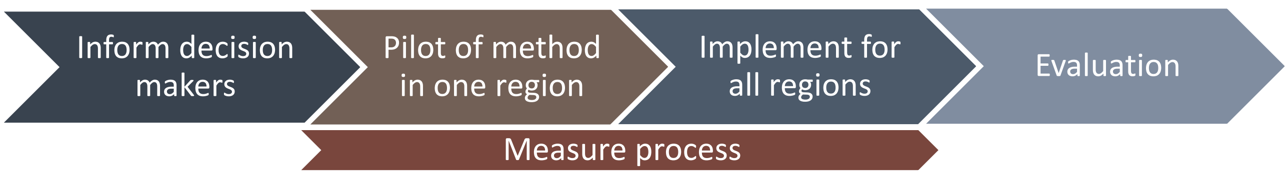


Figure 7.1: Implementation of developed method at ASML.

7.1.1. Inform decision makers

First the results of this research and the implementation plan were presented to the decision makers. The team leader of the team Inventory Control and the executer of the local planning did agree that the findings and conclusions were correct and that the plan has to be implemented. Receiving this presentation included one working hour per person. The executer of this research is not taken into account in the costs, because these are the fixed research costs.

Next the manager supply planning and his manager, director customer logistics, had to agree that this research has to be implemented. In a presentation by the executer of this research the managers were convinced that the implementation could start. Also the team leader of inventory control attended this meeting. This presentation included one working hour per person.

The implementation will be done by the employee who is also responsible for the current multi-echelon model. He will implement both the multi-echelon inventory model and the developed forecast method. The executer of the research handed the materials over to the new responsible person and trained the responsible person on the execution of the methods. This will include two working hours per person.

The next steps will be executed by the new responsible ASML-employee.

Responsible actor	Task	Other actors	Costs
Executer of research	Inform decision makers	Team leader Inventory Control Executer local planning Manager supply planning Director customer logistics	5 hours
Executer of research	Train new responsible person	Responsible employee for multi-echelon model	2 hours

Table 7.1: Tasks, actors and costs of informing decision makers.

7.1.2. Pilot of method in one region

First the pilot for one region has to be executed to check if the developed method decreases the emergency transportation costs in reality. The region that will be chosen is Region2, because this region has significant savings and has SKUs with high and low demand. The extra steps, which have to be taken, are the following:

- Getting the data from SAP;
- Filtering the data on requalification and scrap demand;
- Calculate the forecast for Region2.

This will take around four hours, because the templates are already developed in this research.

The forecast will be the input for Spartan. The responsible person will contact the executer of the local inventory model about the addition of return demand and will contact him about when to deliver the forecast. This discussion will include half an hour per person.

Responsible actor	Task	Other actors	Costs
Responsible person	Determine forecast of Region2	-	4 hours
Responsible person	Discuss about planning	Executer local planning	1 hours

Table 7.2: Tasks, actors and costs of pilot of method in one region.

7.1.3. Implement method for all regions

At this moment the local planning and the central planning of the inventory is executed by two different departments: demand planning and supply planning. This year the planning of both departments will be combined and be executed at the demand planning department. Thereby the responsible person can implement the multi-echelon model and developed method at the same time.

The multi-echelon model in combination with the developed method needs extra data about the requalification and scrap demand. Including these data would not result in that many extra hours, because these data are in this research already standardized. Also here the extra steps for the developed method are the following:

- Getting the data from SAP;
- Filtering the data on requalification and scrap demand;
- Calculate the forecast for all regions.

Gathering the data and calculate the forecast will include around 10 working hours.

The next step is to inform all stakeholders of the review of the forecast and the review of the ROPs and safety stock levels of SKUs. These stakeholders are the SPOCs (six people), tactical planning team (three people), inventory control team (three people) and the local logistic employees (six people). The responsible person has to present both the new model and method to these stakeholders and what the difference in outcome of the ROPs and safety stock levels is. This will include three hours preparation of the presentation for the forecast method and one hour per person for the presentation. The responsible person will present for each group separate.

Next to that, the review tool has to be changed. The current review tool consists of graphs of expected usage, current stock level and ROP. In these graphs the requalification and scrap demand has to be added, so the effect of the full demand has to be taken into account in the review. This will include around 16 hours to change the tool completely.

Responsible actor	Task	Other actors	Costs
Responsible person	Determine forecast	-	10 hours
Responsible person	Present new model and method	SPOCs Tactical planning team Inventory control team Local logistic employees	25 hours
Responsible person	Change review tool	-	16 hours

Table 7.3: Tasks, actors and costs of implement method for all regions.

7.1.4. Measure process

The implementation process has to be measured to see the difference in emergency transportation costs, changes in ROP and safety stock levels and inventory holding costs.

The emergency transportation costs will be measured by getting the data from SAP about the number of emergency transportations per usage and return order. Thereby the decrease of emergency transportations can be measured and what the reduced costs will be. This will be measured per month.

The changes in ROP and safety stocks will be measured for each forecast calculation and review. Two measures will be done:

- The changes in ROP and safety stock levels compared to the current ROP and safety stock after the calculations of the method and model. The goal of this measure is to see what the increase in stock is following the method and model.
- The changes in ROP and safety stocks compared to the current ROP and safety stock after the review of the ROP and safety stock levels. The goal of this measure is to check how much the ROP and safety stocks increase when the review is done.

The inventory holding costs are calculated based on the ROP and safety stock levels and the price of the SKUs.

In the pilot these measures are done for Region2. In the final implementation the measures are done for all regions. The measures have to be standardized and thereby will cost around 24 hours to standardize and then 5 hours to generate the measures.

Responsible actor	Task	Other actors	Costs
Responsible person	Standardize measures	-	24 working hours
Responsible person	Generate measures	-	5 working hours

Table 7.4: Tasks, actors and costs of measuring process.

7.1.5. Evaluate implementation and method

The last phase in the project is the evaluation of the implementation and the evaluation of the method. The evaluation will be done by a panel discussion including one person per type of stakeholder. This will take one hour per person. Next to that, based on the measures the review can be done on what the project delivers in cost reduction. Analysing the measures and panel discussion will cost the responsible person eight hours. The responsible person will present the results to the director customer logistics.

The result will be an overview of advantages and disadvantages of the project. Also the recommendation for a new project will be written down and the improvements and potential new projects for the forecast method will be made clear.

Responsible actor	Task	Other actors	Costs
Responsible person	Evaluation with stakeholders	SPOC Tactical planning team member Inventory control team member Local logistic employee	5 hours
Responsible person	Give advice to the management	Director customer logistics	10 hours

Table 7.5: Tasks, actors and costs of evaluation implementation and method.

7.1.6. Timeline & resources

The timeline of the implementation will be as in table 7.6. The start of the implementation is in January, 2015 and the evaluation is in December, 2015.

Step	Start	End	Milestone
Inform decision makers	January, 2015	February, 2015	No
Pilot of method in one region	February, 2015	August 2015	Yes
Implement for all regions	August, 2015	December, 2015	Yes
Measure process	February 2015	No end	No
Evaluation	December, 2015	December, 2015	Yes

Table 7.6: Timeline of implementation.

There is no other resource needed than the working hours and applications which ASML already has. The necessary programs are Excel and SAP. The total working hours are around 107 hours. Hereby 78,5 hours is for the responsible person. This is excluding the time for the implementation of the multi-echelon model.

7.2. Drawbacks & risks of implementation plan

This section answers the sub-question: "What are the risks and drawbacks of the implementation and how can ASML handle these?". The implementation plan has drawbacks and risks, which are presented here.

7.2.1. Drawbacks

The drawbacks are as follows:

- The new forecast method will be implemented with the multi-echelon model. The drawback of this is that it will be a big change and it will be difficult to measure the differences separate for the multi-echelon model and the forecast method. To handle this drawback first the forecast method is done in a pilot in Region 2. Thereby the effect can be measured before implementing

the model and method. The multi-echelon model can be measured after implementation for region 2, what the difference is with the current situation and the situation with the developed forecast method.
- The implementation of the plan will cost a full year. This is a drawback, because the project has thereby a long term result and it is difficult to keep all stakeholders on one line in a longer period. To handle this drawback the measurement has to be done monthly to keep everyone at the same focus.
- A drawback is that the results of implementing the new forecast method will be difficult to measure on long term. This is because the service demand increases due to having more customers and more machines. Thereby the costs will be increasing with the extra machines. This drawback will be reduced by monthly measuring, but is a drawback which ASML cannot really tackle.
- The last drawback in this implementation is that another person than the executer of this research will implement the research. This drawback is minimized by having clear documentation of the full research and having a hand-over moment.

7.2.2. Risks

The risks are as follows:

- The risk of this project is that there will be too many parts on stock. In this research it is made clear that mostly parts are extra stocked for medium or high usage SKUs. This risk is thereby not really high, but to lower this risk the measurements has to be done correctly and monthly.
- The risk of reacting on return demand in the inventory levels could result in more returns. This is because the solution to get all parts in a short time period to the customer does not depend anymore on having unavailability due to requalification and scrap. This risk can be reduced to make first good arrangements about the targets on reducing the return demand in combination with the implementation of this plan.
- Another risk is that only one person is trained on the new forecast method. When this person forgets some parts or leaves the company there is a risk of a failed implementation. The risk is not that high, because also the executer of the local planning and the team leader of inventory control know the approach and expected results of the forecast method and implementation plan.

7.3. Conclusion

This section gave answer to the question: "How can the new forecast method be implemented at ASML?". The conclusions are as follows:

- The new forecast method will be implemented by first having a pilot at one region and next implement the forecast method together with the multi-echelon model for all regions.

- The costs will include around 107 working hours and the timespan of the implementation is one year. Taking the risks and drawbacks into account it is realistic to stay with the amount of working hours and the timespan.

8. Conclusions & Discussion

Each chapter finished with the answer on the sub-questions of this research. The conclusion in section 8.1 gives the answer on the research question, which is as follows:

"How should ASML respond to orders without usage into the inventory level calculations?

What would be the impact of this incorporation in terms of:

- *Emergency transportation costs;*
- *Inventory holding costs;*
- *Replenishment cycle time;*
- *Risk of not satisfying the customer contracts?"*

Section 8.2 gives the recommendations based on this research. Section 8.3 contains the limitations of this research in the discussion. The last section gives some points for further research.

8.1. Conclusion

This section gives the answer on the research question as mentioned above.

ASML should respond to orders without usage by implementing the developed method for determining the forecast of the local demand and the central demand.

The result of the optimization of local inventory is to choose the developed method based on the annual inventory holding and emergency transportation cost savings. This method results in a saving of around [redacted] million per year, with a pay-back period of two years. Adding extra demand in the optimization of local inventory does not give impact on the DTWP.

The result of the optimization of the central inventory is to add also the developed method. By adding extra demand to the forecast of the central warehouse the inventory holding costs increase with €[redacted] million, whereby the out-of-stocks will be reduced with [redacted] orders. The change in CSD and RCT is low and will not impact the performance of ASML.

The current emergency transportation cost is €[redacted] million annually, whereby the orders without usage cause [redacted]% of these costs. The impact of adding the developed method to the optimization of the local and central inventory optimization results in a decrease of about €[redacted] million in emergency transportation costs. The impact of adding these returns to the optimization of the local inventory is an increase of €[redacted] million of inventory value.

The replenishment cycle time is currently higher of a SKU with a high number of orders without usage compared to a SKU with a low number of orders without usage, as explained in Chapter 3. Although this fact, there is no impact on the replenishment cycle time with the developed method, based in the calculations in Chapter 6. The reason for this is that the return demand is not incorporated in the optimization of the central inventory. When including the return demand in the optimization of the central inventory, the replenishment cycle time was changed with a very small amount, which would have too less impact for investing in inventory value.

The risk of not satisfying the customer contract doesn't differ significant, because the new methods don't affect the DTWP a lot.

Other impacts of adding the return value to the optimization of the local and central inventory are:

- Decreased workload and more efficient consolidation of parts, due to a reduction in emergency transportations. This can result in extra cost reduction;
- Decreased transportations of parts, increased sustainable environment and decreased logistic death on arrivals, by having more parts on stock;
- Decreased workload and more satisfied suppliers, due to a realistic planning;
- Decreased out-of-stocks and critical parts, due to a realistic planning.

8.2. Recommendations

Based on this research the following recommendations are formulated:

- Include the return flow in the optimization of the local and central inventory by determining the forecast with the developed method. This results in the outcomes as described in the previous section "Conclusion".

- In the next years a new multi-echelon inventory model will be implemented at ASML, whereby the optimizations of the local and central inventory are combined. In appendix G the full description and results are presented. Based on the optimizations of the multi-echelon model, the costs of the developed method for the local and central inventory are €[redacted] million annual. The remark has to be made that the CSD is not correct following the customer contracts, because that is not possible in the current prototype software. The expectation is that with the real CSD the annual costs will be around zero. The recommendation is to calculate the methods with the correct CSDs, when the software is available and check if the expectation is correct. After that the developed method can be implemented together with the multi-echelon model.

- It would be worthwhile to do research to find a reverse logistics multi-echelon multi-item inventory model. At this moment there is no model available in the literature, which combines all these three characteristics. The expectation is by adding the return flow fully to the inventory model the costs will be more reduced. Because ASML will implement a new multi-echelon model, it would be a good addition to first discover the possibilities of a reverse logistics multi-echelon model.

- The final recommendation is to reduce the orders without usage. From data analysis came that in some regions there are in amount and in percentage of all orders more orders without usage in one region than another. This means that some regions could learn from other regions in reducing the orders without usage. Thereby from cost reduction perspective the recommendation is to reduce orders without usage in the high %/amount regions.

8.3. Discussion

Section 8.1 presents the conclusions and section 8.2 contains the recommendations for ASML. This section discusses the limitations in this research.

Designing the processes and evaluating the results of the data analysis is done by interviewing employees at ASML. In the timeline it was not possible to interview all stakeholders within ASML. In total 19 employees are interviewed and with these interviews the processes are designed as good as possible. Maybe when other employees were interviewed the result could be slightly different.

The data analysis in chapter 3 is based on data of 2013. This could give a bias, because the demands at ASML for spare parts are low. So when in one year a part has a demand of zero, another year this could be three. Because of limited time, the assumption is made that 2013 would be representative for the last years. In the evaluation of the methods in chapter 6 the demand of the last three years is used, so the bias would be smaller in measuring the impact when changing the demand.

The return types per order are labelled by the engineers. In this research the correctness of the labelling is not analysed. Only the way of labelling is checked with three engineers to evaluate if they label the returns as expected. Based on this check the assumption is taken that all engineers label the returns correct or within boundaries.

As already mentioned in section 8.2 the most optimized safety stock levels would be reached when the inventory model would change to a reverse logistics model. In this research ASML didn't want to change the model, but only the input to not change the inventory model every few years. Next to that, there was not enough time to develop a completely new inventory model.

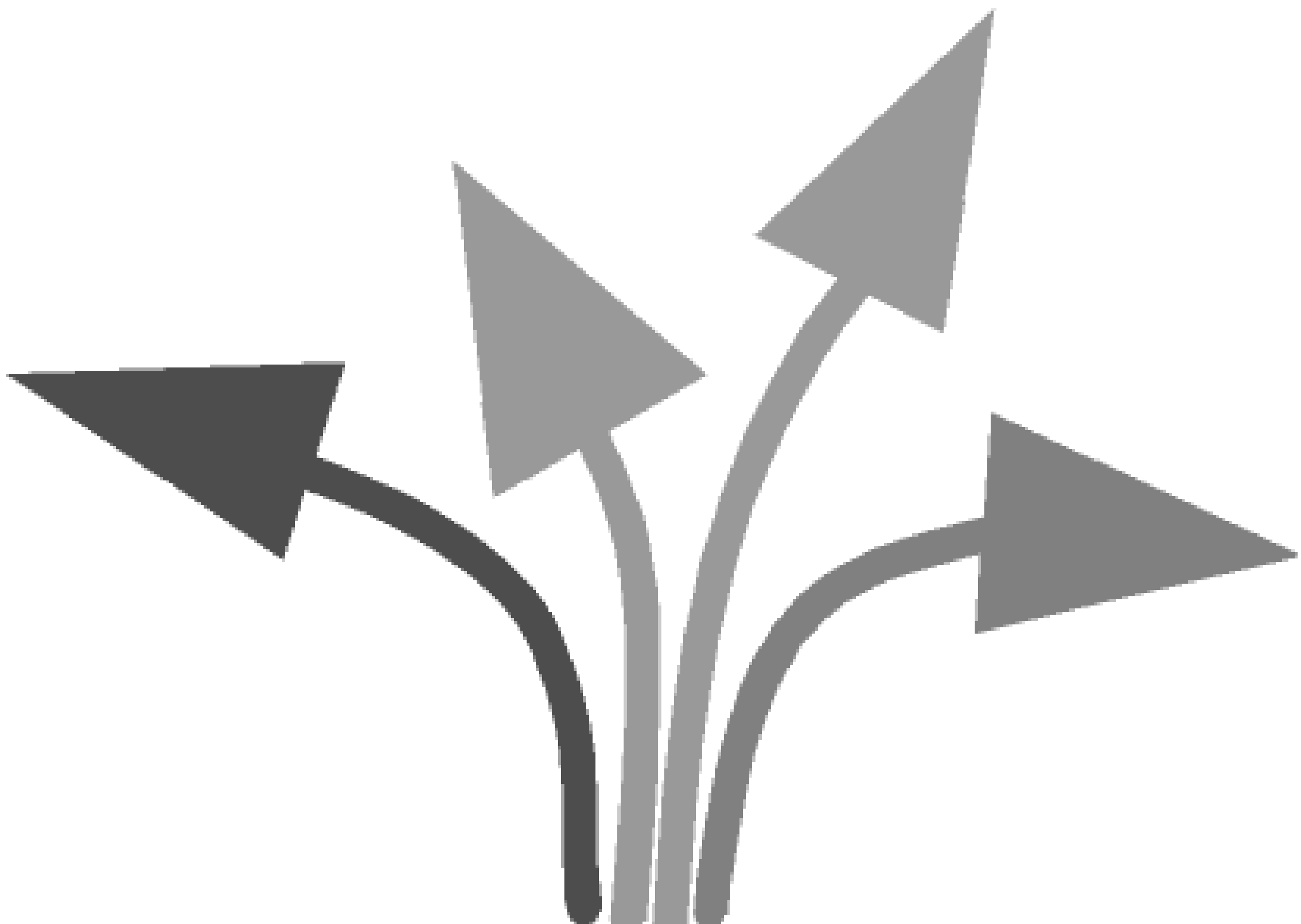
8.4. Further research

Based on the conclusion, recommendation and discussion, the subjects for further research are as follows:

- As already mentioned in the recommendation and the discussion, research have to be done on a new reverse logistics multi-echelon multi-item inventory model to include the return demand not only in the forecast, but in the full inventory model. The expectation is by adding the return flow fully to the inventory model the costs will be more reduced.

- At the moment the return lead time of requalification parts, which have to be tested at the supplier, is almost equal to the return lead time of failed parts, which have to be repaired at the supplier. The reason for this is that this return flow at the supplier has not its own flow, but has to be added to the normal production of the parts to ASML. In further research possibilities to decrease the return lead time could be found out. Then the inventory holding costs could be lowered, because the lead time is reduced.

- The end conclusion, which is also mentioned at the recommendations, it that the best cost decrease would be the decrease of orders without usage. To decrease this further research could be done on how to decrease the orders without usage and why one region has more orders without usage than another region. Possibilities to do research in are to improve the amount of solutions in the system, which the engineers use, to train the engineers more on the ordering and to make a policy on ordering that many parts.



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APPENDIX

Appendix A: Forecasting

A.1: Criteria of changing the failure rates

The failure rates change based on the following criteria (Analyst3, 2014):

1. Is in one location the failure rate of the SKU significant higher than the other locations?
2. Is there a trend in the failure rates?
3. Is a SKU used in a machine, but not in the BOM of that machine?
4. Is the usage of install orders higher than 5% of the normal usage of the SKU?
5. Is in the last months a wrong forecast given of that SKU?

A.2: Approximate evaluation method

This section explains in detail the Greedy approach of Spartan. The Greedy approach of Spartan is given in Figure A.0.1.

The cost difference of SKU i at local warehouse j is measured if the stock level of SKU i in local warehouse j would be increased with one, which is given in formula (A.1) with $C_i(S_i)$ expressed by (A.2).

$$\Delta C(i,j) = C_i(S_i + e_j) - C_i(S_i) \tag{A.1}$$

e_j is the row vector with 1 at element j and the other elements 0. The spare parts provision costs, that depends on the base stock level of SKU i, $C_i(S_i)$, is calculated by adding the holding costs per time unit and the demand times the lateral and emergency transportation costs that depends on S_i with $M_{i,j}$.

$$C_i(S_i) = \sum_{j \in J} C_i^h S_{i,j} + \sum_{j \in J} M_{i,j} \left(\sum_{k \in K, k \neq j} C_{j,k}^{lat} \alpha_{i,j,k}(S_i) + C^{em} \theta_{i,j}(S_i) \right) \tag{A.2}$$

Every time when there is a change in the base stock level $S_{i,j}$, the parameters $\alpha_{i,j,k}(S_i)$, $\theta_{i,j}(S_i)$ and $\beta_{i,j}(S_i)$ have to be calculated as input for the costs and the waiting time-costs-ratio. $\alpha_{i,j,k}(S_i)$ is the fraction of demand for SKU i at local warehouse j delivered from main local warehouse k with lateral transhipment. The main local warehouse is the local warehouses, which can do lateral transhipments. Normally these warehouses are large local warehouses. $\theta_{i,j}(S_i)$ is the fraction of demand for SKU i at local warehouse delivered from central warehouse. The $\beta_{i,j}(S_i)$ is the item fill rate in local warehouse j for SKU i. The determination of the parameters can be found in Figure A.0.2.

The $L\left(S_{i,j}, M_{i.j} t^{reg}\right)$ is the Erlang loss probability function.

The $M_{i,j}$ is hereby the total demand of SKU i at local warehouse j (formula A.3).

$$M_{i,j} = \textstyle\sum_{n \in N_j} m_{i,n} \tag{A.3}$$

In step three the stock level increases of the SKU that provides the largest decrease in waiting time per unit costs increase, as long as the current solution is not feasible. The ratio of decrease in waiting time divided by the increase in costs, $R(i,j)$, is calculated as in formula (A.4), with $\Delta W(i,j)$ expressed by (A.5) and $\Delta C(i,j)$, expressed by (A.1).

$$R(i,j) = \Delta W(i,j)/\Delta C(i,j) \tag{A.4}$$

$\Delta W(i,j)$, the decrease in waiting time is the total waiting time minus the decrease in waiting time by having S_i on stock as in formula (A.5), with $W_{i,j}(S_i)$ expressed by (A.6).

$$\Delta W(i,j) = \sum_{j\in J}\sum_{n\in N_j}\left[\sum_{i\in I}\frac{m_{i,n}}{M_n}W_{i,j}(S_i) - \widehat{W}_n^{obj}\right]^+ - \sum_{j\in J}\sum_{n\in N_j}\left[\sum_{i\in I\{i\prime\}}\frac{m_{i,n}}{M_n}W_{i,j}(S_i) + \frac{m_{i\prime,n}}{M_n}W_{i\prime,j}\left(S_{i\prime} + e_{j\prime}\right) - \widehat{W}_n^{obj}\right]^+ \tag{A.5}$$

$W_{i,j}(S_i)$, Average waiting time for SKU i in warehouse j is calculated by formula (A.6).

$$W_{i,j}(S_i) = \sum_{k\in K,k\neq j} t_{j,k}^{lat}\alpha_{i,j,k}(S_i) + t^{em}\theta_{i,j}(S_i) \tag{A.6}$$

$\widehat{W}_j^{obj}$ is the weighted sums of average waiting times.

Step 1 Set $S_{i,j} \coloneqq 0, i \in I, j \in J$.

Step 2 For each SKU $i \in I$:

Step 2-a Calculate $\Delta C(i,j), j \in J$.

Step 2-b While $min\{\Delta C(i,j)\} \leq 0$;

1. Determine $\hat{j}$ such that $\Delta C(i,\hat{j}) \leq \Delta C(i,j), j \in J$.
2. Set $S_{i,\hat{j}} \coloneqq S_{i,\hat{j}} + 1$.
3. Calculate $\Delta C(i,j), j \in J$.

Step 3

Step 3-a Calculate $R(i,j), i \in I, j \in J$.

Step 3-b While $max\{R(i,j)\} > 0$:

1. Determine $\hat{\imath}$ and $\hat{j}$ such that $R(\hat{\imath},\hat{j}) \geq R(i,j), i \in I, j \in J$.
2. Set $S_{\widehat{\imath,j}} \coloneqq S_{\widehat{\imath,j}} + 1$.
3. Calculate $R(i,j), i \in I, j \in J$.

Figure A.0.1: Greedy method of SPARTAN following A.A. Kranenburg (2006).

Algorithm 6.1

Step 1 For all regulars $j \in J \setminus K$, $\beta_{i,j}(S_i) := 1 - L(S_{i,j}, M_{i,j}t^{\text{reg}})$.

Step 2 For all mains $k \in K$, $\widetilde{M}_{i,k} := M_{i,k} + \sum_{j \in J | k_j = k} (1 - \beta_{i,j}(S_i))\, M_{i,j}$.

Step 3 For all mains $k \in K$, determine $\beta_{i,k}(S_i)$, $\alpha_{i,k,\widetilde{k}}(S_i)$, $\widetilde{k} \in K$, $\widetilde{k} \neq k$, and $\theta_{i,k}(S_i)$, using Algorithm 6.2.

Step 4 For all regulars $j \in J \setminus K$, if $K = \emptyset$, then $\theta_{i,j}(S_i) := (1 - \beta_{i,j}(S_i))$. Otherwise, $\alpha_{i,j,k}(S_i)$ is determined using Equation (6.5) and $\theta_{i,j}(S_i) := (1 - \beta_{i,j}(S_i))\theta_{i,k_j}(S_i)$.

Algorithm 6.2

Step 1 For all mains $k \in K$, $\theta_{i,k}(S_i) := L\left(\sum_{k \in K} S_{i,k}, \sum_{k \in K} \widetilde{M}_{i,k}t^{\text{reg}}\right)$.

Step 2 For all mains $k \in K$, $\beta_{i,k}(S_i) := 1 - L\left(S_{i,k}, \widetilde{M}_{i,k}t^{\text{reg}}\right)$, and $A_{i,k}(S_i) := 1 - (\beta_{i,k}(S_i) + \theta_{i,k}(S_i))$.

Step 3 For *one main* $k \in K$:

Step 3-a Determine $\widehat{M}_{i,\widetilde{k},k}$ using Equation (6.6), and $\widehat{M}_{i,k} := \widetilde{M}_{i,k} + \sum_{\widetilde{k} \in K, \widetilde{k} \neq k} \widehat{M}_{i,\widetilde{k},k}$.

Step 3-b $\beta_{i,k}(S_i) := 1 - L\left(S_{i,k}, \widehat{M}_{i,k}t^{\text{reg}}\right)$, and $A_{i,k}(S_i) := 1 - (\beta_{i,k}(S_i) + \theta_{i,k}(S_i))$.

Step 4 Repeat Step 3 for all other mains $k \in K$.

Step 5 Repeat Steps 3 and 4 until $\widehat{M}_{i,k}$ does not change more than ϵ for each $k \in K$, with ϵ small.

Step 6 For all mains $k \in K$, $\alpha_{i,k,\widetilde{k}}(S_i) := \beta_{i,\widetilde{k}}(S_i)\widehat{M}_{i,k,\widetilde{k}} / \widetilde{M}_{i,k}$, $\widetilde{k} \in K$, $\widetilde{k} \neq k$.

Figure A.0.2: Approximate evaluation method
Algorithm for determining parameters for greedy method of Spartan following A.A. Kranenburg (2006).

A.3: Review of Spartan output

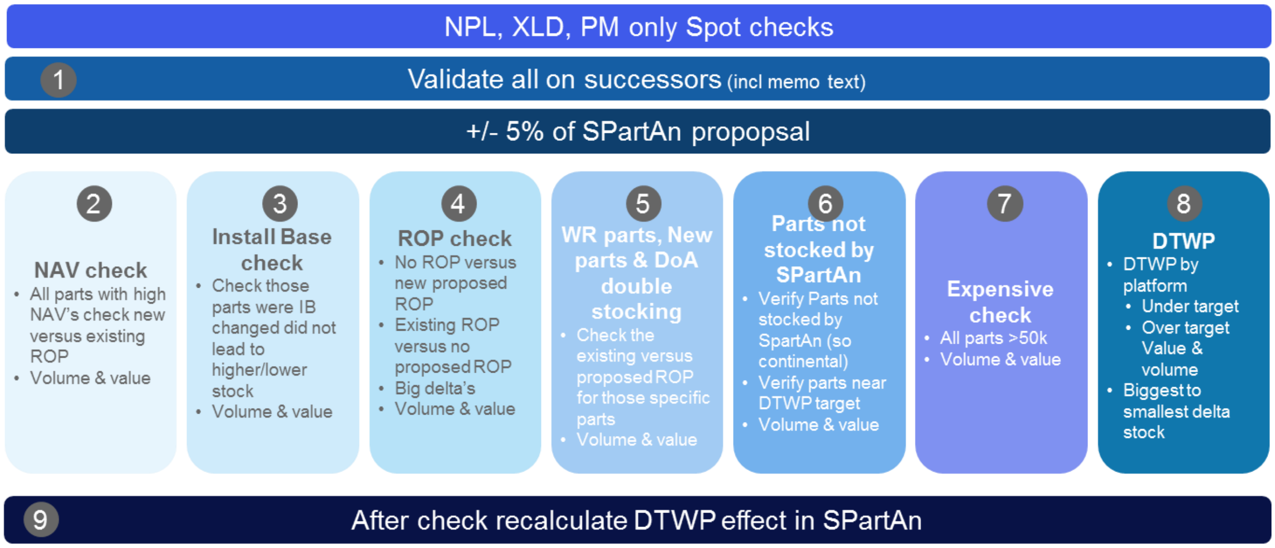

Figure A.0.3: Review of Spartan output

After Spartan is ran some of the inventory levels are changed, because of one of the following reasons (TacticalPlanning2, 2014):

- No cleanroom available at a local warehouse for SKUs which have to be stored in a clean room. These SKUs are stocked on a location nearby with available clean room;
- No cabinet available for dangerous goods at local warehouse, for SKUs which are dangerous. These SKUs are stocked on a location nearby with available dangerous goods cabinet;
- No charger available at local warehouse, for SKUs which have to be charged. These SKUs are stocked on a location nearby with charger;
- Special agreement with the customer about a SKU which has to be available. This SKU will be extra on stock;
- SKU, which was the reason for high downtime of the machine, will be extra on stock.

Appendix B: Confidential: Reference of confidential names of regions

Appendix C: Inventory models

In this paragraph different inventory models are made clear to give an overview of the possible inventory models to use. In chapter 5 the models are applied for the research. In Figure C.0.4 four figures of the inventory system in reverse logistics are given.

Figure C.0.4.A is a closed-loop return system of Teunter (2004). In that system, there is a stock of recoverable and serviceable parts. The recoverable stock is filled with parts to repair. The serviceable stock is filled with the repaired parts and the new produced parts.

Figure C.0.4.B is the recovery system of Choi et al (2007). In this system there are also two inventory points: recoverable and serviceable stock. Next to that, used parts could be scrapped and returned. In this research this could be seen as "used" and "ordered without usage"/"returned".

Figure C.0.4.C also has two inventory points, whereby there is no scrap at the customer. On the other hand there is disposal from the recoverable inventory, which this research also includes. This model is designed by Van der Laan (1997) and referred in different other papers.

In Figure C.0.4.D different forms of reuse and repair are given. Here it can be seen that in every stage in the supply chain parts can be returned. In this research this is applicable for the difference in the return of serviceable, repack and requalification parts. This is designed by Thierry et al (1995) and referred by Mahadevan et al (2002).

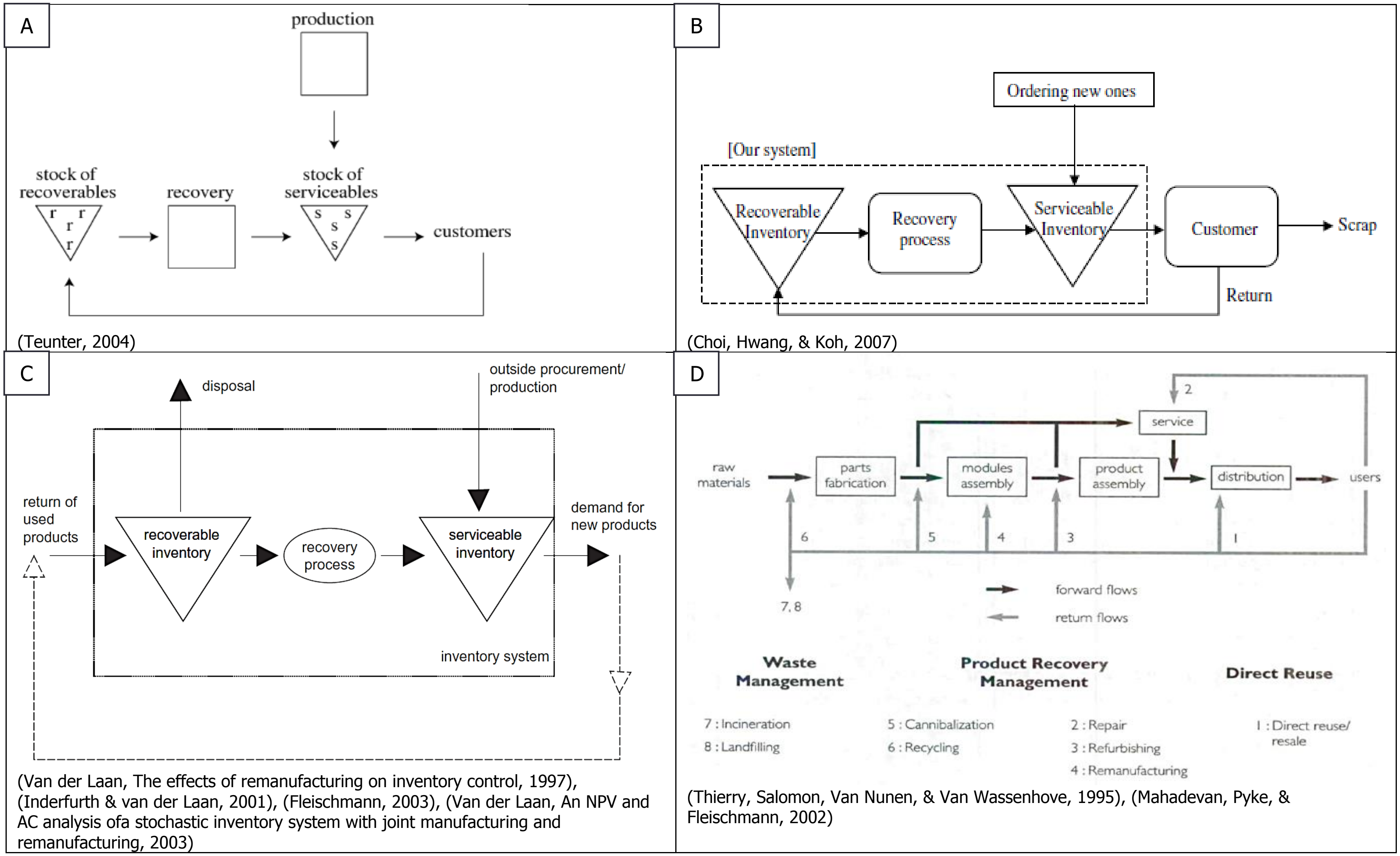

Figure C.0.4: Different inventory figures of the recovery process

Appendix D: Confidential: Figures in chapters 1, 2 and 3

Appendix E: Simulation model in Plant Simulation

In this appendix the simulation model is explained. First a description of the model is presented. Then the experimental factors are explained in detail. At the end the results are given.

E.1: Short description of the Plant Simulation model

The plant simulation model simulates the inventory processes in Region 2. Within this model four processes can be defined. Next to the processes the performance is measured and the input for the model is defined.

Four processes

The four main processes are: replenishment (central warehouse, 1 in Figure E.0.12), demand gathering for the customer (3 in Figure E.0.12), return/usage process (4 in Figure E.0.12) and the overstock process (2 in Figure E.0.12).

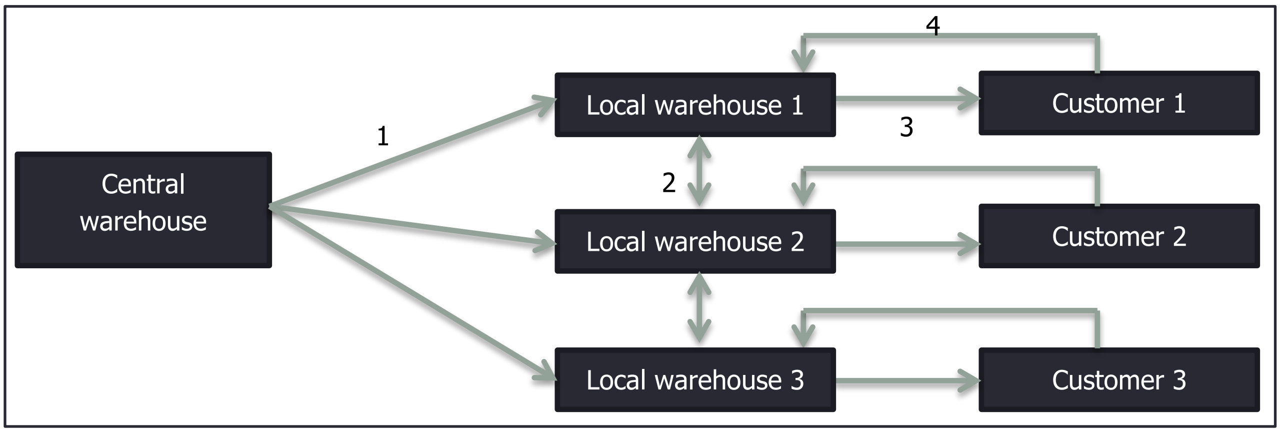

Figure E.0.5: Four processes in simulation.

Replenishment

In Spartan the assumption is that the central warehouse has unlimited capacity. In reality sometimes the central warehouse is out of stock and the part is also not available at other regions, then the part cannot be delivered. In the simulation model, this case is not taken into account, because the model would be too complex and the data is not easy available at ASML. Next to that, the simulation model has to check the correct input of the optimization model, Spartan, when you take the return demand into account. Thereby the availability at the central warehouse is unlimited.

The method "replenishment" is called when a part wants to leave the central warehouse or when a part is used. The goal of this method is to replenish the local warehouses with parts from the central warehouse. The replenishment method checks for a local warehouse for all SKUs if the amount of parts on stock or at the customer is lower than the safety stock level. If that is the case a part is moved from the central warehouse to the replenishment of the local warehouse. This replenishment time is according a Poisson process with a mean of fourteen minutes.

Demand gathering

The demand is simulated with a Poisson process with a mean of the exponential smoothed demand in the last three years. The demand at the customer is gathered by the method "look in warehouse". The demand can be gathered in four possible ways (in order of preference):

1. Part from the stock of the local warehouse of the customer. Hereby no extra costs are needed and the delivery time is zero. This is simulated by sending these parts directly to the customer.
2. Part from the stock of the most nearby other local warehouse in the region of the customer. Hereby some costs are needed and there is a low delivery time.
3. Part from the stock of the second nearby other local warehouse in the region of the customer. Hereby some more costs are needed and there is a bit more delivery time.
4. Part as emergency from the central warehouse. Hereby high costs are involved and high delivery time.

The goal of the method "look in warehouse" is to fulfil the demand with the lowest costs and delivery time.

Return/Usage

After on average fourteen days in a Poisson process the decision is made if a part will return or is used. This decision is made in the method "return_usage_Region2A". With a chance of return per SKU per location the SKU will return or be used. If the part is in the bucket used in this simulation model, the part could be in reality requalified, scrapped or used. This because all these return/used types will leave the local inventory system. The returned parts are the serviceable and repack parts, which will be stocked back in the local warehouse, if they have a safety stock level higher than zero. If there is no safety stock level of that SKU the part is send back to the central warehouse.

The goal of the method "return_usage_Region2A" is having a realistic amount of returns and usage in the simulation model. After usage the check is done if replenishment is needed. After a return the check is done if there is overstock.

Overstock

The overstock is checked when a part returns. There is overstock when the amount of parts of that SKU at the local warehouse and the customer is higher than the safety stock level. In the method "overstock" per SKU per local warehouse is measured if there is overstock and if at another local warehouse has too less parts of this SKU to fulfil the safety stock level. If that is the case the part of that SKU is relocated to the other local warehouse.

The goal of the method "overstock" is to fulfil the safety stock levels and to reduce overstock.

Input

The input in this simulation model is information per SKU. This information is as follows:

- The total demand per day per customer;
- The chance of return per customer;
- The safety stock level per local warehouse;
- The price.

Other input in the simulation model is the following:

- Lateral transportation costs between all local warehouses;
- Emergency transportation costs to a local warehouse;
- Replenishment time to replenish a local warehouse;
- Delivery times between all local warehouses;
- Delivery time of an emergency to a local warehouse;

- Inter arrival time of the demand per local warehouse.

This information is gathered from SAP at ASML and is the same data as in the optimization model. The information is added to the tables.

Performance measurement

The performance measurement contains the methods "calculateperlocation" and "collectmonthlystatistics" and the tables "costperlocation" and "totalcost". The goal of "calculateperlocation" is to calculate the costs of one month per location. The number of emergency and lateral transportations is measured per transportation in the method "lookinwarehouse". The table "costperlocation" lists per location the amount and costs of emergency and lateral transportations. The method "collectmonthlystatistics" has the goal of calculating the emergency and lateral transportation and holding costs per month per local warehouse. The table "total costs" lists this information. The method "collectmonthlystatistics" is called by a generator every month.

Experiments

Four experiments are defined for this simulation, which have results from the optimization. There are as follows:

1. The safety stock levels of the current forecast method, which includes only the usage;
2. The safety stock levels of the forecast, which includes usage and scrapped demand;
3. The safety stock levels of the forecast of method 2 of Kelle and Silver, including usage, scrapped and requalification demand.
4. The safety stock levels of the forecast of the developed method, including usage, scrapped and requalification demand.

Also a fifth simulation is done for checking the simulation model. This simulation contains the safety stock levels of the current forecast method, which includes only the usage and contains only usage as output. This is not the real situation, but it is currently the situation in the optimization model, Spartan.

The experimental settings can be found in next section.

E.2: Experimental settings

The simulation is non-terminating. There is no natural event which stops the simulation, because there is no opening or closing time of the inventory system. This means that there will be steady state behaviour. (Mes, 2013)

Non-terminating simulations use a warm-up period, whereby the observations from the beginning of a simulation depend on the initial conditions, which have to be deleted. After that the steady state average has to be determined. In this research there is chosen for a batch means method, because this will contain one run with N batches and one warm-up period. The reason for this is a reduction in simulation time. (Mes, 2013)

The length of the warm-up period can be found by the graphical method of Welch. Hereby the moving average is used to see visual the length of the warm-up period. The warm-up period is in this case eighteen months. This is because the steady state is then reached for all experiments as mentioned above in the section experiments. For example Figure E.0.13 is given for the warm-up period determination of the current forecasting method. Because of confidentiality the measure of the y-axis is not given.

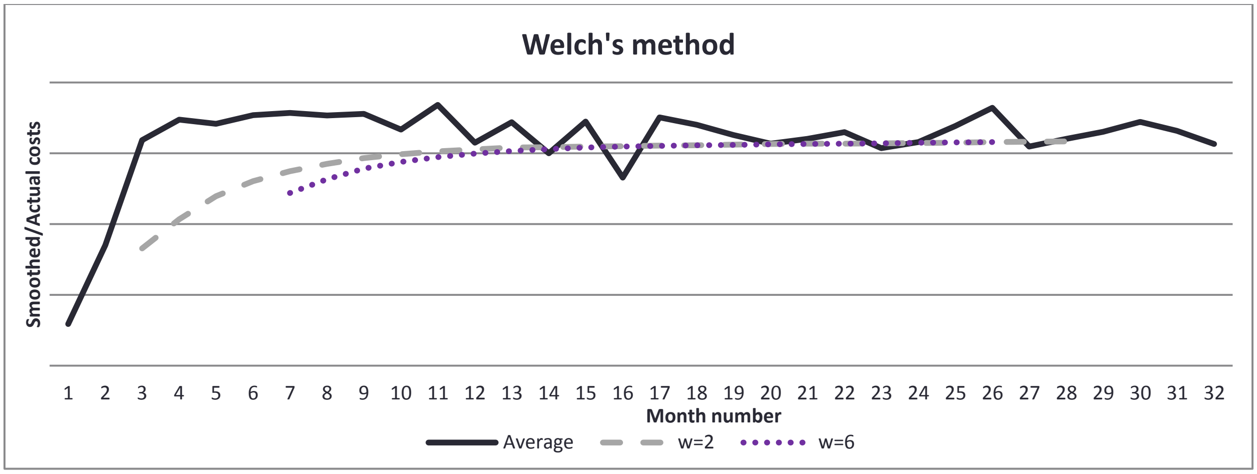

Figure E.0.6: Welch's method for selecting the length of warming up period.

The length of each batch is one month. This means that there are around 850 observations in the case with the lowest demand (only including usage as demand and the current safety stock levels). We assume that a batch of 850 observations is large enough, whereby we can say that the observations are approximately uncorrelated.

The run length will be three years, so 36 months. This is because the expectation is that this will be enough observations to get good average results. So the total run length will be 18 + 36 months = 54 months.

Appendix F: Confidential: Figures in chapter 6