Improving the On Time Delivery performance by the implementation of a Sales Inventory & Operations Planning process

Taking into account the optimization of inventory parameter settings of components with different demand patterns

Master Thesis
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Management summary

This Master thesis provides an analysis of the On Time Delivery (OTD) performance in the Special Vehicles & Equipment (SV&E) market at Power-Packer Europe and lays a foundation for an improved inventory management system in combination with the set-up of a Sales Inventory & Operations Planning process to improve the OTD performance. The current OTD performance is, with an average of 70% (fictitious number), far below the 95% target, see figure 0-1. The On Time Delivery (OTD) analysis revealed that the major root cause for the poor performance is the material supply, which means not all necessary components are available to start the production of a certain product on time.

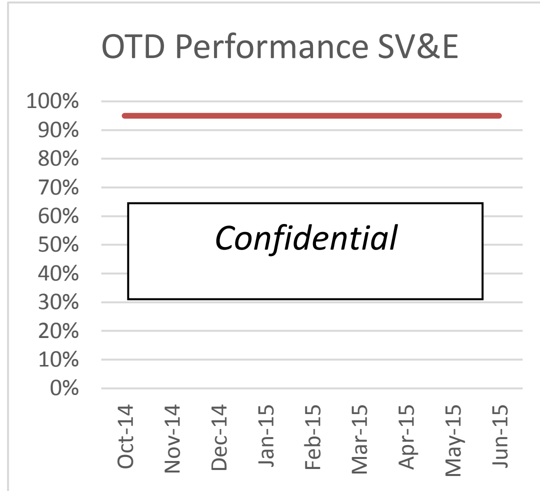


Figure 0-1 OTD Performance SV&E

Due to lower prices abroad, Power-Packer Europe shifted from local component sourcing to component sourcing abroad. This resulted in longer supplier lead times and thus a less flexible supply chain. For the serial production in the Automotive and Truck business this does not cause many problems because customers provide forecasts more than 12 months upfront. However, the SV&E market depends on single incoming orders which should be delivered to the customer within 5 weeks. Currently the inventory system is not organized to properly deal with these intermittent demand patterns in the SV&E market, which results in a poor On Time Delivery (OTD) performance towards customers. Therefore the following main research question has been formulated:

"How can Power-Packer Europe improve the On Time Delivery (OTD) performance in the Special Vehicle & Equipment market, based on a customer lead time of maximal 5 weeks?"

This research question is answered quantitatively by (1) the introduction of a component classification model based on the component lead time, value and demand pattern and (2) a foundation for a new inventory replenishment policy and forecasting method suited for the complex intermittent demand pattern which is common in the SV&E market. The qualitative part is represented by the implementation of a Sales Inventory & Operations Planning process.

The component classification model at Power-Packer, which is mainly used to determine safety stock, is only based on supplier location and component value but does not take different demand patterns into account. Because of this, the calculation of the safety stock quantities only works for smooth demand patterns. We propose a new component classification model, which distinguishes components also based on lead time and demand pattern. Four main demand patterns can now be classified; Smooth, Erratic, Intermittent and Lumpy, see figure 0-2. Based on this classification the right inventory parameter settings, like required safety stock quantities and stock on hand, per component can be determined more accurate to meet the On Time Delivery service level. Besides this, the classification gives a good indication which components are risky to purchase abroad. For example, components showing a lumpy demand should be sourced locally if possible.

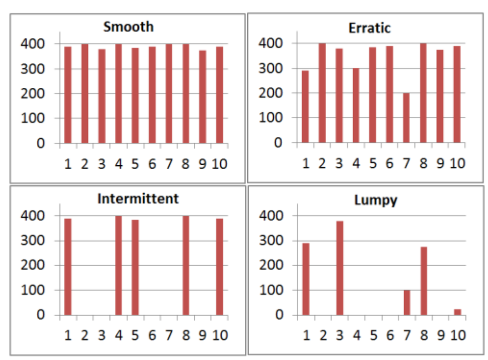


Figure 0-2 Demand pattern classification

Forecasting and setting the right inventory settings for components which show a demand pattern other than a smooth demand pattern is a complex case due to the high uncertainty of when the demand occurs and at what quantity. We propose to use Croston's forecasting method for components with an intermittent demand pattern. We conducted a forecast accuracy comparison between Croston's forecasting method and the forecast method currently used at Power-Packer; this numerical experiment indicated that Croston's forecasting method performed 10-12% better than the forecasting method used at Power-Packer. Besides this, Croston's forecasting method forms the foundation for the order-up-to inventory replenishment policy we outlined and simulated in this report.

The simulation of this new order-up-to inventory replenishment policy, which is especially designed for components with an intermittent (and lumpy) demand pattern, showed that to obtain the target service level of 95% for these components, the inventory value increases by 53% for components with an intermittent demand and 83% for components with a lumpy demand. This corresponds to an extra investment of 199,000 (fictitious number) euro in inventory value to attain the 95% availability target. This investment would be needed for the 37 components with an intermittent demand pattern and the 20 components with a lumpy demand pattern, which were embedded in a product which had an On Time Delivery problem in the period July 2014 up to and including May 2015. Assuming that these critical components caused the On Time Delivery problem and all other components were on stock, this investment would be needed to obtain the On Time Delivery target of 95%.

Although an optimal inventory replenishment policy could improve the On Time Delivery performance, it is recommended to use our proposed classification method to identify the critical components with an intermittent and lumpy demand pattern, and find local suppliers for these components which can deliver them within 10 workdays. However, further research is needed to determine the cost of local sourcing compared to holding the extra amount of inventory proposed by our new inventory replenishment policy.

Besides the quantitative part, the more qualitative Sales Inventory & Operations Planning (SIOP) process, implemented during the execution of this master thesis, forms a new foundation for setting correct inventory parameter settings while taking inventory holding costs into account. This will result in an improved On Time Delivery performance and higher customer satisfaction. A cross functional team monthly reviews, discusses and takes appropriate action based on six main topics: "Forecast accuracy performance", "Inventory and forecast settings of the top 10 selling products", "On Time Delivery performance and problem causes", "Cost of expedited freight", "Upcoming unusual sales", and "Safety stock settings".

Quantitative inventory models provide a good basis for parameter settings, but the human knowledge and interaction is still needed, the SIOP meetings provide a basis for reviewing, discussing and making agreements about these parameter settings. Eventually this must lead to consensus between all stakeholders and improve the On Time Delivery performance in the SV&E market.

Recommendations:	**Responsible**	**Deadline**
Implement our proposed component classification model (classify based on value, supplier lead time and demand pattern).	Hans Langenhof	01-02-2016
Source components with an intermittent and lumpy demand pattern locally to reduce the supplier lead time to a maximum of 10 workdays.	Purchasing	01-12-2016
Implement Croston's forecasting method for products with an intermittent demand pattern which (eventually) cannot be supplied within 10 workdays	Sales	01-02 2016
Go on with the implemented SIOP process and optimize discussion topics based on experience during the SIOP meetings.	Hans Langenhof	01-01-2016
Validate supplier lead times.	LSE team	01-02-2016
Register forecasted demand versus actual demand to determine the forecast error, and use this forecast error to determine optimal safety stock quantities.	Sales	01-02-2016

Preface

After an amazing time in Enschede and at the University of Twente, this Master thesis finalizes my master program Industrial Engineering and Management with the specialization Production and Logistics Management. This final research has been conducted at the headquarters of Power-Packer Europe in Oldenzaal.

First of all I would like to acknowledge all people that contributed to the successful fulfillment of my Master's degree: my roommates who kept me awake when I desperately needed my sleep, the boys from my fraternity Χάος (Chaos) who called me a pussy when I did not drink every Wednesday evening, my car which broke down several times during my time at Power-Packer, my boyfriend Jordi who is always late, my best friend Yvet who left me alone at the University after my Bachelor and of course my parents who stopped paying my school fee last year. Luckily it took me hours to think about the previous sentences, because without all of you, and all others I needed but did not mention by name, I would not have been able to finish my Master thesis successfully: I love you all!

It took a lot of energy and sleepless nights, but despite that I had a nice and educational time at Power-Packer Europe. I would like to thank my supervisor Martien Rindt for this opportunity and his support. But also Hans Langenhof should not be forgotten; he spent a lot of time with me both during workhours and breaks and taught me all ins and outs of the logistics at Power-Packer. And although I thought I was an Excel expert, Albert van Wezel was able to support me with all complicated Excel issues.

It was a pleasure to work with all people at the logistical department, where I was not the only one who got to get coffee for everyone. We even ate pancake rolls on Thursdays with a select group. Every day, at my desk, I had the pleasure to look at my right, where lovely Karin was sitting. Only after a few weeks she realized I was not looking at her but at the Car Dealership outside, fortunately we had a good laugh about it.

Of course I would also like to thank all other people at Power-Packer who supported me and my research, especially all people who attended the Sales Inventory and Operation Planning (SIOP) meeting I set up during my time at Power-Packer.

Next to all others I would like to thank my supervisors Peter Schuur and Ahmad Al Hanbali from the University of Twente, who reviewed my work and gave good advice about how to proceed and improve.

Although I mentioned him before, Jordi Huirne deserves special thanks for the hard time I sometimes gave him. I, a busy man who got to work at Bleeker Occasions even after 5 o'clock, a precisian and someone who does not sleep very well, can be quite a pain in the ass. But he survived, and so did we.

I'm ready for the next challenge.

Steven Donderwinkel

Enschede – November 2015

The authors view during his research: Lovely colleague Karin Voerman

Abbreviation List

Abbreviation		Explanation
ADI	Average inter-Demand Interval	Average interval between two consecutive demands
ASCP	Advanced Supply Chain Planning	ERP planning module in Oracle
BOM	Bill Of Materials	List of all components embedded in the end product
CV	Coefficient of Variation	Measure of dispersion (of a probability distribution)
EDI	Electronic Data Interchange	Used to process demand schedules send by customers
ERP	Enterprise Resource Planning	Business management software, used to collect, store and manage data
FG	Finished Goods	Products which are ready to be shipped
KPI	Key Performance Indicator	A performance measurement
LOB	Line Of Business	The different market segments: SV&E, Automotive, Medical, Truck
LSE	Logistics System Engineer	Function within the Logistics department
LT	Lead Time	Time it takes from ordering to delivery of a product
MAD	Mean Absolute Deviation	Accuracy measure: average of the absolute difference between forecast and actual demand
MOQ	Minimum Order Quantity	The minimum quantity a customer must order
MSE	Mean Squared Error	Accuracy measure: average of the squared errors
OTD	On Time Delivery	Performance indicator for on time delivery of products
NOTD	Not On Time Delivery	Performance indicator for *not* on time delivered products
PO	Purchase Order	Purchase Order Power-Packer places at the supplier
RASCI	Responsible, Accountable, Supportive, Consulted, and Informed	Describes who is responsible for certain tasks and deliverables in a project
SFFG	Shop Floor Finished Goods	Finished products which are not yet booked in inventory
SLOB	Slow Moving and Obsolete	Products which are in inventory but (nearly) not used
SOP	Sales Order Processing	Department which processes all incoming orders
SIOP	Sales Inventory & Inventory Planning	See section 4.3 for a detailed description
SV&E	Special Vehicles and Equipment	Market segmentation

Product made at Power-Packer: Hydraulic cylinder

Contents

1. Introduction

1.1 Company profile

Power-Packer Europe is founded in 1970, with its headquarters in Oldenzaal the Netherlands. Power-Packer is an independent subsidiary of the US based Corporation Actuant. The Actuant Corporation is listed on the NYSE and is a 1.5 billion multinational company.

Power-Packer manufactures (electro) hydraulic actuation systems for convertible roofs, lifting cabins of trucks, medical equipment, marine doors, stabilizing legs, wire ropes, latches and engine air flow management solutions. Power-Packer develops, assembles and markets systems for customers on a global basis including OEM's and Tier 1's in diverse end-markets. Renowned car and truck manufactures are among their regular customers. Power-Packer Europe is ISO/TS certified and has been granted many supplier awards (Power-Packer, 2015) .

Power-Packer markets served include: Automotive, Truck, Medical, Marine, Special Vehicles & Equipment (SV&E).

Besides the headquarters in Oldenzaal, Power-Packer has facilities in, Germany, France, Spain, Turkey, India, Brazil, Mexico and the USA, employing over 1000 people. At Power-Packer in Oldenzaal the production focus is on the Trucking, Special Vehicles & Equipment (SV&E) and Medical applications. The production of the automotive related parts has been reallocated to Turkey, but all other activities, like sales, forecasting and purchasing, are still performed in Oldenzaal.

Figure 1-1 Cabrio hydraulic system

Within the framework of the Master of Science program Industrial Engineering & Management, I performed research on the On Time Delivery (OTD) problems at the Logistics department of Power-Packer in Oldenzaal.

Figure 1-2 Truck

Figure 1-3 Power-Packer Oldenzaal

1.2 Research topic and motivation

The start of this thesis was initiated by the logistics department at Power-Packer Oldenzaal, who faces severe problems with the on time delivery of products and high overdue in the Special Vehicles & Equipment market. The Automotive and Truck market demand can be forecasted quite reliably because the system is constantly updated using the so called EDI schemes provided by the customers. These EDI schemes are filled with the customer forecast. The SV&E market on the other hand depends on single incoming orders from smaller customers, these orders must be shipped to the customer within the maximum lead time of 5 weeks, with an On Time Delivery (OTD) target service level of 95%. Although material sourcing from abroad seemed a good and cheaper option in the past, the longer supplier lead times in combination with the unpredictable demand and inconsistent inventory levels are causing expensive emergency transportation costs and the inability to start the production on time. The exact causes of the low OTD performance however, will be researched and analyzed in this thesis. Besides the low OTD performance, Power-Packer faces high Overdue which is partly caused by the low OTD performance. Overdue is a measure in euros of the total value of orders which cannot be invoiced before the order due date because they are not shipped to the customer before the order due date.

Also the project initiators, Martien Rindt and Hans Langenhof, are supporting the lack of proper internal procedures (way of working) and indicate that the current system set-ups are not completely supporting the demand conditions of the customer (single orders, max lead time of 5 weeks, 95% OTD). Based on experience and the recommendations of external consultants which visited Power-Packer previous year, the implementation of a Sales Operations & Inventory Planning (SIOP) is initiated as a possible solution to improve current parameter settings and enhanced cooperation between different departments.

In short, within Power-Packer there is demand for an adjusted inventory management model which suits the demand patterns and conditions in the SV&E market. Besides this quantitative approach, the implementation of a Sales Inventory & Operations Planning procedure should support the decision making of parameter settings based on the combined knowledge within the different departments. Together this should form the foundation for an improved On Time Delivery (OTD) to customers.

1.3 Research Questions

In order to address the issues mentioned in section 1.2 and to properly determine how to optimize the processes and procedures at the logistical department at Power-Packer Oldenzaal, the following core research question is formulated:

Core research question:
"How can Power-Packer Europe improve the On Time Delivery (OTD) performance in the Special Vehicle & Equipment market, based on a customer lead time which is at maximum 5 weeks?"

To answer this core research question, the core research question is divided in multiple sub research questions; the so called knowledge questions (Heerkens J. , 2005). These questions will be answered by interviews, available data analysis from Power-Packer and reviewing related literature. Section 1.4.2 provides the research method corresponding to each sub question. The following research questions are formulated:

Research questions:

1. What is the current way of working from order acceptance up to and including shipment within the SV&E market?
    a. What does the current flow chart of the involved departments look like?
    b. What are the internal lead times from the different departments and what do they actually do in this lead time?
    c. How much lead time remains for the suppliers if all internal lead times are subtracted from the maximum customer lead time of 5 weeks?
    d. What does the current replenishment policy look like?
    e. How are the current safety stock levels determined?
    f. How is the current forecast method built-up and what is the performance of this forecast?

2. What are the underlying main problems that cause the poor OTD and Overdue performance in the SV&E market?
    a. How are On Time Delivery (OTD) and Overdue defined and related within Power-Packer Europe?
    b. How does the current overall OTD perform?
    c. How does the current Overdue perform?

   d. *What are the main problems which cause the poor On Time Delivery and Overdue performance?*
   e. *What are the underlying causes of these main problems?*
   f. *Which specific products cause the poor On Time Delivery performance?*

3. Based on the literature, how can a Sales Inventory & Operations Planning (SIOP) process improve the On Time Delivery and which inventory replenishment policy can be used for the demand pattern corresponding to the uncertain single order SV&E market?
   a. What is Sales Operations & inventory Planning (SIOP) and how can it improve the overall supply chain in general?
   b. Which inventory replenishment models are supported by the Oracle ERP system which Power-Packer currently uses?
   c. How can the different component demand patterns be distinguished?
   d. Which inventory replenishment model is able to determine appropriate inventory and safety stock levels in the uncertain single order SV&E market?

4. Which component classification model is able to determine the high risk components for the On Time delivery performance in the selected NOTD products?
   a. Which components are embedded in the NOTD products?
   b. Which components have a too high supplier lead time in order to react fast to changes?
   c. How can components be valuated based on their purchase value?
   d. Which components do not have sufficient safety stock to cover for uncertainties?
   e. What are the demand patterns corresponding to the components used in the SV&E market?

5. How does the new inventory replenishment policy for intermittent demand patterns perform and what are the corresponding parameters settings per component in the NOTD products?"
   a. Which inventory replenishment method should be applied to the different components?
   b. What are appropriate safety stock methods?
   c. What is the impact on cost of implementing this new inventory replenishment method?
   d. What are possible options, besides adding extra stock or the implementation of a new inventory replenishment method, to improve the On Time Delivery?

6. What is the appropriate set-up of the Sales Inventor & Operations Planning (SIOP) for Power-Packer Europe in order to be able to increase the On Time Delivery performance in the SV&E market?
   a. Which departments/people should be part of the SIOP meetings and what are their responsibilities?
   b. What subjects should be handled during the SIOP meetings?
   c. Which tools should be developed to support the SIOP decision making process?
   d. Which information should the departments share at the SIOP meetings?
   e. How should the implemented procedure and system set-up be maintained?

7. What is the impact of implementing the new inventory model and SIOP process compared to the current situation?

1.4 Research Approach

The research approach provided in this section is used as a guide to answer the research questions formulated in section 1.3. The research approach is based on the book "Designing a research project" (Verschuren &

Doorewaard, 2010). Section 1.4.1 states the research goal and research objects. In section 1.4.2 the research method for each research (sub) question is provided.

1.4.1 Research goal

The goal of this research is to lay a foundation to improve the On Time Delivery (and corresponding Overdue) performance within the SV&E market. The processes, procedures and parameters used to streamline the logistical performance must be reviewed and improved where possible. This includes identifying critical components, optimally assigning inventory methods to products / components and the implementation of a Sales Inventory and Operations Planning (SIOP) process to support decision making about inventory parameter settings.

1.4.2 Deliverables

This thesis should deliver the following:

Quantitative:

- Product / component (demand pattern) classification model which forms the foundation for the selection of the appropriate inventory method and inventory parameter settings.
- Foundation for an improved forecasting method for items with an intermittent demand pattern.
- Foundation for an improved inventory replenishment policy for components with an intermittent demand pattern.
- Simulation model of the new inventory replenishment including the new safety stock determination method and Croston’s forecasting method.

Qualitative:

- Sales Inventory & Operations Planning (SIOP) proposal and implementation.
- Tools which support the analysis of discrepancies between incoming orders, the forecast, current on hand inventory and safety stock settings, in order to make correct decisions about logistical parameter settings during the SIOP meetings.

1.4.3 Research method

This section provides a clear and simple matrix with the used research method per research question, see figure 1-4 on the next page. The use of these methods gives the ability to answer each research question, which eventually should answer the core research question.

1.5 Scope and assumptions

In this section the scope (boundaries) and assumptions of this research will be outlined:

- The research will focus on the Special Vehicles & Equipment (SV&E) market. Although the processes and procedures in the SV&E market are comparable to the Medical market Power-Packer serves, the scope is limited to the SV&E market because the number of components to review is already over a hundred. However, the developed tools and procedures could also be used in these other markets.
- To limit the scope, the indebt analysis of products will only focus on products which caused an On Time Delivery problem in the period July 2014 – June 2015.
- The in-depth analysis of the Not On Time Delivery (NOTD) causes will only be executed for the major cause of the Not On time Delivery; the material shortage, see paragraph 3.1.4.
- Production planning will be left out of scope.
- Data in Oracle about for example, supplier lead times and cost prices, are assumed to be valid. A complete validation of the accuracy of this data will be too time consuming and therefore out of scope.

- The impact of the Warehouse move from the “Hanzepoort” to the production site a few kilometers away will be left out of scope.

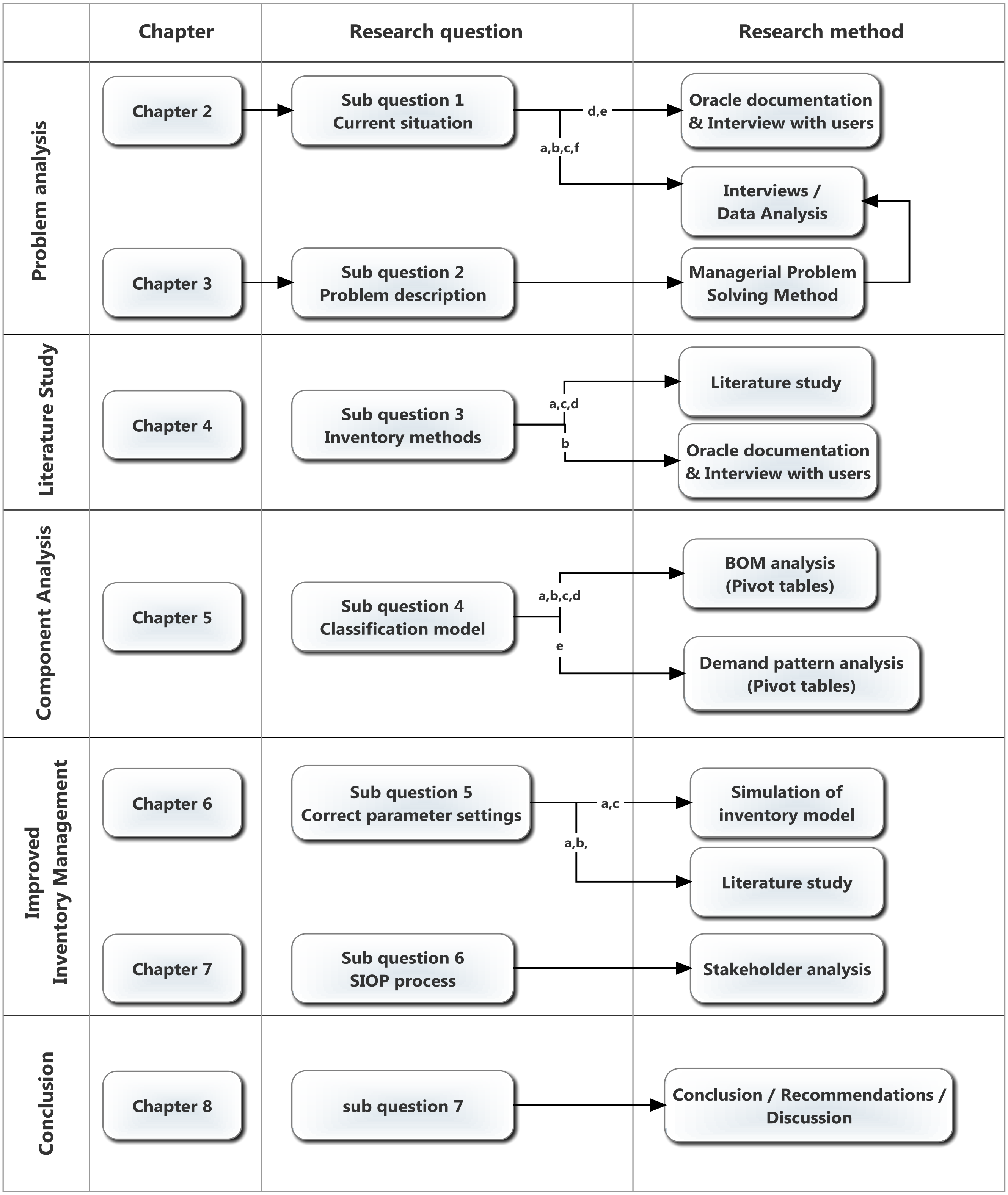


Figure 1-4: Research methods per sub question

Employee at Power-Packer who assembles a subassembly of a hydraulic cylinder

2. Current situation

In this chapter the current situation at Power-Packer Oldenzaal is described. Section 2.1 provides a short overview and description of the departments which could have an effect on the target customer lead time of 5 weeks. In section 2.2 the current determination of safety stocks and inventory levels is outlined. Finally section 2.3 elaborates on the forecast method currently used. Research question 1 and the accompanying sub questions are thereby answered.

2.1 Flow chart departments

In figure 2-1 a flow chart of the current situation is depicted. Only the steps which relate to the current internal lead time are taken into account. In the next paragraphs each step is discussed in more detail. Finally, the remaining supplier lead time is determined, which is equal to the five weeks customer lead time minus the internal lead times. Based on this calculation, it is possible to identify which suppliers are critical in the supply chain to reach the objective: a maximum customer lead time of five weeks, with 95% On Time Delivery (OTD).

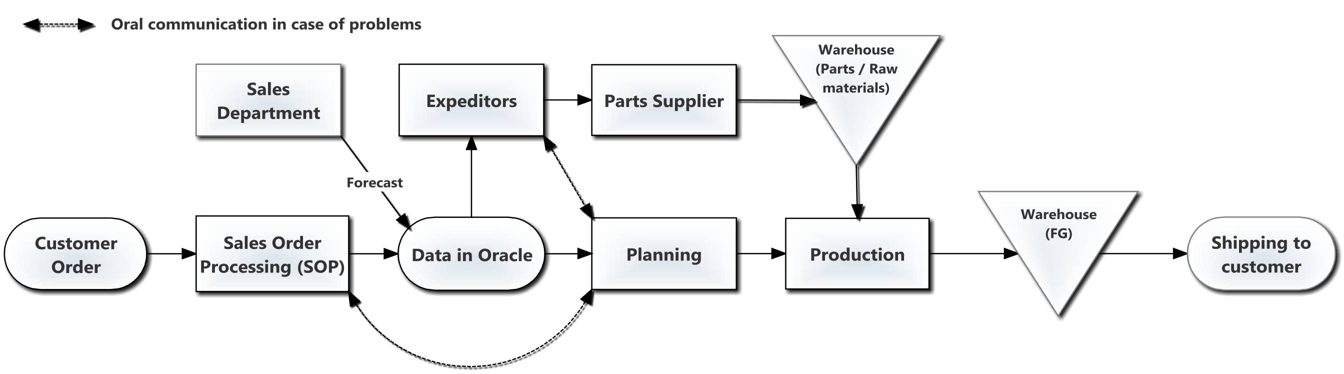


Figure 2-1: Flow chart departments

2.1.1 Sales Order Processing (SOP)

The Sales Order Processing (SOP) department processes all incoming orders. As opposed to the Automotive and Truck orders which come in via Electronic Data Interchange (EDI), the orders from SV&E customers come in by email. These orders need to be processed manually into the ERP system (Oracle). This is quite a time consuming task, in which a mistake is easily made. Normally the SOP department processes the incoming orders within 24 hours. Some customers deliver order schedules with an additional number of weeks with a demand forecast. However, in the SV&E market these schedules are rare; only 3 customers provide a forecast with a maximum of 6 months. These weekly schedules can change a little each week, but enable Power-Packer to make a more reliable forecast for the coming weeks. Based on the product lead time, the SOP department sets a due date for the order. In general this lead time is 5-6 weeks. If a customer order requests a due date within the normal lead time, SOP contacts the planning department to ask whether it is possible to deliver the order on the requested due date.

2.1.2 Planning

After the SOP department processed all incoming orders, the planning department can make an aggregated planning. Although the production of one single order normally does not take more than one day, the planner provides production with the overall demand schedule of the upcoming week. This gives production some flexibility; they can plan the sequence of the orders themselves. For example, an order with a due date on Monday June 15 must be produced somewhere in the week before (June 8 until 12), see figure 2-2.

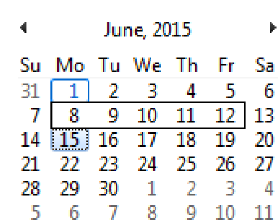


Figure 2-2: Planning

2.1.3 Oracle

Since November 2013 Power-Packer Oldenzaal uses a new ERP system called Oracle. Previously they used the ERP system BAAN, but the parent company Actuant Corporation uses Oracle. This system connects all business activities, like Sales, Planning, Logistics, Production and Warehousing.

2.1.4 Expeditors

The expeditors are responsible for the material planning and purchase. Of course, the Purchasing department is responsible for supplier selection, contracts, prices and agreements about reserved raw material for Power-Packer. The purchasing department handles all material purchases for which no contract is available yet, in all other situations the materials are automatically order when the expeditors run the MRP system, which calculates the required materials. In the ideal situation this task would be nothing more than just purchasing the material requirements which are calculated by Oracle, but unfortunately this job becomes much more complicated and challenging due to suppliers which cannot deliver on time or rush orders. As mentioned before, sometimes SOP gets a customer request to deliver the products within the specified customer lead time. If this is the case, the planner gets in contact with the expeditors to verify if they can get the required materials on time.

2.1.5 Warehouse

While writing this report, Power-Packer Oldenzaal is executing a big warehouse project. The warehouse, which is currently situated at the Hanzepoort, will be moved to the production location which is a few kilometres away. This project should save a lot of (transportation) time and money, but is out of the scope of this project.

2.1.6 Lead Times

Power-Packer's ultimate goal is to deliver 95% of all SV&E products within a customer lead time of 5 weeks. To be able to determine which items and suppliers are critical in achieving this objective, the current situation must be analysed to determine the remaining supplier lead time. As was previously mentioned, SOP normally needs only one day to process the incoming orders. In the ideal situation the required parts will be ordered the same or the next day, but the current system only orders on Tuesday morning (MRP runs in the night of Monday – Tuesday). So, if an order is processed on Monday the materials will be ordered the next day. But if SOP processes the order on Tuesday the required materials will be ordered a week later on Tuesday. Taking into account the three days currently required to pick and inspect the raw materials from the internal warehouse, the 7 days required for production and the 2 days needed to move and pick the finished goods, only 10 working days are leftover for the supplier to deliver the parts! This means that if Power-Packer wants to meet the target customer lead time of five weeks, in the worst case all parts which cannot be supplied within 10 working days must be on stock when the order comes in or should have been ordered already based on an (accurate) forecast, see figure 2-3.

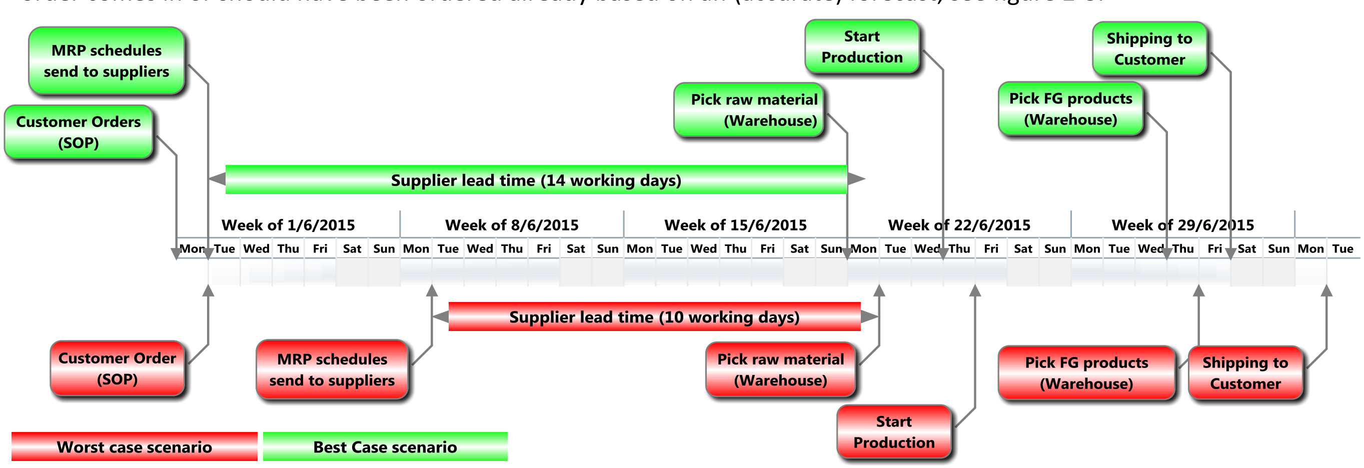


Figure 2-3 Remaining supplier lead time

2.2 Current replenishment policy and determination of safety stocks

In this section the current determination of safety stock and inventory base stock levels on component level is described. Oracle provides several options to calculate the safety stock of a component. Within Power-Packer they make use of the option "MRP planned percent" and "Non-MRP planned". Within SV&E more than 90% of the items have a fixed safety stock which is calculated based on the "Non-MRP planned" method, see section 2.2.1. The other 10% is calculated based on the "MRP planned" option, see section 2.2.2.

2.2.1 Non-MRP planned safety stock

In case of the "Non-MRP planned" option, the safety stock is a fixed quantity which is calculated on the basis of an ABC/DE classification and the supplier location.

ABC/DE Classification	
A	Cumulative 0-80%
B	Cumulative 80-95%
C	Cumulative 95-100%
D	Items with no forecast but *with* physical available stock
E	Items with no forecast and *without* physical available stock

Table 2-1 ABC/DE Classification

The ABC/DE analysis is used to determine the impact of a certain component on the total inventory costs. For example, 20% of the components are accountable for 80% of the total inventory costs. Within Power-Packer the ABC/DE analysis is based on the next two months forecasted inventory costs. The total value per component in the inventory is sorted from high to low. The components in this sorted list, which together account for 80% of the total inventory value, get an A classification. The components which account for the next 80 till 95% of the total inventory are classified as B components. The remaining 95-100% gets a C classification, see table 2-1.

A simplified example of the ABC/DE classification heuristic will be explained below (see table 2-2):

1. Suppose the complete inventory consist of 6 components (see column 1)
2. Take the forecast in units per component for the next two months (see column 2)
3. Calculate the forecasted inventory value per component: column 2 times column 3 (see column 4)
4. The 2 months forecasted inventory value (column 4) is sorted from high to low
5. Next the cumulative percentage per component from the total forecasted inventory value is calculated: Component 1: (€1,000,000.00 / **€1,609,000.00**)*100% = 62%
   Component 2: ((€1,000,000.00 + €500,000.00)/ **€1,609,000.00**) * 100% = 93%
6. Based on this cumulative percentage and table 2-1 the component gets an A,B or C classification:
   Component 1: cumulative percentage is 62% → see table 2-1 → classification A
   Component 2: cumulative percentage is 93% → see table 2-1 → classification B

	2 months inventory forecast (units)	Component price	2 months inventory forecast (value)	Cumulative %	Class
Component 1	1,000,000	€1	€1,000,000.00	62%	A
Component 4	20,000	€25	€500,000.00	93%	B
Component 5	11,000	€5	€55,000.00	97%	C
Component 2	10,000	€5	€50,000.00	100%	C
Component 3	10,000	€0.50	€5,000.00	100%	C
Component 6	No forecast	No forecast		100%	D / E
Total	**1051000**		**€1,609,000.00**		

Table 2-2 Example ABC/DE Analysis

This ABC/DE classification is the first part which is used to determine the fixed safety stock level. The next criterion is the location of the component supplier. The locations of the suppliers are divided in Europa (EUR), the Netherlands (NL), Turkey (TR), Overseas by Air (OverseasAir) and Overseas by boat (Overseas).

To calculate the safety stock quantity, the ABC/DE classification and the supplier location are merged. So if a component is produced in Europe and has an A classification, the merged term becomes: EurA. Based on this merged term the number of Safety Stock days (SS Days) can be looked up in a table, see table 2-3. For example: a component with an A classification with a supplier location in Europe needs 2 Safety Stocks days according to the table. The number of Safety Stock days in the table is based on experience without a proper foundation.

Location +ABC	SS days	Location +ABC	SS days	Location +ABC	SS days	Location +ABC	SS days	Location +ABC	SS days
EurA	2	NLA	2	TRA	3	OverseasAirA	5	OverseasA	15
EurB	3	NLB	3	TRB	5	OverseasAirB	7	OverseasB	20
EurC	12	NLC	12	TRC	15	OverseasAirC	15	OverseasC	25
EurD	-	NLD	-	TRD	-	OverseasAirD	-	Overseas D	-

Table 2-3 Number of Safety Stock days based on supplier location and ABC/DE classification for a component

Eventually the fixed safety stock quantity is calculated using the following formula:

$$\boldsymbol{Fixed\ Safety\ Stock} = \left(\frac{\mathbf{2}\ \boldsymbol{months\ forecast\ in\ units}}{\mathbf{8}\ \boldsymbol{weeks} * \mathbf{5}\ \boldsymbol{days}}\right) * \boldsymbol{SS\ days}$$

Fixed Safety Stock heuristic:

1. Determine if a component has an A,B,C,D or E classification
2. Determine the component supplier location
3. Merge the ABC/DE classification and the supplier location
4. Lookup the corresponding Safety Stock days in table 2-3
5. Determine the average daily forecasted inventory in units over the next two months
6. Multiply the average daily forecasted inventory in units with the number of Safety Stock days

In practice, these fixed safety stock amounts are updated only 4 times a year.

Running example: safety stock calculation in combination with intermittent demand patterns

The current safety stock determination method, described above, depends on the demand in the upcoming two months and was designed mainly for items which are used each week, see figure 2-4. However, within the SV&E market many components show a so called intermittent demand; a period with demand is followed by periods with zero demand. These periods with zero demand have a huge impact on the current safety stock calculation. Take for example component DSA8029-041 (Figure 2-5), which has a Spanish supplier and is categorized as a C-component, which results in 12 SS days according to table 2-3. Calculation of the safety stock on 14 September 2015 in the current situation will be as follows:

$$\boldsymbol{Fixed\ Safety\ Stock} = \left(\frac{\mathbf{2}\ \boldsymbol{months\ forecast\ in\ units}}{\mathbf{8}\ \boldsymbol{weeks} * \mathbf{5}\ \boldsymbol{days}}\right) * \boldsymbol{SS\ days} = \left(\frac{\mathbf{15}}{\mathbf{8} * \mathbf{5}}\right) * \mathbf{12} = \mathbf{4.5}$$

Taking into account the lead time of 30 days, the average order quantity and the forecast error within the SV&E market, this safety stock quantity will be unable to cover for single incoming orders just 5 weeks before the due date. To be able to react on sales orders without a forecast, the supplier should have been able to supply within 10 working days. If this is not the case, the safety stock should cover this in the current situation because there is no stock held if there is no frequent demand. One of the logistical managers indicated this situation as playing "Russian Roulette", in the best case there is still some inventory left from previous orders, but in the worst case there is no inventory at all to be able to supply the customer within the 5 weeks lead time.

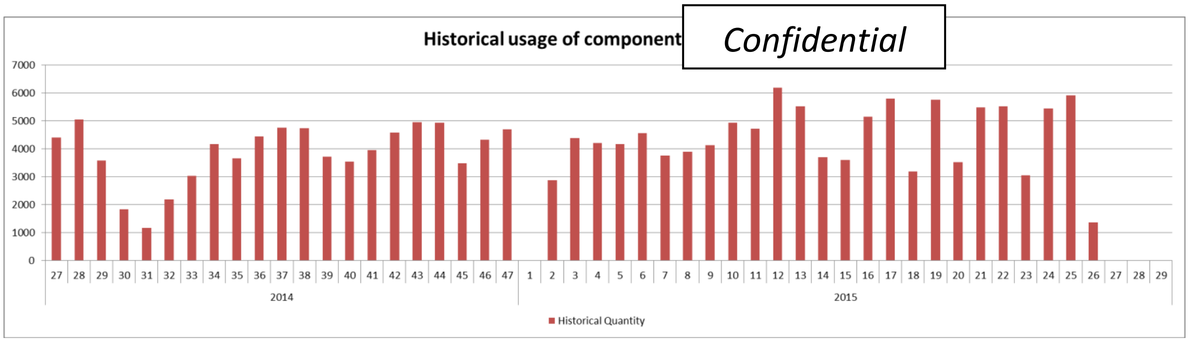


Figure 2-4: Historical usage of component 1016-018 (per week)

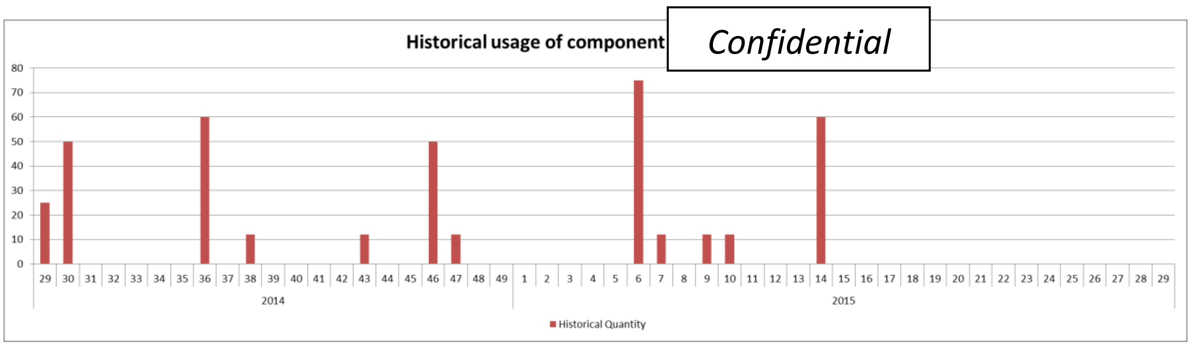


Figure 2-5: Historical usage of component DSA8029-041 (per week)

2.2.2 MRP planned safety stock

The "MRP planned percent" safety stock is determined using safety stock buckets and safety stock percentages. In this case the safety stock is dynamic and will be updated by Oracle. The safety stock will be calculated as a user-defined percentage (called Safety Stock Percent) of the average gross requirements for a user-defined number of days. This user-defined number of days is equal to the Safety Stock Bucket Days. So if the user defined number of Safety Stock Bucket Days is equal to 5, Oracle will average the gross requirement over these 5 days. The average gross requirement per day is multiplied by the user defined percentage (Oracle, 2013). See table 2-4 for a simple example:

Safety Stock Bucket days	5
Safety Stock Percentage	**150%**
Demand 1-Jul-15	200
Demand 2-Jul-15	100
Demand 3-Jul-15	100
Demand 4-Jul-15	250
Demand 5-Jul-15	350
Average over 5 Bucket days	**200**
Safety Stock	**300**

Table 2-4: Example MRP planned safety stock

Average over 5 Bucket days (200)* Safety Stock Percentage (150%) = Safety Stock (300)

A small side note: the value of the safety stock in the inventory report of Power-Packer is not based on the average gross requirement over the specified number of bucket days, but is based on the average gross requirement over 2 months. The actual safety stock however, is calculated by Oracle, so this way of reporting has no influence on the safety stock calculation.

2.2.3 Replenishment policy

As mentioned in section 2.1.6 the required materials are ordered every Tuesday morning, based on the MRP calculations which run on Monday night. The MRP demand calculations are based on the forecast and sales orders. Of course, the sales orders which are already in the order book consume part of this forecast. Based on the forecast and the sales orders in the order book (+ safety stock), the MRP system calculates exactly when components need to be ordered to be on stock in time. Parts should be in inventory 2 weeks prior to shipping to the customer; this time is needed for production and warehouse activities. The MRP system works with a Demand Time Fence (DTF). Oracles user's manual describes the DRF as follows: *"The demand time fence is bordered by the current date and a date within which the planning process does not consider forecast demand when calculating actual demand. Within the demand time fence, Oracle Master Scheduling/MRP and Supply Chain Planning only consider actual demand. Outside the demand time fence, the planning process considers forecast demand"* (Oracle, 2013). Figure 2-6 provides an example of the current situation with a DTF of 8 weeks. In the SV&E market, the Customer demand is generally only known for 6 weeks. The Advanced Supply Chain Planner (ASCP) sees zero demand after week 6. So using a Demand Time Fence of 8 weeks could result in a serious underestimation of demand.

	Demand Time Fence (8 weeks)								Demantra Forecast									
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Customer	**100**	**100**	**100**	**100**	**100**	**100**	**?**	**?**	?	?	?	?	?	?	?	?	?	?
Forecast	100	200	50	100	70	100	100	100	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
ASCP	**100**	**100**	**100**	**100**	**100**	**100**	**0**	**0**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Production	100	100	100	100	0	0	100	100	100	100	100	100	100	100	100	100	100	100
Supplier	100	100	100	100	0	0	100	100	100	100	100	100	100	100	100	100	100	100

Figure 2-6: ASCP demand translation of customer and forecast demand

The MRP replenishment policy used by Power-Packer Oldenzaal can be described by the so called Periodic review policy with variable order quantities. (**R,s,S** policy). The Review period is 1 week (ordering every Tuesday).

Generally the MRP module (part of the Oracle ERP system) calculates the combined demand of a hole week into one single purchase request. In most of the cases the purchased components have a Minimum Order Quantity (MOQ) and a Fixed Lot size. Due to these Minimum Order Quantities and Fixed Lot sizes it is possible that the on hand inventory level becomes higher than the actual quantities needed.

In short, the inventory level depends completely on the requirements entered in the MRP system, which take into account safety stock, Minimum Order quantities, Fixed Lot Sizes, forecasted demand and actual demand. However, the DTF settings determine which demand (customer or forecast) is used to calculate the demand requirements.

2.3 Current forecasting methods

The unsophisticated forecast method is mainly based on historical sales. The forecast could be updated every month based on information from the customer, which could for example be information about a customer increasing its production due to a big new order. The forecast, with a time horizon of 17 months, provides the number of units per product in a certain month and is mainly based on the history of the previous year. The monthly forecasted demand is sent to the ASCP module. ASCP, which is used by the planning and material purchasing department, divides the forecast into week buckets, which is not optimal as will be illustrated with the following running example:

The monthly forecast is 100 units; ASCP translates this to 25 units per week. If the monthly forecast of 100 units is based on one single customer who always orders 100 units at the same time, this translation into 25 units each week results in unnecessary ordering and handling costs. Besides this, the on hand inventory will be too low to supply the 100 units at the same time (except if the order is placed in the fourth week of course). This issue, caused by a setting in the "Demantra" forecasting module, is not yet solved and is beyond the scope of this thesis.

The responsible person for the SV&E forecast indicated that the overall forecast error is about 20%. Unfortunately this does not provide any information whether the amount was right per SKU! The Forecasted versus the Actual numbers per product are registered, but the validity of these numbers should be questioned. The person responsible for the forecast indicated that these numbers are manually saved and that wrong numbers could have been used in the past. So unfortunately the performance of the forecast cannot be determined and/or validated.

2.4 Conclusion

Chapter 2 gave answer to sub question 1: *"What is the current way of working from order acceptance up to and including shipment within the SV&E market?"*

Currently the Sales Order Processors (SOP) receives single incoming orders by email for the SV&E market and processes them in the ERP system Oracle, promising the customer a lead time of 5 weeks. Planning uses this input to make a production planning for one week. So, the production lead time is one week for all products. The expeditors / material planners run the MRP system which calculates what materials need to be ordered. If all internal lead times are subtracted from the customer lead time, 10 workdays are left for the supplier to deliver the materials. Besides the current way of working, the analysis of the current situation already revealed some serious problems which could harm the On Time Delivery performance:

- The remaining supplier lead time for components which do not have an accurate forecast is only 10 days. This means components which cannot be supplied within 10 working days need to be on stock.
- The current safety stock method only works for items with a smooth demand pattern. A serious availability problem for components with an intermittent demand pattern could be the result.
- The replenishment policy is based on smooth demand patterns and accurate forecasts which are common in the Automotive and Truck market, but not in the SV&E market!
- The Demand Time Fence (DTF) of eight weeks does not suit the sales order book which is filled for a maximum of 6 weeks, this results in a gap of 2 weeks without demand in the DTF.
- Forecasting the SV&E market is a hard task for the Sales department and is currently mainly based on historical sales in a certain period.

These problems seem to be underlying causes of the poor On Time Delivery performance. In Chapter 3 the problem description and identification will elaborate on the main root cause for the On Time Delivery performance and connects the findings of this chapter with that root cause.

KANBAN inventory at Power-Packer

3. Problem description

This section provides the problem description related to the insufficient On Time Delivery performance and high Overdue at Power-Packer Oldenzaal. This description is based on the Managerial Problem Solving Method (MPSM) (Heerkens H. , 2012). In section 3.1 the problem identification is described. Section 3.2 provides the problem diagram which indicates main problem and the underlying causes of this problem. Section 3.3 outlines the core problem and finally section 3.4 describes the involved parties in this main problem.

3.1 Problem identification

This section elaborates on the On Time Delivery Problem and Overdue problem which were briefly mentioned in chapter 1 and 2. Paragraph 3.1.1 elaborates on the performance indicators OTD and Overdue and how they are related. The current situation, which has been discussed in chapter 2 and is further analyzed and outlined in section 3.1.2, is not in line with the desired situation. Therefore, paragraph 3.1.3 provides a short description of the desired situation. And finally paragraph 3.1.4 analyses the major underlying cause of the poor OTD performance. Based on this, the scope of this thesis can be narrowed to the most important issue.

3.1.1 OTD and Overdue

Power-packer uses On Time Delivery and Overdue as their main key performance indicators (KPI’s) for their logistical activities. These KPI’s are imposed by the Parent Company, Actuant. Although both indicators are related to each other, there are some important differences which need to be addressed. The On Time Delivery (OTD) KPI indicates whether an order is ready to be shipped before or on the due date. In most of the cases, products which are ready must be picked up by the customer themselves, which in practice means they need to arrange the transportation to their production plant. If the customer does not pick up the ready products before the due date, the order becomes Overdue. Power-Packer cannot invoice the customer before the order has been shipped. So, Overdue orders are orders which have not been invoiced before the due date. In short, orders get a Not On Time Delivery (NOTD) status if they are not ready before the due date, orders get an Overdue status if the order is not invoiced before the due date.

- The On Time Delivery KPI can be defined as: *All order lines which are produced on time and ready to be shipped from the warehouse before or on the due date specified on the order.*
- The Overdue KPI can be defined as: *All order lines which could not be invoiced before the due date specified on the order (where invoicing is only possible after the products are shipped, unless the payment term is “prepayment”, in this case the customer needs to pay before the products are shipped).*

The Sales Order Processing (SOP) department makes the On Time Delivery (OTD) reports. There are of course multiple reasons why a certain product could not be produced on time, see table 3-1 below for an overview of the Not On Time Delivery (NOTD) categories specified and registered by the SOP department.

HOLDS / QUALITY	Engineering holds, Design related Quality issues, line move quality, part change raw.
CUST_ORDER < LEAD TIME	Customer dropped in EDI orders less than Power Packer lead time.
MFG_CAPACITY	Equipment and/or people related output constraints
MFG_EQUIP	All issues related to Manufacturing equipment, tooling, spare parts shortage, etc.
MFG_QUAL	Manufacturing quality defects, delays, extra inspection, etc.
MAT_SUP_CAPACITY / DELIVERY	Supplier capacity issue constraining their output and causing Power Packer customer NOTD events / Parts are not on time available at Power Packer
MAT_SUP_QUALITY	Supplier quality issue resulting in a late delivery or unusable parts
LOGISTICS_WH	Log issues in WH causing production delay or delay in moving parts to FG

LOGISTICS_EXPEDITION	Log issues resulting in delay of having goods on time at shipping dock
ENGINEERING	Engineering holds, Design related Quality issues, line move quality, part change raw, projects
SOP	OE/update errors, delay SOP release/pick approve, auto Customer feed errors missed, decision not to ship due to consolidated shipments
CUST_CONV_OR_NEW_FG	New part start-up/conversion (including RAW LT/available ,BOM delays, engineering release)
PUR_REQ	Purchase requisition sent to supplier too late
CUST_PAYMENT	Customer is on credit hold or prepayment on shipment

Table 3-1: Not On Time Delivery root cause classification

Section 3.1.4 analyzes the frequency of occurrence in each category. This provides an indication about the major causes of the poor OTD performance were this thesis should focus on.

3.1.2 Current situation

The On Time Delivery performance is currently far below the target of 95%. After analysis of the On Time and Late shipments in the period October 2014 until June 2015, the average On Time Delivery was only X%, see Figure 3-1.

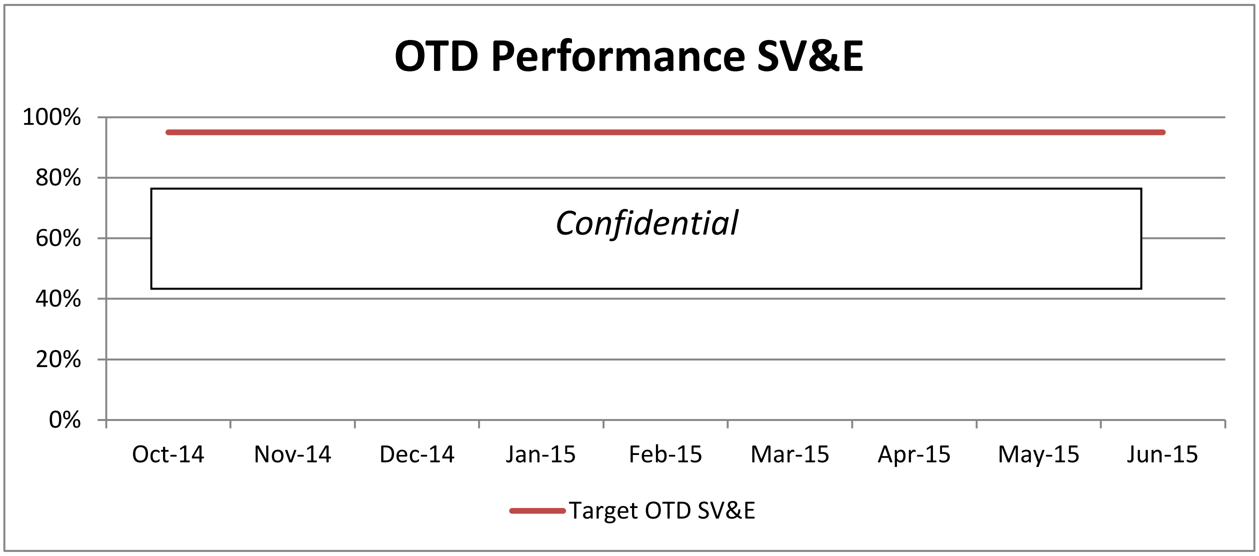


Figure 3-1 Current OTD performance

The average Overdue amount over the period December 2014 until May 2015 was €293,978.61 (fictitious number), see Appendix A. Every time an order is too late, this immediately causes Overdue. But besides late orders, there are also other causes for the Overdue (for example a customer paying too late). Determining all exact proportions of Overdue causes per case would be a very time consuming task because this data is not always available for each Overdue issue and if it is available the format is just a text note. However, as is discussed in section 3.1.1, the Overdue is correlated to the OTD performance, increasing the OTD performance would immediately result in a lower Overdue. A more in-depth analysis of the Overdue can therefore be found in Appendix B and will not be further handled in this thesis.

Currently the parameter settings and procedures to set and maintain these parameters seem to be a major problem. The following running example illustrates a case in which products are not delivered on time because the required items to produce the product were out of stock, although this should not have caused any problems when looking at the parameters in the ERP system.

Running example:

After subtracting all internal lead times from the maximum customer lead time of 5 weeks, there remain 10 days for the external supplier to produce and deliver the parts to Power-Packer (see figure 2-3). In theory this would mean that all components from suppliers with a lead time of 10 days or less can be delivered on time and Power-Packer would not need any stock or safety stock for these components at all (ignoring lead time variability).

Unfortunately, not all lead times in the ERP system seem to be correct. For example, a small sample of components was taken which were identified by the SOP employees as the Not On Time Delivery cause. Surprisingly, several components had a lead time of 10 days[1]! Theoretically these components should not cause any problems! After an interview with one of the Expeditors, it became clear that the lead times in the system were incorrect in some cases. But these are the numbers which the MRP system uses to calculate the order dates! Besides this it was mentioned that the 10 days lead time is no problem if the supplier gets a forecast from Power-Packer, but in the SV&E market the forecast is quite unreliable and in some cases not available at all!

This is just one simple example which shows that the parameters in the ERP system are not correct and could cause On Time Delivery problems. Besides this, there seems to be no procedure to improve and maintain the system parameters. Both the SOP employees and the Expeditors observe these problems, but no one has the responsibility or time to update these incorrect parameters.

3.1.3 Desired situation

In the desired situation each customer is supplied within 5 weeks after the order has been placed, with a target customer service level of 95 percent. In practice this means that 95% of the customer orders must be produced and ready for shipment before the due date. In this situation the inventory settings in Oracle are correct and there are processes and procedures available to maintain these correct settings. Besides this, the communication and conformity between departments should be improved using a Sales Inventory and Operations Planning method. If this can be accomplished, all needed parts are available at the right place, in the right amount and at the right time to start the production on time.

3.1.4 On Time Delivery Analysis

In order to get a clear view about the major causes of the OTD problems within the SV&E market, we conducted a Pareto analysis. This analysis identifies the most frequent causes of the "Not On Time Delivery". The Pareto analysis is based on the OTD data collected by the SOP department in the period July 2014 up to and including May 2015, intercompany transactions were left out.

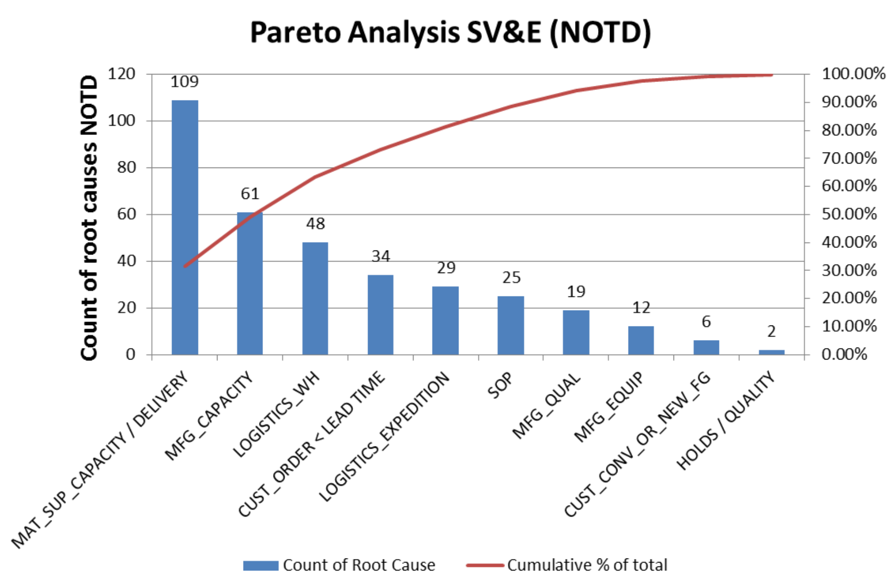


Figure 3-2: Pareto Analysis NOTD causes SV&E

As can be seen in figure 3-2, MAT_SUP_CAPACITY / DELIVERY can be regarded as the major cause of the OTD problems. In 31.5% of the NOTD cases, there is a problem with the on time delivery of materials needed during

[1] As mention in section 1.5, lead times in the system are assumed to be valid and verifying these lead times will not be done in this research

production at Power-Packer. This is equal to 109 MAT_SUP_CAPACITY / DELIVERY issues out of a total of 345 OTD problems in all categories. In the interview with an employee of the SOP department it was mentioned that in this category no distinction is made between a supplier who delivered the materials too late and Power-Packer ordering the materials within the supplier lead time. For example, the customer orders products from Power-Packer with a lead time of 5 weeks, if the supplier lead time of the raw materials exceeds this 5 weeks Power-Packer should have ordered the materials earlier. This immediately underpins and substantiates the problem issued in the introduction of this thesis: If a supplier lead time exceeds the customer lead time and there is no proper stock quantity available, this will immediately result in a Not On Time Delivery (not taking any possible emergency shipments into account).

The second cause, MFG_CAPACITY, is related to the capacity constraint of people and equipment. But as was mentioned in paragraph 1.5, the capacity constraint will be left out of scope. The third cause, LOGISTICS_WH, corresponds to problems in the warehouse of Power-Packer Oldenzaal, for example, Finished Goods arriving in the warehouse must have a status update to FG (Finished Good) in the ERP system before they can be released to the customer. Activities corresponding to the warehouse will also be left out of scope.

As the focus of this thesis will be on the first category, this category will be elaborated in more detail in the following sub paragraph.

MAT_SUP_CAPACITY / DELIVERY by Customer

The Pareto Analysis indicated that on time delivery of materials from suppliers is the major cause for the poor OTD performance towards the customers of Power-Packer. Going one step further in the analysis means the identification of the customers and products which are involved. Each product again consists of multiple components, and one or more of these components causes the delayed production start. An analysis of the products within the MAT_SUP_CAPACITY / DELIVERY category resulted in 75 different products which caused an On Time Delivery problem in the period July 2014 up to and including May 2015. The frequency in which these products caused an OTD problem is partly summarized in figure 3-3 (see Appendix C for the complete overview of the 75 products). The major problem is not caused by the product itself but by one or more of the components within these products, these were not available at the start of the production. Unfortunately, the data about which components caused the delay is incomplete. Therefore the Bill Of Material (BOM) of each of the 75 products will be analyzed in the next sections to identify the current high risk components.

Confidential

Figure 3-3 Products causing NOTD

3.2 Problem diagram

To get a clear inside in the problems and causes of the low OTD performance, we performed an analysis of the most frequent root causes in section 3.1.4. This resulted in the material supply as major cause of the OTD problems. The underlying analysis of the problem diagram (see figure 3-4) can be found in section 3.1.4. By identifying the most frequent cause of the OTD problem, it was possible to narrow the scope of this thesis. The focus of this thesis is on the underlying problems of the material supply indicated in the red rectangle, see figure 3-4.

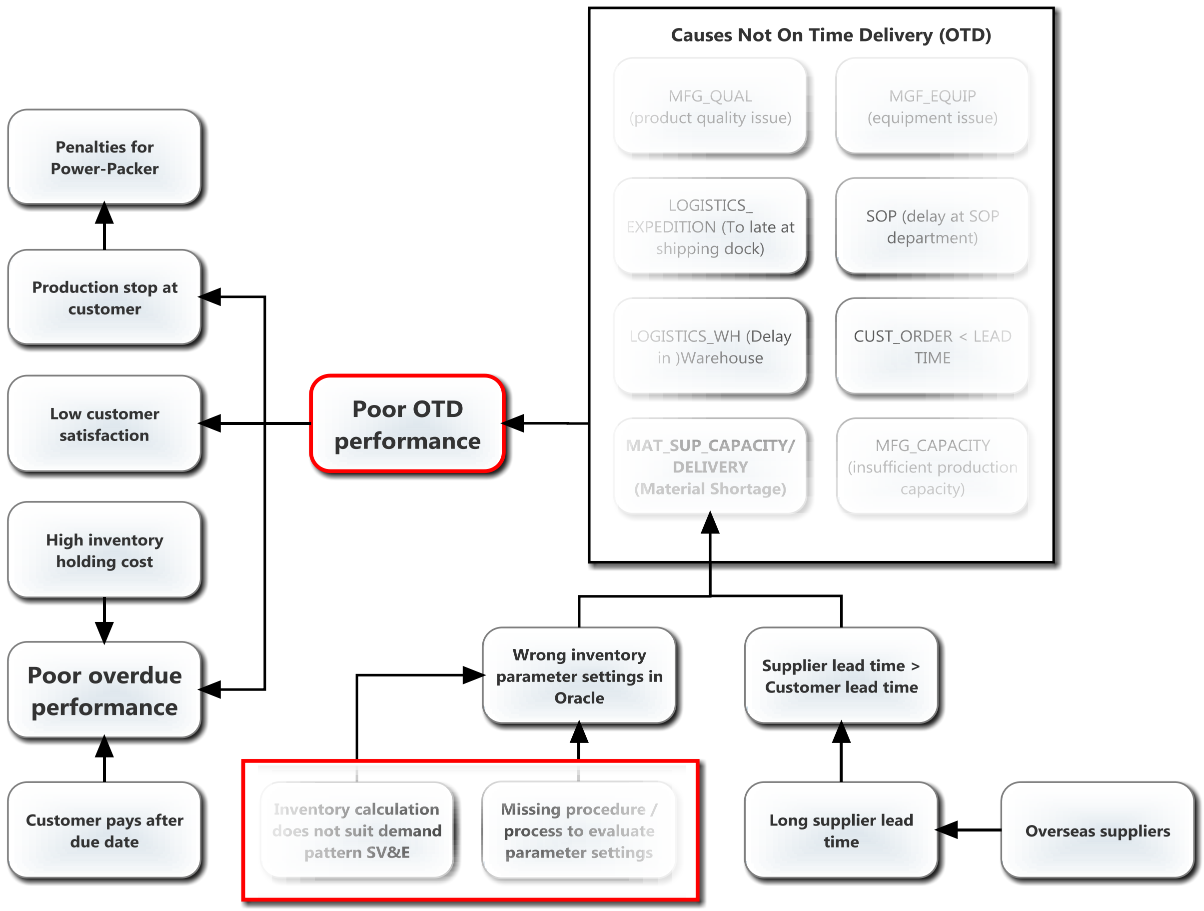


Figure 3-4 Problem Diagram

3.3 Identification of the core problem

The core problem of the insufficient OTD performance in the SV&E market is the material supply, certain parts needed to start production on time are not in stock and finished goods to immediately supply the customer are also not available. But the underlying core problem of the material supply is much more interesting; the current inventory method and parameter settings in Oracle do not support the demand patterns in the SV&E market. The component classification model is unable to distinguish different demand patterns and is designed for components with a smooth demand pattern. Our analysis of the current situation in Chapter 2 revealed problems with the inventory replenishment policy using a DTF of 8 weeks and as the running example in section 2.2.1 shows, the safety stock calculation is not suitable for intermittent demand patterns. Together with the forecast method described in section 2.3 this result in serious material shortages. Besides this, the running example in section 3.1.1

shows that there is no incentive or possibility to discuss shortcomings in these inventory parameter settings during a structured meeting.

3.4 Involved parties

This part briefly describes which parties are involved in the problem and from which parties this subject needs support to become a success, section 2.1 already gave a small introduction how these departments are connected.

Involved departments

- **Sales Order Processing (SOP):** is responsible for processing of the incoming orders and the OTD registration. Based on this registration it was possible to identify the major cause of the OTD performance problem.
- **Expeditors:** All orders which seem to become a problem will require a big effort of the expeditors. They need to arrange the materials on time, in the hope this is still possible. The current parameter settings and uncertain demand make it a very challenging task.
- **Logistical Support Engineers (LSE):** These employees are, among other things, responsible for the correct settings in Oracle. Adjusting parameters like safety stock and reporting to the logistical manager about current inventory status are just two examples of responsibilities which are closely related to this thesis.
- **Sales department:** the sales department is responsible for the forecast on which the logistics department depends a lot. An accurate forecast with a long planning horizon makes the logistical tasks much easier. Besides this, the sales department has a better understanding of upcoming changes in demand.
- **Planners:** Currently the planners look if all materials are available to start production. In most of the cases they register which components are not available, but unfortunately the procedure to register these components is not strictly defined.
- **Higher management:** Implementation of new processes and procedures requires support from higher management. However, higher management initiated this thesis and its subject, so no problems in this aspect are expected.

3.5 Conclusion

In this chapter we gave answer to sub question 2: “What are the underlying main problems that cause the poor OTD and Overdue performance in the SV&E market?”

First we outlined the relation between the two Key Performance Indicators (KPI’s) On Time Delivery and Overdue. An order is not On Time Delivered when it is *not ready* to be shipped on or before the due date. It becomes overdue when the order is not actually shipped and invoiced on or before the due date. Because the underlying causes are nearly the same for both KPI’s, the report focusses on OTD performance. Our analysis of the current performance revealed an average On Time Delivery of 60% (fictitious number) instead of the target of 95%.

The Pareto analysis revealed that the main problem causing this poor OTD performance is the “Material Supply”, material shortages on component level inhibit the production start of certain products. 31.5% of the On Time Delivery problems are caused by material shortages, corresponding to 75 different products which were not delivered on time in the period July 2014 up to and including May 2015. The underlying problems for these material shortages were already partly uncovered in Chapter 2; the current inventory management system and the corresponding parameter settings do not fit the demand pattern in the SV&E market. Both the inventory replenishment policy and safety stock calculations are based on smooth demand patterns, the current component classification method is unable to distinguish the different demand patterns, which should make it possible to take appropriate actions. Besides this there are no processes or procedures to discuss and review shortcomings in these inventory parameter settings during a structured meeting.

4. Literature Study

In this chapter we provide our literature study. In section 4.1 we describe the MRP approach and the importance of correct MRP parameter settings in an environment with uncertain demand and lead times. This uncertain demand is reflected in the different demand patterns of the components used in SV&E Products. To distinguish between these demand patterns a component demand pattern classification must be set up and suitable inventory replenishment methods must be found, see section 4.2. Section 4.3 elaborates on the Sales Inventory and Operations Planning (SIOP) method which will be implemented at Power-Packer to gain better insides in the current processes and cooperation between departments.

The articles used originate from Scopus and were found using the following keywords: “MRP” and “Uncertain demand”. To limit and improve the search results, both forward and backward search were used to elaborate on certain topics like “safety stock”. The literature search methodology for demand patterns and inventory replenishment policies can be found in appendix D.

4.1 MRP and corresponding system parameters

There are many ERP systems with inventory control systems which are based on the Materials Requirements Planning (MRP) approach. The MRP logic provides optimal just-in-time material requirement schedules. This method works fine in deterministic environments with predictable material requirements. In a stochastic environment however, this method needs some proper parameterization (Dolgui & Prodhon, 2007). Although these parameters could improve the MRP planning and reduce the random factors in a stochastic environment, other improvement methods for uncertain supply chain planning must not be neglected (Maloni, 1997).

4.1.1 MRP Approach

In essence the MRP approach is really straightforward; the goals is to determine a replenishment schedule for a given time horizon, based on the Bill Of Materials (BOM) and demand in that particular horizon. If a product can be assembled directly from several items, the product is said to be one-level with multi-items. In some cases an item consists of two or more sub-items, in this case we have a multi-level with multi-items product, see figure 4-1 (Dolgui & Prodhon, 2007). Of course, it is possible that the same items are used in several products. This makes the MRP calculation more complex, but the use of an ERP system with an MRP inventory control system solves this complexity.

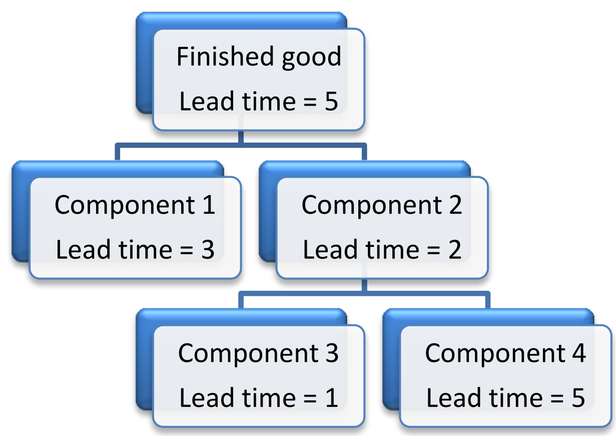


Figure 4-1: Bill Of Material (BOM)

An MRP system becomes complex when operating under uncertainties. The input data is not deterministic in most of the cases, but subject to uncertain and unpredictable events. Actual demand quantities are uncertain and lead times can change due to many external factors like the weather, quality issues or capacity constraints of the supplier. To buffer for these quantity and time uncertainties extra buffer parameters are needed, see section 4.1.3.

4.1.2 Oracle MRP inventory support

Oracle Corporation is an American corporation who develops database software and ERP systems. The variety in software applications is huge, all with their own range of possibilities. As mentioned in section 2.1.2 Power-Packer Oldenzaal currently uses an Oracle ERP system. This ERP system incorporates a MRP module which calculates the required materials based on forecast and sales orders. Chapter 2.2 dealt with different types of safety stock settings (MRP-Planned and Non-MRP Planned). Non-MRP planned safety stocks are defined by the user and are fixed. With the MRP-Planned safety stock determination, Oracle will calculate a dynamic safety stock quantity based on the forecast. This can be based on a user-defined percentage (see section 2.2.2) or on the Mean Absolute Deviation method MAD. A comprehensive description of the Mean Absolute Deviation method will follow in section 4.1.4. In essence the Oracle ERP system supports four inventory planning methods: (1) Not planned (which is equal to MRP planning), (2) Reorder point planning, (3) MIN-MAX planning and (4) Vendor Managed. For further details see the Oracle documentation (Oracle Applications, 2015).

4.1.3 Parameter settings in an MRP system

To adjust for uncertainties, the MRP system can be extended by setting some extra parameters. These parameters should soften the impact of the uncertain events. The most frequently used parameters are:

1. **Safety stock.**
2. Safety lead time
3. Lot-sizing rules
4. Freezing the MPS
5. Planning horizon

The remaining literature will focus on safety stock as uncertainty buffer because the others are less suitable due to the long lead time components. For example, increasing the planning horizon will not add any value because the forecast and sales orders in the SV&E market have a maximum time span of 2 months, while components have lead times which exceed this time span. Adding safety lead time will only increase the long lead times and the forecast and sales orders stay unknown in this period. Freezing the MPS would lead to even less flexibility which is currently is already a problem due to the long supplier led times compared to the promised customer lead time.

Safety stock

Safety stock is nothing more than adding extra inventory to be able to absorb unexpected demand. So it reduces the risk of being out of stock, but on the other hand increases the inventory holding costs. The goal is to minimize inventory holding cost, given a certain service level. The basic safety stock needed to attain this service level is calculated by the standard deviation in demand times a safety factor k, this is a statistical number which depends on the target service level, see table 4-1 for an overview of the safety factors[2]. The safety factor used can also be adjusted per product, for example, items with a strategic importance or high profit margin could be provided with a higher safety factor. Those items will have a lower change of stock out, due to the higher safety stock. Equation 1 is used to calculate the safety stock when a periodic review policy is used:

Target Service Level	Safety factor k
84.0%	1
85.0%	1.04
90.0%	1.28
95.0%	1.65
97.0%	1.88
98.0%	2.05
99.0%	2.33
99.9%	3.09

Table 4-1: Safety factor at a certain service level

$$\boldsymbol{safety\ stock = k * \sqrt{L + R} * \sigma_D} \qquad \textbf{(Eq. 1)}$$

$k = Safety\ factor\ (from\ table)$
$L = Total\ Lead\ time$
$R = Review\ Period$
$\sigma_D = Standard\ deviation\ of\ demand$

With this formula only the demand variability has been taken into account. When the demand variability (σ_D) is negligibly small and lead time variability is the main concern, the safety stock calculation is equal to equation 2.

[2] The safety factor k corresponds to the Normal distribution. So the calculation of safety stock using this safety factor k assumes a normal demand distribution.

$$\boldsymbol{safety\ stock = k * D_{avg} * \ \sigma_{L+R}} \quad \textbf{(Eq. 2)}$$

σ_{L+R} $= Standard\ deviation\ of\ lead\ time + review\ period$
D_{avg} $= Average\ demand$

If the demand and lead time variability are independently identically distributed (assuming normal distribution) the combined safety stock equation is equal to equation 3.

$$\boldsymbol{safety\ stock = Z * \sqrt{\left((L+R) * \sigma_D^2\right) + \left(\sigma_{L+R} * D_{avg}\right)^2}} \quad \textbf{(Eq. 3)}$$

4.1.4 Safety stock calculation using Mean Absolute Deviation (MAD)

To test how accurate the forecast method has been, one could use the Mean Absolute Deviation. The MAD compares actual demand with the forecasted quantity in that certain period to get the forecast error. The difference is always an absolute number. Finally it calculates the mean of the absolute forecast errors over a certain number of periods (N). This can be formulated as equation 5:

$$MAD = \frac{1}{N}\sum|Forecast - Actual\ demand| \quad \textbf{(Eq. 5)}$$

To be useful as standard deviation in the safety stock calculation, which assumes the Normal distribution, the MAD can be converted to the standard deviation of forecast error by multiplying the MAD by 1.25 (Silver, Pyke, & Peterson, 1998). Substitution into equation 3 will yield equation 6:

$$\boldsymbol{safety\ stock = Z * \sqrt{\left((L+R) * (1.25 * MAD)^2\right) + \left(\sigma_{L+R} * D_{avg}\right)^2}} \quad \textbf{(Eq. 6)}$$

The following can be concluded from equation 6: to reducing the required safety stock one must improve the forecast accuracy, reduce the lead time, review period, lead time variability or service level.

4.2 Demand pattern and inventory model classification

As just discussed in section 4.1.1, the MRP inventory replenishment policy works optimal for known deterministic demand. Although Power-Packer works in an MRP environment, this inventory replenishment policy could not be optimal for all items. The right choice of replenishment policies in an MRP environment are discussed by Hautaniemi *et al (1999).* Before the right replenishment policy can be determined, a component classification should be made which takes into account component value, lead time and the demand pattern of the component (Hautaniemi, 1999). In an Assemble-To-Order (ATO) environment, as is the case for Power-Packer, the final assembly schedule is known only a few weeks in advance, which causes a problem for the MRP system. The demand input for the MRP system is too late to order the long lead time components. Therefore an optimization of the forecast should be one of the main concerns while dealing with uncertain demands. Some companies shifted from MRP systems to Reorder Point (ROP) systems. Axsater and Rosling (1994), however, presented how different ROP policies could be imitated with MRP, but they also indicated that in some practical situations a simple reorder point could be advantageous because of lower administrative costs (Axsater & Rosling, 1994). Besides the long lead time, a relatively low-production volume, a varying demand and zero-demand periods on component level add problems to the effective use of MRP managed inventory.

To keep de classification of components simple and understandable, three main criteria would be used: Value of usage, supplier lead time and demand distribution pattern, see figure 4-2. The simplest analysis used to classify components based on usage value is the ABC-Analysis, as currently used by Power-Packer and described in section

2.2.1. However, in the classification method of Hautaniemi *et al only A- and C-classes are used.* C-items are low value and should always be available and managing these items should be based on simple methods. Because A-items are much more valuable, a proper balance between service level and low inventory holding cost should be attaint.

The second step is the isolation of components with a supplier lead time shorter than the final assembly schedule (Group II). Inventory management of these components can be based purely on customer orders and MRP, because these components can be order after the customer order and still be on time for the final assembly of the product. Only the supplier lead time uncertainty should be buffered in this case.

Third the components demand distribution should be classified. Hautaniemi *et al* use three classes: singular, lumpy and continuous demand.

Group III: Singular: "Demand now and then, usually one unit per order (Poisson distributed)"
Group IV: Lumpy: "Demand occurs now and then, but in batches of variable sizes (unknown distribution)"
Group V: Continuous: "Demand is relatively continuous (Normal distribution)"

Group III components are difficult to manage using MRP. Jacobs and Whybark (1992) found that ROP method performs better and with less effort than the MRP method for components with significant forecast errors. The replenishment quantity could be based on the EOQ-model is this case. It should be noted however that the EOQ model assumes a constant demand over the year and that there is a fixed cost for every order placed, regardless of the quantity ordered.

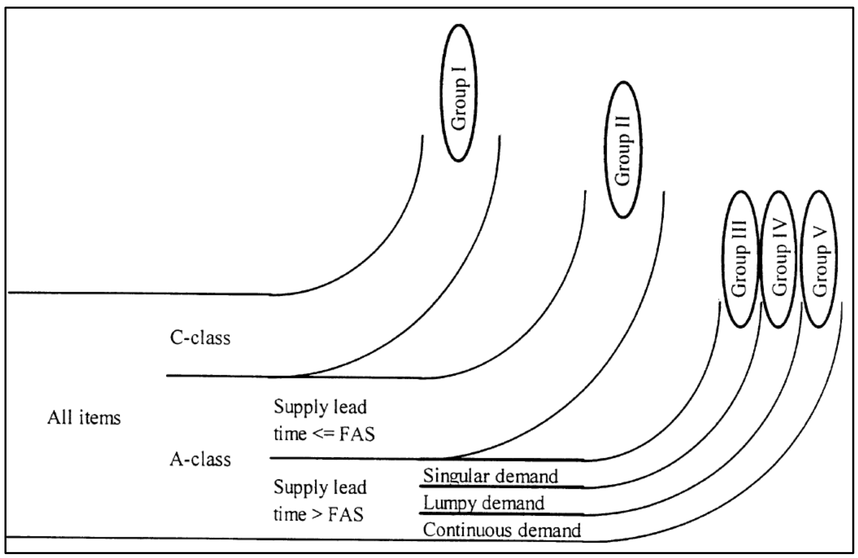


Figure 4-2: Classification procedure (Hautaniemi, 1999)

Group IV is the most difficult to manage. Increasing the lead time to the customer to be longer than the supplier lead time would move these items into Group II. But this is undesirable for the customer satisfaction performance.

Group V components can easily managed by MRP based on the sales forecast. Some safety stock must be implemented to cover for small uncertainties in demand.

The classification of demand patterns was later also studied by Syntetos *et al* (2005). Their classification method will be described in section 4.1.4.

Although the classification of SKU's gives some guidance in the selection of an appropriate inventory replenishment model, the intermittent, singular, erratic and lumpy demand patterns are still classified as troublesome. In the literature these demand patterns are commonly referred to as intermittent demand patterns. A recent study evaluated commonly used forecasting and replenishment methods to manage components which are characterized by intermittent demand. The result of this extensive study revealed that no combination of forecasting and replenishment methods consistently outperformed the others. The only way to prevent a shortage was by placing demanded units an average of 10 weeks before the inventory was required (Mitchell & Niederhausen, 2010). Besides this, the research focused on replenishing intermittent demand components with relatively short lead times, the extension to components with long lead times would probably result in even more inventory to cover for the uncertain demand pattern.

4.2.1 Demand pattern classification

In the literature a great deal is written about forecasting methods, but a lot less about how to deal with forecast error in combination with the determination of safety stock quantities to protect against uncertainties. When demand is stable, apart from the normal variability which is always present, complex forecasting methods are unnecessary. To identify whether and how a SKU can be forecasted easily using a forecasting process, one could use the Coefficient of Variation (Mant, 2001).

$$Coefficient\ of\ Variation\ (CV) = \frac{Standard\ Deviation}{Mean} \qquad \textbf{(Eq. 4)}$$

The CV indicates what kind of demand pattern we are dealing with, see figure 4-3 for the different demand patterns and the corresponding CV. If the CV is very low, as with product A, exponential smoothing could for example be an easy and simple forecasting technique. Product B, with a high CV, shows an intermittent demand pattern, with occasional high demands compared to the regular demand quantities. Product C has a CV which is even greater than its mean. The Poisson distribution could be helpful in this case ($\boldsymbol{\sigma^2} = average\ demand$). Also product D has a high CV but the demand pattern looks much different compared to product C. The intervals between demands are typical for a seasonal product.

	A	B	C	D	E
1	Patterns of Demand				
2			Product Demands		
3	Period	A	B	C	D
4	-1	500	40	0	0
5	-2	510	55	0	0
6	-3	485	180	0	500
7	-4	490	29	2	600
8	-5	520	65	0	550
9	-6	510	70	1	400
10	-7	515	300	0	200
11	-8	488	80	1	0
12	-9	495	200	0	0
13	-10	503	60	0	0
14	Average	501.60	107.90	0.40	225.00
15	Std. Dev	11.41	84.00	0.66	246.22
16	Coefficient	0.02	0.78	1.66	1.09

Figure 4-3 Different demand patterns

To distinguish between overall demand variability and demand peaks which are followed by periods of zero or low demand, Syntetos *et al* (2005) proposed a categorizing scheme which divides demand patterns into smooth, erratic, intermittent or lumpy. The categorization is based on the average inter-demand interval (ADI), measured in the same time units as the review period (weeks) and the squared coefficient of variation (CV^2) (Syntetos, 2005):

- Smooth demand: ADI ≤ 1.32, $CV^2 \leq 0.49$ *Demand pattern is quite stable in all periods (fast moving parts)*
- Erratic demand: ADI ≤ 1.32, $CV^2 > 0.49$ *Irregular demand pattern with frequent demand occurrences*
- Intermittent demand: ADI > 1.32, $CV^2 \leq 0.49$ *Demand pattern with quite constant demand, but relatively many zero demand periods*
- Lumpy demand: ADI > 1.32, $CV^2 > 0.49$ *Demand with great differences between demand quantities and many periods with zero demand*

When calculating the squared coefficient of variation, only the non-zero demand periods are taken into account.

4.2.2 Forecasting methods for intermittent demand

The goal of the suggested demand pattern categorization method by Syntetos *et al* (2005) was to determine which forecasting method works best for a certain demand pattern. Before Syntetos *et al (2005)* defined their fixed cut off values (the average inter-demand interval and the squared coefficient of variation), Johnston and Boylan (1996) compared the well-known "Single Exponential Smoothing" (SES) method with Croston's method. The simulation results indicated that Croston's method performed better for demand patterns with an inter-demand interval greater than 1.25 forecast review periods. Croston (1972) developed a forecasting method which is currently regarded as the standard method to forecast intermittent demand. This method is currently widely used in forecasting software packages (Syntetos, 2005). Since the introduction of Croston's method, several articles were published which showed that Croston's method was biased and proposed some adjustments. Syntetos (2001) proposed an exactly unbiased modification of Croston's method, the SY method. Syntetos *et al* (2005) made an extension of this study and came up with an improvement of Croston's method, the Syntetos–Boylan Approximation (SBA). Finally they were able to determine cut-off values to determine which forecasting method performs best in combination with a certain demand pattern. These cut-off values were given in the previous section and are depicted in figure 4-4 together with the best performing forecasting method associated with these cut-off values. One of the latest developments in forecasting intermittent demand is the proposal by Teunter *et all* (2011), who suggested a forecasting procedure called TSB. This method has been tested on accuracy together with the Croston's method, SBA method, SY method and de SES method. Unfortunately the two data sets used led to different and sometimes opposite findings in relation to forecast accuracy and inventory performance, so no direct conclusion could be given which forecast method should be used (ZiedBabai , Syntetos, & Teunter, 2014). This research revealed that there is a need for more empirical testing of forecasting methods for intermittent demand. To gain some inside in the different intermittent demand forecasting methods currently mentioned in the literature, the next paragraph will explain Croston's method, for an extensive explanation of the others I refer to the articles mention above.

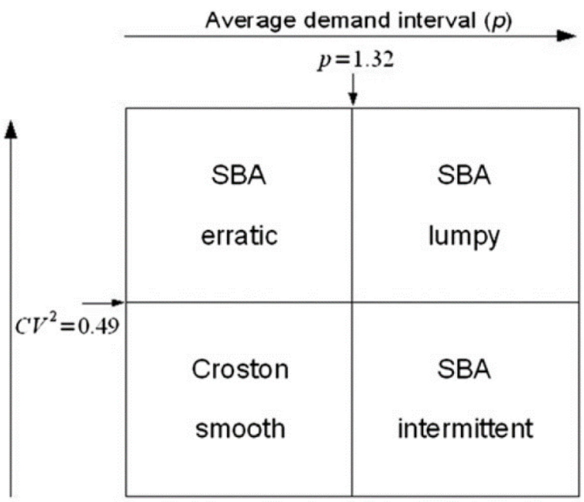


Figure 4-4 Classification according to Syntetos et al. 2005

Just as the lack of research conducted in the area of the forecast accuracy of different intermittent forecasting methods, the research area of demand classification for forecasting and stock control has not received sufficient attention in the academic literature. Mainly the implication on stock control policies would be an interesting research area. Finally extending the classification by other relevant criteria, like part value and criticality, would increase the attractiveness and practical usage (Heinecke, Syntetos, & Wang, 2013).

Croston's forecasting method

This section elaborates mathematically on the Croston's forecasting method for intermittent demand. The mathematical expressions of the other forecasting methods based on Croston can be found in Appendix E. The notation is based on the work of Teunter & Sani (2009) and will also be used in section 4.2.3:

μ = mean demand size per period (weeks)
$\mu f_{L,t}$ $= forecast\ for\ total\ lead\ time\ demand\ after\ period\ t$
σ^2 $= variance\ of\ the\ demand\ size$

$p \quad = mean\ demand\ interval, i.e. number\ of\ period\ between\ successive\ demands$
$z_t \quad = demand\ size\ in\ period\ t$
$p_t \quad = demand\ interval\ between\ the\ demand\ in\ period\ t\ and\ the\ previous\ demand$
$d_t \quad = demand\ in\ period\ t$
$zf_t \quad = demand\ size\ forecast\ after\ period\ t$
$pf_t \quad = demand\ interval\ forecast\ after\ period\ t$
$df_t \quad = demand\ forecast\ after\ period\ t$
$MAD_t \quad = forecast\ for\ the\ Mean\ Absolute\ Deviation\ of\ the\ demand\ size\ forescast\ after\ period\ t$
$L \quad = lead\ time\ (number\ of\ periods)$
$\epsilon_t \quad = forecast\ error\ for\ total\ lead\ time\ demand\ for\ the\ order\ triggered\ in\ period\ t$
$\sigma^2_{L,t} \quad = variance\ of\ forecast\ error\ for\ total\ lead\ time\ demand\ after\ period\ t$
$\alpha \quad = smoothing\ parameter, smoothens\ impact\ of\ new\ demand\ size\ and\ demand\ interval$

Croston's forecast relies on the interval between consecutive demands and the size of these demands. What differs from the Single Exponential Smoothing (SES) method is that Croston only updates the estimates if a positive demand occurs. Not taking the zero demand periods into account should be better while forecasting intermittent demand. Croston's method can mathematically be described as follows:

$$demand\ size\ forecast\ after\ period\ t: \qquad if\ d_t > 0\ then\ zf_t = \alpha z_t + (1-\alpha) zf_{t-1}$$

$$demand\ interval\ forecast\ after\ period\ t: \qquad if\ d_t > 0\ then\ pf_t = \alpha p_t + (1-\alpha) pf_{t-1}$$

$$forecast\ of\ demand\ per\ period\ after\ t: \qquad df_t = zf_t / pf_t$$

Croston's forecasting method is based on the following assumptions (Croston, 1972):

1. The distribution of the nonzero demand sizes are independent and identically distributed (i.i.d) Normal.
2. The distribution of the inter arrival times are independent and identically distributed (i.i.d) Geometric.
3. Demand sizes and inter arrival times are mutually independent.

Assumptions 1 and 2 cannot be correct because assuming the distributions to be i.i.d. would result in using the mean as the forecast and not the Single Exponential Smoothing method. According to the paper of Shenstone & Hyndman, models which use Croston's forecasting method should be based on the assumption that the process is non-stationary, auto-correlated and has a continuous sample space including negative values. Taking these assumptions into account, the Croston method would not suite a process to model intermittent demand. However, many empirical analyses support the use of Croston's method for forecasting intermittent demand and Shenston & Hyndman were not able to come up with a unique underlying model which suits the assumptions (Shenstone & Hyndman, 2005).

4.2.3 Inventory policy for intermittent demand

The order-up-to level inventory control policy is currently the most commonly used inventory policy for intermittent demand (Teunter & Sani, 2009). Teunter & Sani produced a paper to calculate order-up-to levels for products with intermittent demand. In this paper, Croston's forecasting method is used to determine future demand, these Croston forecasts need to be transformed into an expected total lead time demand which can be used to calculate the order-up-to levels. Besides this an estimate for the forecast error is needed. This expected value and the forecast error are used to determine the inventory control parameters.

Based on the Croston demand size forecast (zf_t) and the demand interval forecast (pf_t) the forecast of demand per period after period t is equal to $df_t = \frac{zf_t}{pf_t}$.

The forecast error, measured as the Mean Absolute Deviation (MAD) is also updated each period:
$MAD_t = \alpha|z_t - zf_t| + (1-\alpha)MAD_{t-1}$.

The estimated total lead time demand is equal to:
$\mu f_{L+T,t} = zf_t + L * df_t$

The complex part for the calculation of the order-up-to level is the standard deviation of the forecast error for total lead time demand, which is part of the safety stock calculation: $k * \sigma_{L,t}$ (with k as the inverse of the standard normal distribution at a certain service level, this service level is the expected probability of not hitting a stock-out). It is assumed that a demand occurs at time t, the forecast error for demand during lead time, starting at time t, is than expressed as follows[3]:

$$\epsilon_t = z_t + \sum_{k=1}^{L} d_{t+k} - \mu f_{L,t-1}$$

$$\epsilon_t = z_t + \sum_{k=1}^{L} d_{t+k} - zf_{t-1} - L * df_{t-1}$$

The problem is that the latter terms zf_{t-1} and $L * df_{t-1}$ are correlated. So finally the variance of the forecast error becomes quite a complex equation, the mathematics and assumptions behind this equation can be found in the paper by Teunter & Sani (2009). The following expression is based on a periodic review policy, because it is only updated after a demand has occurred in a certain week, but the review period is covered by z_t as mentioned in footnote 3. The expression for the variance of the forecast error for total lead time demand is expressed as follows:

$$\sigma_{L,t}^2 \approx \frac{2\beta^2}{2-\alpha} + L\left(zf_t^2 * \frac{1}{pf_t}\left(1-\frac{1}{pf_t}\right) + \frac{\beta^2}{pf_t} + \left(\frac{(2+\alpha)}{2-\alpha}\frac{(\beta)^2}{pf_t}\right)\right) + L^2 * \left(\frac{\alpha}{2-\alpha}\right) * \left(\frac{pf_t - 1}{pf_t^3} * \left(zf_t^2 + \frac{\alpha}{(2-\alpha)} * \beta^2\right) + \frac{\beta^2}{pf_t}\right)$$

With $\beta = 1.25 MAD_t \sqrt{1 - \frac{\alpha}{2}}$

The order-up-to level S is calculated by: $S = \mu f_{L,t} + k\sigma_{L,t}$.

If the inventory position (on hand – backorders + on order) is less than the order-up-to level, the difference is ordered. This is actually the same as the MRP system works at Power-Packer. The only difference is that the demand forecasts for the upcoming periods are not calculated using Croston, but by the forecast based on historical sales. Besides this the safety stock calculation is not based on the forecast error, but on the safety stock method described in chapter 2.

The results of the order-up-to inventory policy described above are quite close to the target service level. However, there still is significant room for improvement. Especially with regard to the normality assumption for total lead time demand. The normality distribution often provides a poor fit (Teunter & Sani, 2009). In the paper of Teunter, Syntetos & Babai (2010) which also deals with intermittent demand patterns, lead time demand is modelled as a compound binomial process. Although it performs better on the data set they are using, they

[3] The review period R is covered by z_t in the equation. This value is equal to the demand in period t.

assume that the first two moments are available to be able to estimate the complete demand size distribution. In practice it is impossible to estimate the complete demand size distribution. Since all the distribution parameters need to be estimated by the generated Croston updates, the inventory model becomes extremely complex. We should keep practicality and simplicity in mind as well (Teunter & Sani, 2009).

4.3 Sales Inventory & Operations Planning (SIOP)

This section describes the Sales (Inventory) & Operations Planning process. In the literature Sales Inventory & Operations Planning (SIOP) and Sales & Operations Planning (S&OP) are sometimes used interchangeably. The scientific literature about this process is accessed via Scopus using the search terms “Sales and Operations Planning” and its abbreviation S&OP and “Sales Inventory and Operations Planning” and its abbreviation (SIOP). Because the S&OP / SIOP process is also implemented under the guidance of consultancy firms, their expertise is also written down in this section to get a more practical insight in the S&OP / SIOP process.

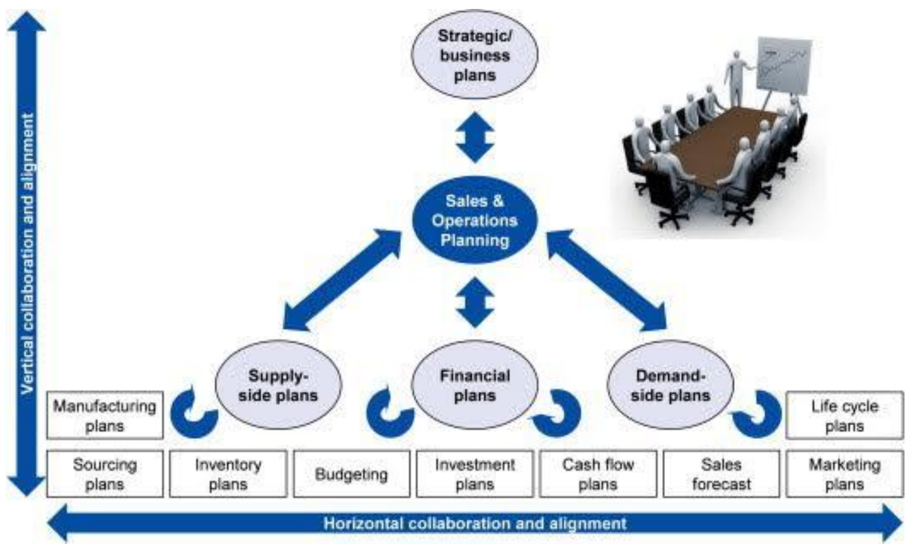


Figure 4-6: Alignment of plans through S&OP

The Sales Inventory & Operations Planning (SIOP) is a business process which adds the role of inventories to the traditional Sales & Operations Planning (S&OP). S&OP has traditionally been referred to as a decision-making process for balancing demand and supply at the aggregate level. Over the years the usage of the term S&OP broadened to operations at a detailed level for individual products and customer orders (T. F. Wallace, 2008). Therefore, T.F. Wallace uses the term “Executive S&OP” for planning at the aggregate level and the term S&OP for the overall planning process which includes the detailed level. To increase the confusion even more, the term Sales Inventory & Operations Planning (SIOP) is also used for the detailed planning level. This causes confusion which needs to be clarified. For Sales & Operations Planning at the aggregate level the term Executive S&OP will be used in the remainder of this text. For Sales & Operations Planning at the detailed level, the term S&OP or SIOP will be used, see figure 4-5.

Aggregate Level (strategic)	Detailed level (tactical / operational)
• Executive S&OP	• Sales and Operations planning (S&OP) • Sales Inventory & Operations Planning (SIOP)

Figure 4-5: Terminology usage Executive S&OP, S&OP, SIOP

S&OP is an ongoing process in which on a monthly basis the planning is reviewed and evaluated. All key stakeholders are involved to generate one profit maximizing plan. By reviewing and evaluating the demand and supply, early warning signals can be send when the demand and supply plan becomes imbalanced. Figure 4-5 illustrates the vertical and horizontal alignment of the various plans from different key areas (Wagner, Ullrich, & Transchel, 2014).

The classical model of Executive S&OP, which takes into account a long time span, starts with demand planning and based on this demand planning a supply planning is made. The classical model of Executive S&OP is just a very flexible guideline, therefore the sophistication used to plan demand and supply varies a lot among different companies. The use of statistical software and forecast accuracy measurement in demand planning is not fully embraced at many companies. However, the biggest deficiency in supply planning is that companies do not take customers service levels into account. To account for uncertainties in demand while attaining a certain target service level, inventories become a very important part of the Sales & Operations Planning (Valentine, 2012). This more detailed approach, which takes into account short term decisions, in the supply chain will be covered by the Sales Inventory and Operations Planning (SIOP).

Calculations of safety stock are in many cases just calculated using simple “rules-of-thumb”, for example 5 days demand as safety stock. These approaches are really simple to implement but neglect the target service level. Calculation of inventory levels based on the required service level allows optimizing inventory levels and corresponding optimized capital investments.

Products with a stable demand, for example products in their maturity phase, do not need to cover many uncertainties. Employing simple statistical forecast software should give a good indication of future demand. Accounting for uncertainties however is much more complicated. The calculation of optimized inventory levels based on customer service levels is not an option in most ERP systems. The combination of inventory optimization algorithms and the Executive Sales & Operations Process could address the gap in supply planning. The major challenge is to select the appropriate inventory optimization model for products with many different demand patterns and uncertainties.

To create a robust and ongoing SIOP process, structured and regular actions should be taken. Weekly or monthly meetings with pre-defined deliverables and action plans will ensure continuous improvement of the SIOP process. Key areas like Sales, Finance, Operations, Customers and Suppliers must be integrated in the SIOP process. Table 4-2 represents the key deliverables per department on which the SIOP process runs. It specifies the process steps,

Process Step	Participants	Input	Output	Why do this?
Step 1 Run Sales Forecast Reports	❖Demand Planners ❖Product Managers	❖Demand history by SKU	❖Statistical model for next rolling period based upon history	❖Create the statistical baseline for consensus building of the demand plan
Step 2	❖Demand Planners ❖Sales Manager	❖Statistical demand plan based upon history	❖Unconstrained Demand Plan based upon consensus of the team	❖Determines the unit requirements by month by product family.
Demand Planning Phase	❖Business Unit Manager ❖Marketing Manager	❖Demand Drivers that will impact projected demand	❖Chart history & Forecast for visual trend assessment	❖Document assumptions and plan to achieve forecast by family
	❖Supply Manager ❖Product Managers	❖Assumptions	❖Address trend discrepancies	❖Assigns ownership of actions required to deliver demand plan
			❖Document assumptions impacting Demand Drivers	
Step 3	❖Supply Manager ❖Purchasing Manager	❖Forecast demand units and inventory	❖Inventory targets for future planning periods	❖Projects production requirements which will drive RM requirements.
Supply Planning Phase	❖Materials Manager ❖Manufacturing Manager	❖Production capacity plans	❖Production requirements to reach inventory target	❖Projects capacity constraints and actions
	❖Engineering Manager		❖Capacity constraints and action plans to address ❖Assumptions	
Step 4	❖Supply Manager ❖Purchasing Manager	❖Resulting Demand and Supply Plan	❖Consensus plan for Demand and Supply for the next period	❖Produces ONE plan for the team to work on
Partnership Meeting	❖Operations Planning Manager ❖Manufacturing Manager	❖Inventory projections	❖Projected revenue	❖Summarizes key issues for the Executive level complete with action/owners
	❖Sales Manager ❖Finance Manager	❖Gaps to meet unconstrained Demand Plan	❖Key assumptions	❖Results in a Financial rollup for revenue and P&L projections
		❖Assumptions ❖Units and Sales Prices	❖Gaps to Annual Forecast number ❖Key actions addressing gaps	
Step 5	❖Execs (CEO, CFO, VP/GM)	❖Financial roll based upon consensus plan	❖Agreement on rolled Plan (may include adjustments)	❖Produces ONE plan for the team to work on
Executive S&OP Meeting	❖Business Unit Manager ❖Operations Manager	❖Key Assumptions		❖Provides the business outlook by Business Unit
	❖Operations Planning Manager ❖Finance Manager	❖Gaps summarized from Annual Forecast ❖Plan to address gaps		❖Rolls up to Corporate outlook which can be used for quarterly stock analysts meetings.

4-2: SIOP process steps, participants, inputs and outputs (Pragmatek, SI&OP – Your Navigation Plan for Success, 2014)

participants, inputs and outputs of the meetings and why this should be done (Pragmatek, 2014). As mentioned before, there are no strict guidelines how a meeting should be structured. The special needs vary per company.

4.4 Conclusion

This chapter answered sub question 3: *"Based on the literature, how can a Sales Inventory & Operations Planning (SIOP) process improve the On Time Delivery and which inventory replenishment policy can be used for the demand pattern corresponding to the uncertain single order SV&E market?"*

The Sales Inventory & Operations Planning (SIOP) is a business process which adds the role of inventories to the traditional Sales & Operations Planning (S&OP). However, currently SIOP and S&OP are used interchangeably in literature and both focus on the tactical / operational level, while the term Executive S&OP is now used for planning at the aggregated level. SIOP/S&OP is an ongoing process in which on a monthly basis the planning is reviewed and evaluated. All key stakeholders are involved to generate one profit maximizing plan. Since the SIOP process takes the inventory settings into account, the SIOP meetings can add value by the implementation of correct inventory parameter settings based on the knowledge of the cross functional team. The combination of inventory models and shared human knowledge about practical issues should improve performance and thereby the On Time Delivery performance.

The basis for good inventory management is the component classification; different component characteristics require a different inventory management policy, which includes the replenishment and safety stock calculation methods. Based on the classification of Syntetos et al, component demand patterns can be distinguished based on two criteria: the Coefficient of Variation (CV) and the Average Demand Interval (ADI). The combination of the two criteria results in one of the following demand patterns: Smooth, Erratic, Intermittent or Lumpy.

Due to the low volume of the generally custom products, many components show a demand pattern with periods without demand, the so called intermittent and lumpy demands. The standard inventory replenishment policies do not fit this demand pattern. Teunter et al (2009) developed an inventory replenishment policy especially designed for components with an intermittent demand pattern. This inventory replenishment policy is based on Croston's forecasting method which is commonly used for intermittent demand patterns.

Seals used in the production of products at Power-Packer

5. Component classification methods

The core problem, described in section 3.3, revealed that the some of the component demand patterns in the SV&E market are not supported by the current inventory settings. However, there is currently no method to classify these components. Therefore, in this chapter we provide a component classification method which assigns components to a certain category based on the component characteristics: Value, Supplier lead time and Demand pattern. Based on these characteristic it is possible to take appropriate action per component, like; determination of inventory replenishment strategies, safety stock calculation, sourcing strategies and lead time agreements with customers. To tackle the most critical products first, we based and tested the component classification method on the components used in products which had an On Time Delivery (OTD) problem in the period July 2014 – May 2015. Section 5.1 starts with the identification of these products and components.

5.1 NOTD component analysis

As has been mentioned in section 3.1.4, there are one or more components which caused a delay in the production of a certain product. These components were not in stock on time, so it was impossible to manufacture the product. The OTD analysis identified 75 different products with an NOTD hit, these 75 different products consists of many different components. Which components actually caused the OTD problem is only partly registered, therefore the complete Bill Of Materials (BOM) of these products will be reviewed.

5.1.1 Bill Of Materials (BOM)

To determine which components are used in the 75 products, de Bill Of Material (BOM) of each product has been reviewed. The Bill Of Material represents the product structure of a product and lists all raw materials, sub-assemblies, sub-components and the corresponding quantity used in the end product.

Of the 75 products, 62 BOM's could be reconstructed. The other 13 products are purchased and directly resold without any added value. Of course, these 13 products do not have any underlying components. The Bill Of Material review revealed that the other 62 products consist of 688 different components in total.

All components need to be present to be able to start production of the end product. The case becomes even more complicated due to the use of the same components in multiple products. Many components are not only used in SV&E products but are also used in products in the Automotive, Truck and Medical market. All these markets have their own demand patterns and uncertainties. These and other factors which complicate the problem will be dealt with in the upcoming sections.

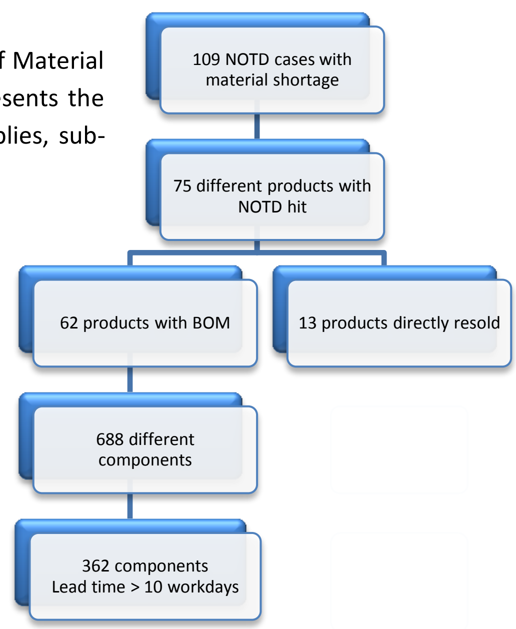


Figure 5-1: Number of components in NOTD products

5.1.2 Component value

Component value has a big impact on total inventory value and use of working capital. As had been discussed in section 2.2.1, the ABC-analysis is already used at Power-Packer to determine whether a certain component represents a huge or a small percentage of the total inventory value. Components with a (very) low value should be purchased in larger quantities because ordering and handling cost are higher than the inventory holding cost. In most of the cases these low value components must also be ordered in larger quantities because the Minimum Order Quantity (MOQ) specified by the supplier is higher. The component purchase price of O-rings, screws, and small balls and springs are in most of the cases under 1 eurocent. A production stop on these items would be extremely painful, having them on stock will cost only a few cents while a production stop or dissatisfied customer will cost a lot more. The well-known Economic Order Quantity (EOQ) could be used for low value components. This formula determines the optimal quantity taking into account ordering and inventory holding costs.

5.1.3 Supplier lead time (risk)

As has been discussed in paragraph 2.1.6 (figure 2-3), in the worst case scenario the supplier lead time may **not exceed 10 days**. In this worst case there is no accurate forecast which the MRP system can use to order components upfront, which is quite common in the SV&E market. There are only 3 customers who provide a forecast, but even these forecasts change a lot each time the forecast is updated. The only way to buffer against long lead time component demand is inventory, which in the MRP environment of Power-Packer should be set as a certain amount of safety stock.

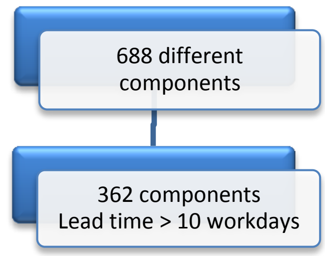


Figure 5-2 Long lead time components

Of the 688 components, 362 components have a lead time that exceeds the supplier lead time of 10 days (see figure 5-2). This is no problem if the demand is forecasted and the MRP system is able to order before the actual sales order comes in. However, an error in this forecast causes excess component inventory or a lack of components which cannot be supplied on time anymore. This demand variability could partly be covered by safety stock. But if there is no safety stock available and the forecast is to low, this will immediately result in OTD problems.

In short, components with a lead time exceeding 10 workdays should be buffered by safety stock because the SV&E forecast is very unreliable. While components with a lead time of 10 workdays or less should not need any (safety stock) inventory at all[4]. In general these components are sourced locally and the supplier is very flexible in supplying the components any time.

5.1.4 Demand patterns

Most of the components used in the selected NOTD products are also used in other products, for example in products made for the Truck OEM or Automotive market. The demand in these two markets is significantly higher and more frequent than in the SV&E market. Besides this, the forecast in the Truck OEM and Automotive market is much more reliable. Due to the relatively small quantities of these parts used in the SV&E market no big problems are present in this category. The demand patterns of these repetitive high volume components are all quite smooth and completely different from the components which are only used in the SV&E products. An analysis of the material usage of the 362 selected components will support this statement.

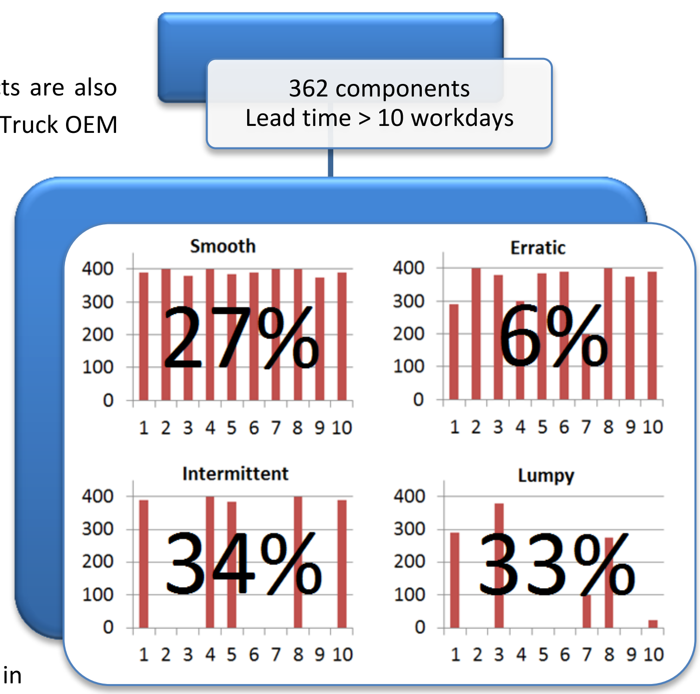


Figure 5-3: Demand pattern distribution SV&E

Figure 5-3 shows the distribution of the different demand patterns within the selected SV&E components, based on the classification method of Syntetos *et al* (2005), described in section 4.1.5. Based on this classification, most of the 362 selected high risk components (34 percent) show an

[4] In this case it is assumed the lead times in the system are correct and agreed with the supplier. 10 workdays is a worst case scenario, so buffering for supplier lead time variability should not be necessary but could be considered.

intermittent demand; a demand pattern with a quite constant demand, but relatively many zero demand periods. These components will need a different approach than the smooth and accurately forecastable demand patterns Power-Packer is used to in the Automotive and Truck OEM market. The running example in section 2.2 section provided an example which shows that the current safety stock calculation method does not suit the intermittent demand pattern with many zero demand periods. This running example together with this analysis underlines the need for a classification method based on demand pattern. The second largest category, the so called Lumpy category, is one of the hardest categories to deal with because demand occurs on very uncertain moments and the quantities vary a lot (Hautaniemi, 1999). These are typically components which should not have a supplier lead time which exceeds 10 working days. A shift towards local sourcing would be the best option for these components. For examples of the different demand patterns based on real data see Appendix F.

A comprehensive analysis of the components classified as intermittent and lumpy by Syntetos *et al* (2005) revealed that even the demand patterns within these categories showed huge differences with respect to the number of weeks with orders. The component usage of 52 weeks was taken in the period July 2014 – June 2015[5]. Components classified as intermittent by Syntetos *et al* (2005) showed weeks with actual demand ranging from 1 week with demand to 33 weeks with demand. Components which are demanded just 1 or 2 times a year should not be held on stock, Hautaniemi (1999) classified these components as "Singular". For these components it is recommended to make agreements with the customer about the product lead time.

5.1.5 The component classification model

This paragraph provides our component classification model to determine how critical certain components are and what actions should be taken to improve the On Time Delivery of products in which these components are embedded. It thereby answers sub question 4.

Figure 5-4 shows the component classification model based on the three sub categories discussed in the previous paragraphs. The classification is done in three consecutive steps: First the component value is evaluated. If the component value is less than 1 euro the component should be ordered in larger batches to save ordering costs, this quantity could be based on the Economic Order Quantity.

If the component value is more than 1 euro, the second step is to determine if the Supplier Lead Time is smaller than 10 working days. If this is the case, there is no inventory needed in theory because the supplier lead time is smaller than the remaining customer lead time after all internal lead times at Power-Packer are subtracted from the total customer lead time of 5 weeks. However, if the supplier lead time is longer than 10 working days, the demand pattern of the component becomes in important factor.

Based on the demand pattern the best inventory management system should be determined. Currently Power-Packer inventory management system is build based on smooth and erratic demand patterns, so no direct action is required for components with this demand pattern. The intermittent demand pattern however, needs some additional attention because the way the inventory is currently managed is not in line with the intermittent demand pattern as has been discussed many times in this thesis. Therefore chapter 6 will provide a foundation for a new inventory replenishment method, safety stock calculation and forecasting method for components with an intermittent demand pattern. The most critical components are the components which show a Lumpy or Singular demand pattern. The uncertain demand intervals and quantities make it extremely hard to predict optimal inventory quantities. Sourcing these components abroad makes the supply chain very inflexible. Therefore these

[5] It must be mentioned that the component usage is only based on the actual usage in production, so components directly resold are not taken into account (which is a rare event). At the moment of writing, only this so called WIP component issue could be extracted from Oracle.

components should be sourced from local suppliers. However, components which are only used a few times a year, the Singular demand pattern, could be at the end of production. We define a component as Singular if the number of periods (weeks) with a demand is less than 25 percent of the total number of periods. Determining whether there is still demand for this component is an important action. Another option could be to make agreements with the customer about a longer lead time if the customer only orders the corresponding products once in a very long while.

5.2 Conclusion - Quantitative part 1

This chapter answered sub question 4: “Which component classification model is able to determine the high risk components for the On Time delivery performance in the selected NOTD products?” Based on the needs of Power-Packer we developed a component classification model. The component classification model depicted in figure 5-4 provides the foundation for the selection of the right inventory management system and corresponding inventory parameter settings. Based on “Component Value”, “Supplier Lead Time” and “Demand Pattern”, better decisions can be made for the selection of the inventory replenishment policy and the inventory parameter settings. Chapter 6 elaborates on the actions that need to be taken for components with an intermittent demand pattern, which is a common demand pattern in the SV&E market. These components from a high risk at moment because the current inventory models are based on components with a smooth demand pattern embedded in products with reliable forecast (from the Automotive and Truck business).

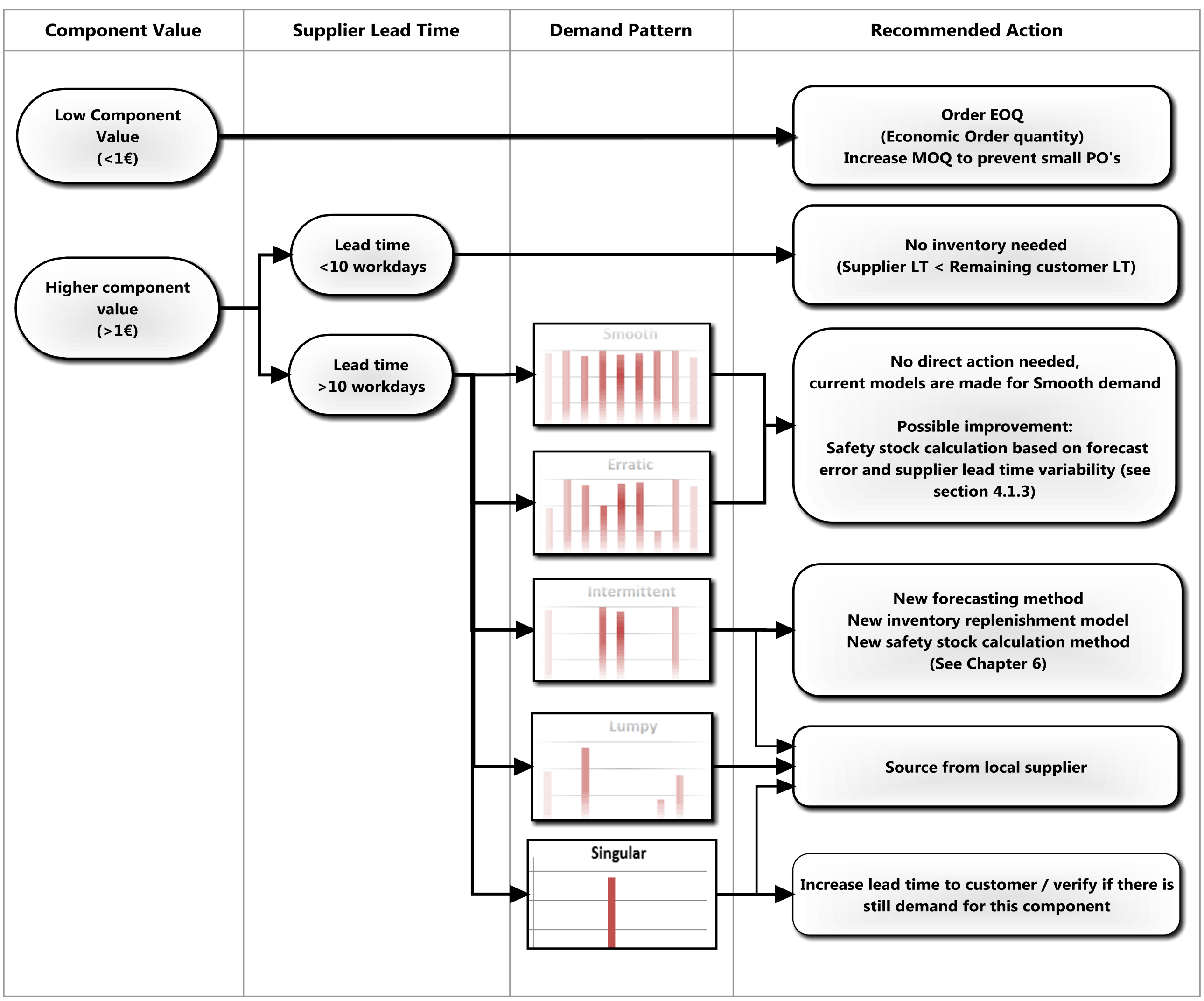


Figure 5-4 Component classification method

6. The foundation for an improved inventory management system

In this chapter we lay a foundation for an improved inventory model, especially for components showing an intermittent demand pattern. In chapter 5 we introduced the new component classification model which is based on the demand pattern, lead time and costs of a component. Based on this classification, better inventory parameter settings can be determined. As we mentioned before in section 1.2, the current inventory management system is based on high volume production with accurate forecasts. However, markets like the SV&E market with less frequent demand patterns (intermittent, lumpy and singular demand patterns) require a different inventory management system. Besides this foundation for an improved inventory management system, we describe the Sales Inventory & Operations Planning (SIOP) process and its implementation plan. The SIOP process brings together a cross functional team which reviews the Key Performance Indicators (KPI's) like On Time Delivery and Overdue performance and defines actions to improve these KPI's during a structured monthly meeting, these actions include adjustments of the inventory parameter settings where needed.

6.1 Inventory parameter settings and inventory replenishment

The inventory parameter settings include a wide range of parameters. In the next paragraphs a foundation to improve the most critical parameter settings will be outlined. Paragraph 6.1.1 deals with the Demand Time Fence (DTF) parameter setting, this is not in line with the demand conditions of the SV&E customers. Paragraph 6.1.2 outlines which improved safety stock method could be used based on the demand pattern of a component. The safety stock calculation for intermittent demand patterns will be dealt with as part of the new inventory replenishment policy for intermittent demand patterns described in paragraph 6.1.4. In paragraph 6.1.3 accuracy of the recommended Croston's forecasting method for components with an intermittent demand patterns is tested and evaluated.

6.1.1 Demand Time Fence (DTF)

As discussed in paragraph 2.2.3 the Demand Time Fence (DTF) determines whether the actual sales orders or the Demantra forecast is used to calculate demand for the upcoming periods. This parameter is a user-defined number of days. Currently this parameter is set at 40 workdays, which means ASCP uses the first 40 workdays of actual sales orders in the order book to determine the demand up to and including 40 workdays from the current date. Of course, when orders are placed far before their due dates the forecasted demand becomes much more accurate. In the SV&E market however, the order book is generally only filled for 5 to 6 weeks (25 to 30 workdays). So ASCP sees zero demand for week 7 and week 8! So, if next week shows that there actually is demand in week 7, fewer materials are ordered than would probably be needed. In this case the safety stock (if available) must be used to absorb this forecast error. If the safety stock cannot absorb this error, an On Time Delivery problem occurs! Therefore, the first parameter setting which must be changed immediately is the Demand Time Fence. The Demand Time Fence must be in line with the number of weeks the order book is normally filled with actual orders, see figure 6-1. Which in practice also means that long lead time components (>6 weeks) are always ordered based on the Demantra Forecast.

	Demand Time Fence (6 weeks)						Demantra Forecast											
Week	**1**	**2**	**3**	**4**	**5**	**6**	7	8	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Customer	**100**	**70**	**100**	**80**	**100**	**90**	?	?	?	?	?	?	?	?	?	?	?	?
Forecast	100	100	100	100	100	100	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
ASCP	**100**	**70**	**100**	**80**	**100**	**90**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Production	100	80	100	90	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Supplier	100	80	100	90	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Figure 6-1 Demand Time Fence of 6 weeks instead of previous 8 weeks

Based on the problematic DTF issue described above, immediate action has been taken. All DTF settings were reviewed and changed to 30 days (6 weeks)[6] were necessary while writing this report.

6.1.2 Safety stock parameter settings

Analysis of the safety stock settings in paragraph 2.2.1 revealed that the current safety stock determination does not hold for components with intermittent demand patterns. Safety stock calculation for components with an intermittent demand pattern is a complicated task due to the fact that demand is sporadic and literature for safety stock calculation is mainly based on the assumption of a normal distribution. Teunter & Sani (2009) recommend using an Order-Up-To policy with demand forecasts based on Croston's forecasting method. Calculation of the safety stock should then be based on the standard deviation of the forecast error during total lead time demand. This forecasting method and inventory replenishment policy will be discussed in sections 6.1.3 and 6.1.4. The safety stock calculations are part of the inventory replenishment policy described in section 6.1.4.

Although the current safety stock method used by Power-Power has been designed for the smooth demand patterns in the Automotive and Truck market, also this safety stock calculation method could be improved. To improve this safety stock calculation, the Mean Absolute Deviation method can be used to get an estimate of the forecast. For items showing a smooth demand pattern the assumption of a normal distribution function is plausible. Equation (6) described in section 4.1.4 should be used to determine the safety stock settings for components with a smooth demand pattern:

$$\boldsymbol{safety\ stock = Z * \sqrt{\left((L+R)*(1.25*MAD)^2\right)+\left(\sigma_{L+R}*D_{avg}\right)^2}}$$

This safety stock calculation takes into account the standard deviation of lead time demand. If we assume lead time to be fixed, the last term $\left(\boldsymbol{\sigma_{L+R} * D_{avg}}\right)^{\mathbf{2}}$ could be left out of the equation. Unfortunately both forecast versus actual demand and supplier lead times are currently not properly saved at Power-Packer which makes the calculation based on equation 6 impossible at the moment. Forecast values constantly change due to the wrong DTF parameter settings and are not available on a weekly basis but only monthly. So before safety stock calculations can be made based on forecast errors, the forecasted demand versus the actual demand per week should be saved properly. Because the biggest problem concerning safety stock calculation is for components showing an intermittent demand pattern, the next paragraphs will focus on methods designed to overcome component shortage for components showing an intermittent demand pattern.

6.1.3 Comparison of forecasting methods (Croston versus Demantra)

The forecast is an extremely important input for the on time purchase of materials. Therefore, in this paragraph we compare the forecast accuracy of the recommended Croston forecast for components with an intermittent demand pattern, with the forecast accuracy of the current forecast method (Demantra) which is entirely based on historical sales.

At Power-Packer, forecasting is the responsibility of the Sales department. However, the logistics department depends to a large extent on this forecast. As we mentioned before in sections 1.2 and 2.4, the Automotive and Truck market forecast is quite reliable. Forecasting the SV&E market is much harder due to the single incoming orders with sometimes many weeks without demand. According to the literature this so called intermittent demand can best be forecasted using Croston's forecasting method (Syntetos, 2005), or one of its derivatives, as

[6] Although some products have a lead time of 5 weeks, the DTF is not changed to 5 weeks because in this case the system will plan fixed production orders based on forecast. During the SIOP meeting it became clear that this was undesirable.

described in section 4.2.2. Besides this, the Croston forecast forms the foundation for the new inventory replenishment policy introduced in the next section.

Power-Packer forecasts on product level and not on component level. The MRP system translates the product forecasts into a component forecast. Manual translation becomes extremely complex and time consuming because components can be used in several end products, therefore a limited number of components are used while comparing the two different forecasting methods. Take for example component 1111-025, which is used in three different end products. Table 6-1 shows the November forecast of these three end products: DPE7-111300, DPE7-111301 and DPE7-111302. As can be seen in the first row of table 6-1, the forecast schedule is divided in four, four and five weeks. ASCP translates the aggregated 4 or 5 weeks forecast to weekly demand as described in section 2.3. So, to be able to translate these forecasts to a weekly component forecast, the total forecast (row 6 in table 6-1) has been divided by the number of weeks the end product is forecasted (row 1 in table 6-1), just as ASCP currently does.

Forecast for # weeks	**4**	**4**	**5**	**4**	**4**	**5**	**4**	**4**	**5**	**4**
	6/10/2014	3/11/2014	1/12/2014	5/1/2015	2/2/2015	2/3/2015	6/4/2015	4/5/2015	1/6/2015	6/7/2015
DPE7-111300	0	24	0	100	50	0	0	0	95	0
DPE7-111301	0	90	60	0	60	30	63	100	0	0
DPE7-111302	0	0	0	0	52	0	0	0	0	52
Total forecast	**0**	**114**	**60**	**100**	**162**	**30**	**63**	**100**	**95**	**52**

Table 6-1 Demantra November end product forecast in specified time span

The calculated weekly component forecast has been compared with the actual component usage in that week. The same has been done for the forecast calculated based on Croston's forecasting method. We compared the forecast accuracy of Croston with the forecast accuracy of Demantra for 5 intermittent demand components used in product DPE7-111301, which had many On Time Delivery (OTD) problems. The forecast accuracy is measured by the Mean Absolute Deviation (MAD)[7], see section 4.1.4. The forecast accuracy of Croston showed nearly no difference when different values for smoothing parameter α were used, see table 6-2. The accuracy of Croston's forecast scored 10%-12% better than the current forecasting method, over the 5 tested components. See Appendix G for an example of the forecast accuracy measurement.

α	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
MAD Demantra	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6
MAD Croston	20.9	21.8	22.0	22.0	21.9	21.8	21.8	21.7

Table 6-2 Forecast accuracy based on Mean Absolute Deviation (MAD) for item 1111-025

The comparison performed in Excel showed that the Croston forecast accuracy is higher than the forecast accuracy of the current forecasting method. In the next section we introduce an inventory replenishment policy which uses Croston's forecast as input to determine order-up-to levels for components with an intermittent demand pattern.

6.1.4 Inventory Replenishment – Order-up-to Levels based on Croston

The component classification model described in section 5.1.5 already indicated that for the inventory replenishment method for components with a smooth demand pattern no direct action is required. Components with a low value should be replenished in larger quantities to find an optimum between ordering and holding costs. For components with an intermittent demand pattern, another inventory replenishment method is needed. The most commonly used method for components with an intermittent demand patterns is the order-up-to policy (Teunter & Sani, 2009), described in section 4.2.3. Teunter & Sani (2009) developed an order-up-to inventory replenishment model especially for intermittent demand patterns based on Croston's forecasting method. In the

[7] The forecast accuracy has also been tested using the Mean Squared Error (MSE). Using this error measure the accuracy of Croston's forecast method scored even 17-21% better than the current forecasting method.

previous section we revealed that Croston's forecasting method outperformed the current forecasting method at Power-Packer. Therefore using the new inventory replenishment model, which is based on Croston's Forecasting method, should be a better fit than the current inventory replenishment model which is completely forecast based and uses a poor performing safety stock calculation method.

6.1.4.1 Simulation model of new inventory replenishment policy

A simulation model has been built to simulate the On Time Delivery performance when the new order-up-to replenishment policy introduced by Teunter & Sani (2009) will be used. All steps described in section 4.2.3 are programmed in in Excel 2010 using VBA. The performance of the new inventory replenishment model has been evaluated by a numerical experiment, based on historical component demand per week. For each experiment the historical demand in the period November 2013 until June 2015 has been used and was limited to the data corresponding to the selected 362 components which were used in products with On Time Delivery problems. The data before 2015 has been used as warm-up period for the simulation, and the data from 2015 is used for the performance measurement. The simulation is initialized at Croston's forecast = 1, demand interval = 1, Mean Absolute Deviation = 0, net inventory (on hand – backorder) = 0, stock on order = 0 and the Order-Up-To level = 0.

A detailed explanation of the new inventory replenishment method and the notation can be found in section 4.2.3. The simulation steps are exactly the same as described by Teunter & Sani (2009):

"In each period **with a positive demand**, the following actions are taken in this order:

1. *The demand occurs,*
2. *Stock on hand, stock on order and backorder levels are updated,*
3. *The order-up-to level is updated to* $\mu f_{L,t} + k\sigma_{L,t}$ $(Demand\ during\ lead\ time + Safety\ Stock)$*, where safety factor k is the inverse of the standard normal distribution at the "no stock out probability" service level: NORM.S.INV(service level) function in Excel,*
4. *If the inventory position (net inventory + on order) is less than the order-up-to level then the difference is ordered,*
5. *An order arrives if one has been placed L period ago.*

Limitations

Because the data with the components which actually caused the On Time Delivery (OTD) problem is not adequately saved at Power-Packer, it is impossible to compare the service level performance of the new inventory policy per single component. However, it is possible to determine total inventory value needed to attain the required service level of 95% using the new inventory replenishment policy. To compare the difference in total inventory value, the average value of the current inventory on hand[8] at Power-Packer is compared with the average value of the components that need to be on stock based on the new inventory replenishment policy to attain a certain service level. This reveals what the difference in total inventory value is at a certain service level.

Before the experiments at different service levels are done, an optimal value of alpha (α), used for Croston's forecast, will be determined in the next section. This α is a smoothing parameter.

[8] The average on hand per component is based on the inventory reports of Power-Packer in the period 21 January 2015 – 1 September 2015. In this period the on hand component inventory is registered every two weeks and the average over these registered on hand inventory has been taken to determine the average on hand per component

Determine Croston smoothing parameter α (Alpha)

The smoothing parameter α determines the impact of the realized demand on the demand forecast for the next period, the same holds for the demand interval. α is always between 0 and 1; an α near 1 would place extra weight on the new demand(z_t), while an α near 0 would place more weight on the previous forecast demand (zf_{t-1}): $demand\ size\ forecast\ after\ period\ t\ if\ d_t > 0\!:\ zf_t = \alpha z_t + (1-\alpha) zf_{t-1}$

Several experiments with a fixed target service level of 95% and a varying value of alpha were done. This experiment indicated that a higher alpha results in a higher actual obtained service level, but at high cost! One extra percentage point in service level increased the inventory value by 34%! Because an alpha of 0.055 obtains the required service level of 95%, this value of 0.055 will be used in the upcoming experiments, see figure 6-2.

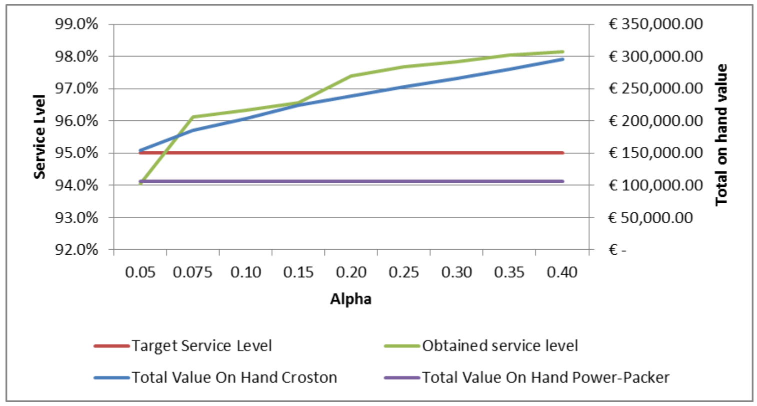


Figure 6-2 Determination of alpha

Validation of the Simulation model

Before we can state any conclusions about inventory costs using the new replenishment model, we validated the model on accuracy. This means that we compared the target service level used in the simulation with the actual obtained service level. We used the historical demand data of 37 components with an intermittent demand pattern. The obtained service levels showed no extreme deviations from the target service levels used as input parameter in the simulation model, see table 6-3. Deviations of this order are also observed in the article of Teunter & Sani (2009), but are assigned to the assumption of normally distributed total lead time demand, which is a poor fit in most of the cases. This could be improved by identifying the correct distributions, but this will make the case too complex for practicality. Overall the simulation model works properly and in accordance with the results of Teunter & Sani (2009) for all specified target service levels (with α=0.055).

Target Service Level % (input in Simulation)	80.0%	82.5%	85.0%	87.5%	90.0%	92.5%	95.0%	97.5%	99.0%
Actual obtained Service Level % (output of Simulation)	84.2%	85.8%	87.5%	89.2%	91.0%	93.0%	95.1%	96.4%	97.0%

Table 6-3 Target Service Level compared with Actual obtained Service Level using the new inventory replenishment policy

The next section provides the impact on the inventory value when our proposed replenishment policy is used with a target service level of 95%.

Simulation output for components with an intermittent demand pattern

For the first experiment 37 components, of the selected 362 components, with a value of more than 1 euro, a lead time of more than 10 workdays and an intermittent demand pattern were used in the simulation. The results are graphically displayed in figure 6-5 and the raw simulation output can be found in Appendix H. The simulation reveals that the target service level of 95% can be obtained, but this is associated with an increased inventory value from €106,665 to €162,703. This total increased inventory value of €56,038 (53%) is required for the 37 selected components. So even with an optimal inventory replenishment policy for components with an intermittent demand pattern, the total inventory value increases with 53%. This is really undesirable taking into account the pressure from higher management to decrease the total inventory value.

Besides this, the actual obtained service level represents the proportion of components which can be delivered directly from stock. However, Power-Packer must produce complete batches which make the case even worse. Because the complete required quantity must be available, a second performance indicator is added to the simulation, the “Average OTD percentage”. If not all components are available to produce the complete batch, the order cannot be made, which results in a backorder. The total number of times a backlog occurs divided by the total number of orders give the “Average OTD percentage”:

$$Average\ OTD\ percentage = \frac{Total\ Backorders}{Total\ \ number\ of\ orders} * 100\%$$

If this “Average OTD percentage” is used as measure, the total inventory value needed to obtain a 95% score is even more. As can be seen in figure 6-5, to obtain a 94.8% “Average OTD percentage”, an increase of 78% in total inventory value is needed! So even with an improved forecasting method and an optimal inventory replenishment policy especially designed for components with an intermittent demand pattern, an increase of 78% in the inventory value of these 37 components is required, which corresponds to €83,354.

Simulation output for components with a lumpy demand pattern

Although the classification method based on Syntetos et al (2005) makes a difference between intermittent and lumpy demand patterns, in general the literature uses the term intermittent demand for both. To test the performance of the new order-up-to inventory replenishment policy for components with a lumpy demand pattern, the simulation has also been executed for components which are classified as lumpy.

The simulation output can be found in the Appendix H. To obtain a service level of 95%, the inventory value of components with a lumpy demand pattern is even 84% percent higher than the current inventory value, which corresponds to an increase of €42,990 for the selected 20 components used in one of the products which caused an On Time Delivery problem in the period July 2014 – May 2015.

Simulation output for safety stock quantities

The current safety stock quantities are not based on a certain service level and achieved services level per component are not available and cannot be obtained or calculated from the available data. As has been discussed in section 2.2.1 the current safety stock method underestimates the required safety stock for components with an intermittent or lumpy demand pattern.

The new inventory replenishment policy of Teunter et al (2009) uses the standard deviation of the forecast error of total lead time demand ($\sigma_{L.t}$) and a safety factor *k (inverse of the standard normal distribution at a certain service level, this service level represents the no stock out probability)* to determine the safety stock quantity: $k * (\sigma_{L,t})$ with:

$$k = \Phi^{-1}(service\ level)$$

$$k = \Phi^{-1}(0.95) = 1.645 = NORM.S.INV(0.95)\ in\ Excel\ 2010$$

$$\sigma_{L,t}^2 \approx \quad \frac{2\beta^2}{2-\alpha} + L\left(zf_t^2 * \frac{1}{pf_t}\left(1-\frac{1}{pf_t}\right) + \frac{\beta^2}{pf_t} + \left(\frac{(2+\alpha)}{2-\alpha}\frac{(\beta)^2}{pf_t}\right)\right)$$

$$+ L^2 * \left(\frac{\alpha}{2-\alpha}\right) * \left(\frac{pf_t - 1}{pf_t^3} * \left(zf_t^2 + \frac{\alpha}{(2-\alpha)} * \beta^2\right) + \frac{\beta^2}{pf_t}\right)\ \ with\ \ \beta = 1.25MAD_t\sqrt{1-\frac{\alpha}{2}}$$

We implemented the safety stock calculation in the simulation model of the new order-up-to replenishment policy. The simulation results show, as was expected, a huge increase in safety stock quantities needed to obtain a service level of 95%. Figure 6-3 shows the total safety stock value for the selected components with an intermittent and lumpy demand pattern. To cover for the high demand uncertainty in these two categories, a relatively high safety stock quantity is needed compared to components with a smooth demand pattern.

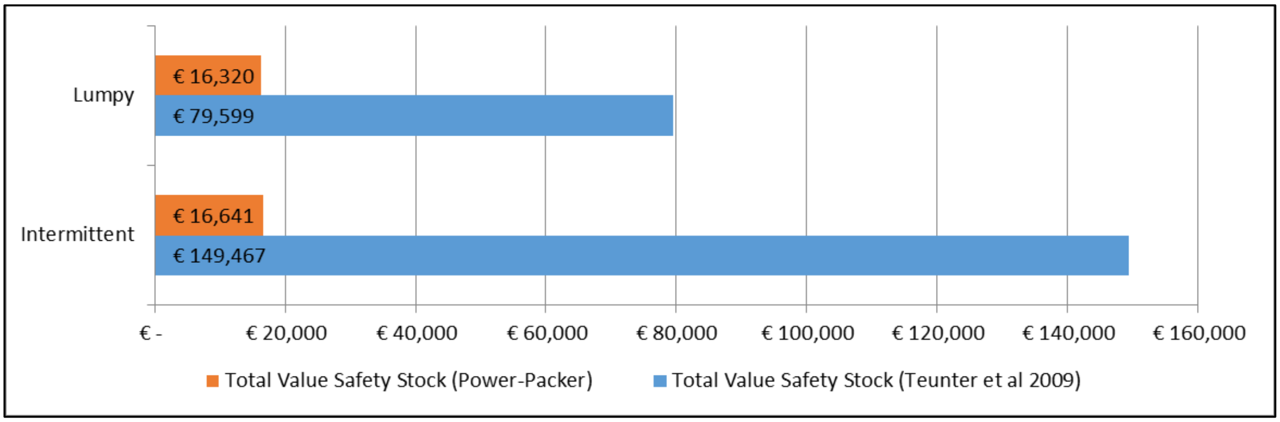


Figure 6-3 Safety Stock value for selected components

The total safety stocks value is part of the total inventory value on hand. As can be seen in figure 6-4, the average safety stock value represents a huge part of the total average inventory value on hand. At first, this is due to the fact that the safety stock should cover for variances in demand and the variance in forecast error of total lead time demand, which are relatively large for components with intermittent and lumpy demand patterns. Second, one should also keep in mind that the calculated safety stock is not always actually on hand! Part of the safety stock could have been used to cover for these variances, which lowers the value on hand. But the average safety stock value, which is based on the calculated safety stock quantities, in the simulation stays the same although not actually on hand. So the stated safety stock quantity could be higher than what is actually on hand at a certain moment! Unfortunately this gives a somewhat distorted picture if we compare the average safety stock value and average on hand value, but gives a good indication about the extra safety stock value needed in comparison with the current safety stock calculation method.

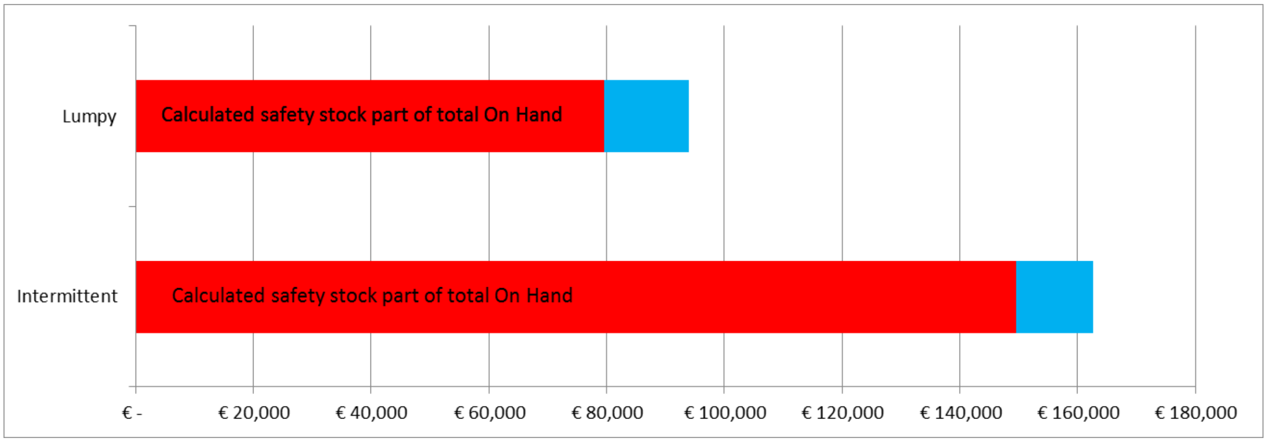
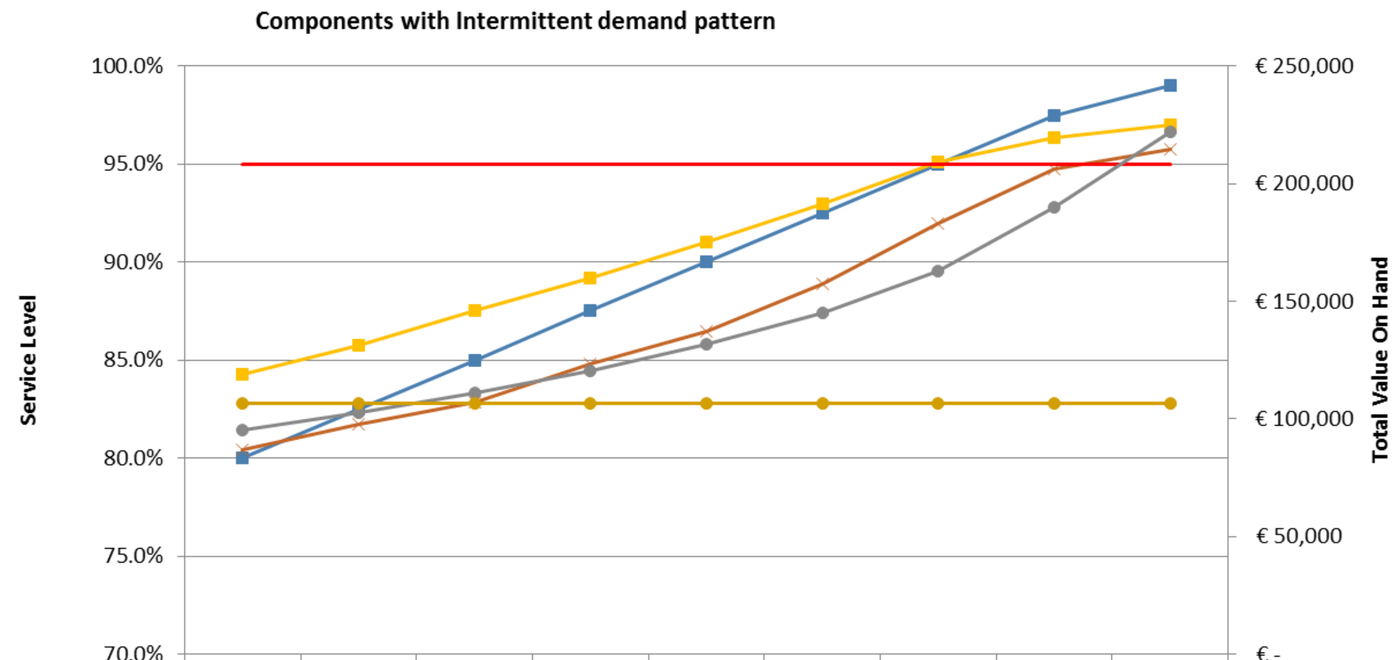


Figure 6-4 Calculated safety stock part of the actual total On Hand value using inventory replenishment based on Teunter et al (2009)



	80.0%	82.5%	85.0%	87.5%	90.0%	92.5%	95.0%	97.5%	99.0%
Target Service Level % (used in Simulation)	80.0%	82.5%	85.0%	87.5%	90.0%	92.5%	95.0%	97.5%	99.0%
Actual obtained service level % (new inventory policy)	84.2%	85.8%	87.5%	89.2%	91.0%	93.0%	95.1%	96.4%	97.0%
Average OTD percentage	80.4%	81.7%	82.8%	84.8%	86.4%	88.9%	92.0%	94.8%	95.8%
Target Service Level % Power-Packer	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Inventory holding costs using Croston	-11%	-4%	4%	13%	23%	36%	53%	78%	108%
Total Value On Hand Croston	€ 95,075	€ 102,663	€ 111,059	€ 120,525	€ 131,610	€ 145,068	€ 162,703	€ 190,020	€ 222,030
Total Value On Hand Power-Packer	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665

Target service Level

Target Service Level % (used in Simulation)
Actual obtained service level % (new inventory policy)
Average OTD percentage
Target Service Level % Power-Packer
Total Value On Hand Croston
Total Value On Hand Power-Packer

Figure 6-5 Results of the simulation run of 37 components with an intermittent demand pattern

Sensitivity analysis safety stock quantities

In the previous section we outlined that a large safety stock quantity is needed to cover for the uncertainty of components with an intermittent or lumpy demand pattern. In this section we perform a sensitivity analysis to reveal the impact of different supplier lead times (L) on the required safety stock quantity. If we take a closer look at the safety stock formula in the previous section, we see that the lead time (L) seems to have a big impact on the calculated safety stock quantity because nearly all terms are multiplied by L or L^2.

To test the impact of lead time (L) on the required safety stock quantity, we performed a sensitivity analysis on the safety stock calculation: $k * (\sigma_{L,t})$. The target service level is set at 95%, thus $k = 1.645$. Because k is a constant we focus or safety stock sensitivity analysis on $(\sigma_{L,t})$. In the first sensitivity analysis the lead time is the only variable, all other parameters are fixed, with: $\alpha = 0.055$, $MAD_t = 100$, $pf_t = 2.5\ and\ zf_t\ = 100$. Figure 6-6 shows the results of the sensitivity analysis.

As can be seen the safety stock quantity decrease if the lead time decreases. This is quite obvious because less uncertainty has to be covered. Decreasing the lead time from 11 to 3 weeks, results in a safety stock quantity reduction of 719 units to 406 units, this is equal to a reduction of 43.4%. See Appendix I for an overview of the reduction in percentages compared to the initial lead time of 11 weeks.

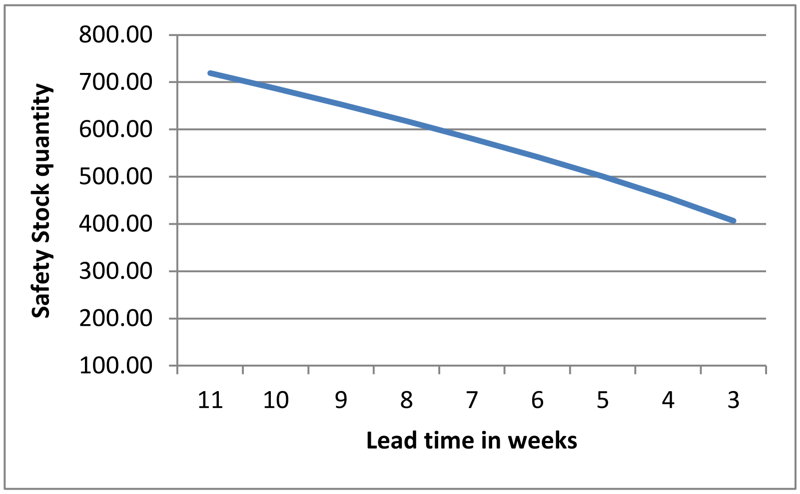


Figure 6-7: Impact of lead time on safety stock calculation

The same sensitivity analysis has been done with historical demand data from Power-Packer. Ten items with an intermittent demand pattern and a current lead time of 11 weeks were used in the sensitivity analysis. The target service level and α were kept at 95% and 0.055 respectively. The other parameters vary based on their historical demand data and de corresponding calculations of Teunter & Sani (2009). Figure 6-7 shows the results when we adjust the lead time from 11 to 3 weeks, in steps of one week. As can be seen the required safety stock value at a service level of 95% decreases from €70,324 at a lead time of 11 weeks to €38,797 at a lead time of 3 weeks. This is a decrease of 44.8%. This is in line with our first sensitivity analysis.

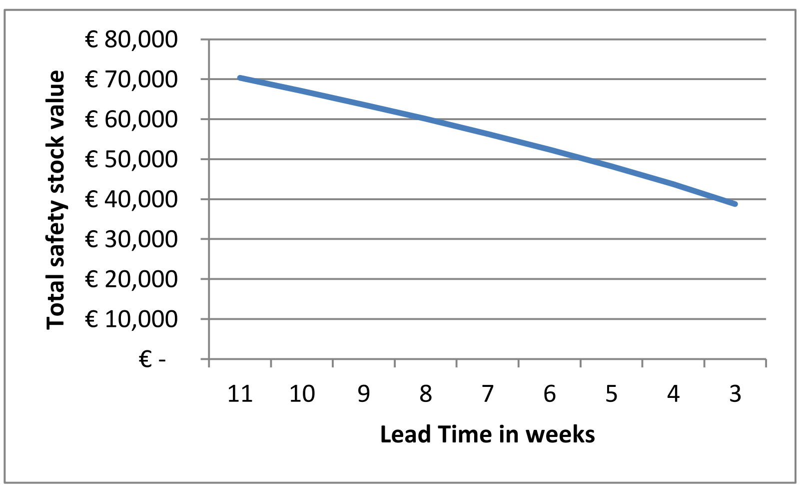


Figure 6-6: Impact of lead time on the total safety stock value for 10 selected components which currently have a lead time of 11 weeks

6.1.5 Other options to improve the On Time Delivery (OTD)

Managing components which do not have a smooth demand pattern is a challenging task. One of the biggest impacts on material purchasing is the forecast. A smaller forecast error decreases the need for safety stock to cover for uncertainties. As has been discussed in the literature part, there are many improved forecasting methods based on Croston. However, there is no consensus about which performs best yet. That is something which still needs more empirical testing. This is something that could also be done at Power-Packer, testing the best forecast method based on historical data.

However, products with intermittent and lumpy demand patterns ask for an agile supply chain which can respond quickly to changes in demand. Sourcing these components abroad from suppliers with lead times of more than 10 weeks is asking for trouble. So sourcing components with an intermittent or lumpy demand pattern locally would be the most obvious action. Also the sensitivity analysis performed in section 6.1.4, which shows that lead time reduction decreases the need for safety stock significantly, supports this local sourcing recommendation. However, one must take into account the fact that all new suppliers must be formally reviewed and the quality of the delivered components must meet the required quality.

Finally the internal lead times could be decreased. This was something left out of scope during this master thesis. The internal lead time analysis revealed that there are only 10 workdays left for the supplier if all internal lead times are subtracted from the customer lead time.

6.1.6 Conclusion – Quantitative part 2

After the first quantitative part of this thesis, which provided a new component classification method, the second quantitative part of this thesis answers sub question 5: “How does the new inventory replenishment policy for intermittent demand patterns perform and what are the corresponding parameters settings per component in the NOTD products?”

The first critical parameter setting, the Demand Time Fence, has been adjusted to 6 weeks instead of 8 weeks to get rid of the demand gap of 2 weeks which could cause serious materials shortage problems because the actual demand was underestimated.

To determine improved inventory parameter settings for components with an intermittent demand pattern, the order-up-to inventory replenishment policy by Teunter et al (2009) has been simulated using historical demand data of Power-Packer. This inventory replenishment policy is based on Croston’s forecast. Numerical experiments revealed that Croston’s forecast performs 10-12% better than the current forecasting method, measured by the Mean Absolute Deviation (MAD). So it could be assumed Croston forms a good foundation for the new inventory replenishment policy.

The new inventory replenishment policy provides inventory parameter settings for order-up-to quantities and safety stock values. However, the simulation results for components with an intermittent demand pattern showed that to obtain a 95% service level, the current on hand inventory value will be 53% higher (or the equivalent of €56,038 for the 37 selected components). For components with a lumpy demand pattern the same inventory replenishment policy indicated an increased on hand inventory value of 84% (or the equivalent of €42,990 for the 20 selected components). This is mainly caused by an increase in safety stock quantities which must cover for large variances in demand and forecast errors. So although an optimal inventory replenishment policy is used, especially designed for components with an intermittent demand pattern, extra investments in inventory must be made compared to the current inventory value.

So to decrease shortages and improve the On Time Delivery of products, besides the implementation of a new inventory replenishment policy, extra inventories will be needed for components of which the supplier lead time exceeds 10 workdays. Or lead times must be decreased by, for example, sourcing these components locally.

The author presenting the SIOP process at Power-Packer Oldenzaal

6.2 Sales Inventory & Operations Planning (SIOP)

The previous chapters dealt with the difficult quantitative task of setting appropriate parameter settings together with the simulation of an inventory replenishment policy for components with an intermittent demand pattern. It gave a guideline to distinguish between components with different demand patterns and what actions should be taken to assure an improved On Time Delivery Performance. This chapter outlines the more qualitative Sales Inventory & Operations Planning process (SIOP) which is implemented at Power-Packer to assure and maintain overall consensus within departments about the correct parameter settings and thereby improving the On Time Delivery performance.

As opposed to the Executive S&OP meeting which focusses on high level strategic decisions, the implementation of a SIOP process at Power-Packer Oldenzaal must support the lower level decisions for the short run (up to 3 months). In particular keeping all parameter settings up-to-date by constantly reviewing what went wrong and trying to predict what the near future brings.

Calculating parameters based on statistical assumptions provides a basis for the parameter settings, but the human practical knowledge is a key component in improving the OTD performance. Therefore, a multi-disciplinary team is set up which attends the monthly SIOP meeting which should lead to consensus about what actions should be taken to improve the OTD taking into account the associated (inventory) costs.

The upcoming paragraphs elaborate on the SIOP process proposal for Power-Packer Oldenzaal. This SIOP process proposal is based on the SIOP/S&OP phases proposed in the literature and in consultation with higher management (Business leader and Manager Logistics). A pilot of this SIOP process proposal has already been implemented during the execution of this Master thesis.

6.2.1 Team Members

The first step in setting up the SIOP process is the selection of an appropriate team and defining the corresponding responsibilities. This team consists of directly and indirectly involved members. The directly involved members attend the actual SIOP meetings while the indirect team members only make and update the needed reports. The team has been composed in accordance with higher management to ensure people with the right competencies are selected for the jobs. Each team member has certain responsibilities. To get a clear picture about these responsibilities a “responsibility assignment matrix” has been set up, also known as RASCI (Responsible, Accountable, Supportive, Consulted, and Informed). A RASCI describes who is responsible for certain tasks and deliverables in a project. The RASCI associated with the SIOP process at Power-Packer Oldenzaal can be found in Appendix J.

The multidisciplinary team with competencies in different business areas consists of a Sales Order Processer (SOP), an Expeditor (material planner), a Production planner, a Sales Support Manager and a Production team leader. The meeting is guided by the Team leader Logistical Support. When needed, a representative of the purchasing department will be added to the team.

6.2.2 Product scope of the SIOP meeting

To narrow the enormous amount of products to be reviewed, the next step in setting up the SIOP process is to determine the scope. In accordance with the logistical managers of Power-Packer, the scope of the products to be reviewed is narrowed to products which show abnormalities in comparison with the forecast. These abnormalities can be found using the newly developed Delta Dashboard, see paragraph 6.2.3 point 1. Besides this a top 10 of products, which are most important according to the sales representative, are quickly reviewed using the developed SIOP Dashboard, see paragraph 6.2.3 point 2. Finally a selection of products which caused problems is discussed.

6.2.3 SIOP Process

The SIOP process is not just a monthly meeting, but an ongoing process of improvements. Each day new raw data is collected and stored. This raw data is used to produce several reports which give insight in for example historical sales, current sales orders, demand forecasts, On Time Delivery (OTD) problem data, inventory positions and safety stock settings. On itself this data is quite useless, but during the SIOP meeting al this information is combined to be able to make decisions which should improve the customer satisfaction and meanwhile reduce cost.

For the actual SIOP meeting, six main topics are selected which are of great importance to improve the OTD performance, taking into account the SIOP process steps described in the literature. The six main topics are briefly summarized below and a detailed explanation follows in the next paragraphs, see figure 6-8.

1. **Forecast vs. Order book:** The sales forecast is compared with the actual sales in the order book.
2. **Review Top 10 items:** The 10 most important products, selected by the sales department, are reviewed in detail to assure the OTD of these products does not result in any problems.
3. **OTD / Overdue:** The OTD problems and their causes are discussed and required actions to prevent future occurrences are taken. The Overdue can partly be caused by the OTD problems. Overdue problems which did not result from NOTD issues need to be solved.
4. **Urgency Shipments:** Extra costs made to deliver products on time must be analyzed.
5. **Tenders / Big aftermarket orders:** Big tenders could result in material shortage and violation of capacity constraints. Timely action should be taken.
6. **Safety stock:** The safety stock settings, which are based on statistical calculations, could be wrong when exceptional (external) events occur. Adjusting the Safety stock based on information of the team could be necessary.

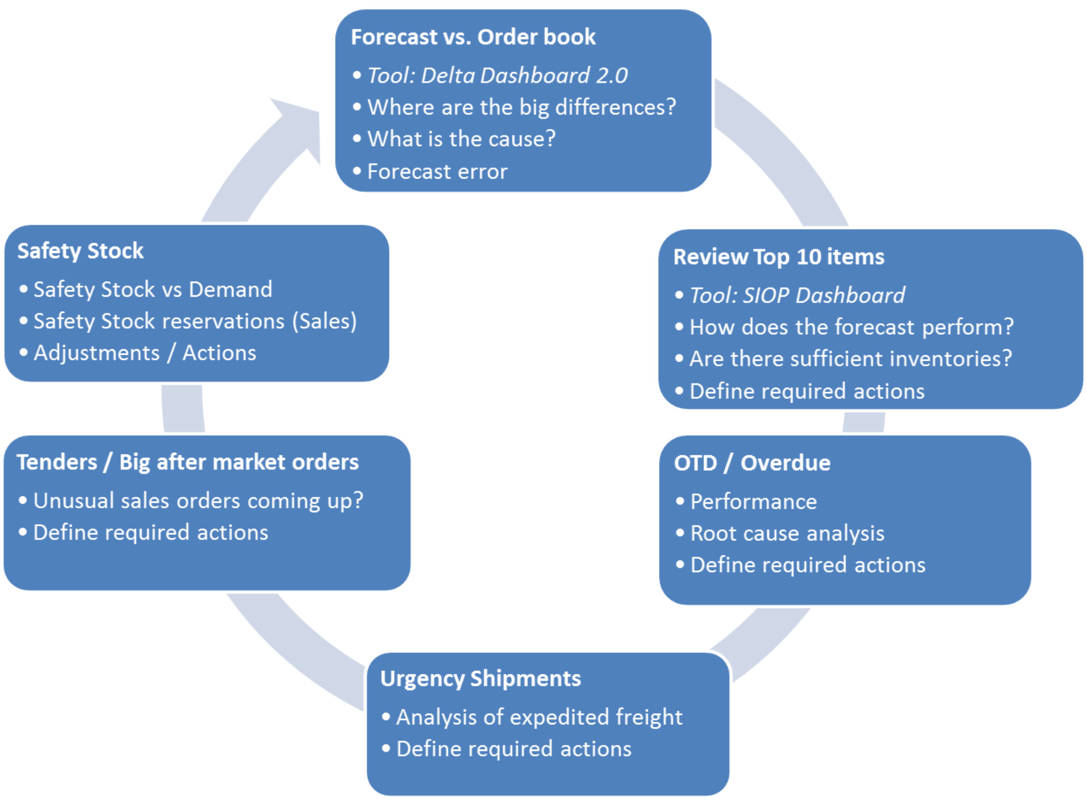


Figure 6-8 SIOP process cycle

1. *Forecast vs. Order book*

Each month the forecast is updated by the sales department. However, this update does not deviate much for products in the SV&E market. As mentioned in section 2.3 the forecast is mainly based on historical sales. The MRP raw material purchase requisitions are completely based on the sales forecast and the orders in the order book (see section 2.2.3.). An accurate forecast is important to get the right materials on time, especially long lead time components are critical because the purchase of these components is completely based on the forecast. During the SIOP meeting the biggest deviations between the forecast and the actual sales orders are discussed.

Delta Dashboard (Tool)

To be able to recognize abnormal differences between the forecast and the actual orders in the order book of Power-Packer, a new tool has been developed called *"The Delta Dashboard"*. This tool combines two reports: the "Consensus Forecast" report from the sales department and the "Sales & Backlog" report from the logistical department. The tool imports the raw data from both reports and combines this into a clear overview which displays the Forecast and Order book values per product. The user can select which months to display, which customers to include in the analysis and which Line of Business[9] to review. Big differences should instigate to discuss and reveal what causes these big differences.

Example: See figure 6-9, product X. As can be seen, the forecast is 150 units each month. The actual sales orders on the other hand are much higher! During the first SIOP meeting it immediately became apparent that the forecast was not updated for this product, even after months of increased demand. This could result in serious material shortages for long lead time products as mentioned before. Immediate action was required from the responsible sales person.

The opposite problem could also be the case: when the forecast is much too high, the inventory is filled with unnecessary components. This has a big impact on the total inventory holding costs.

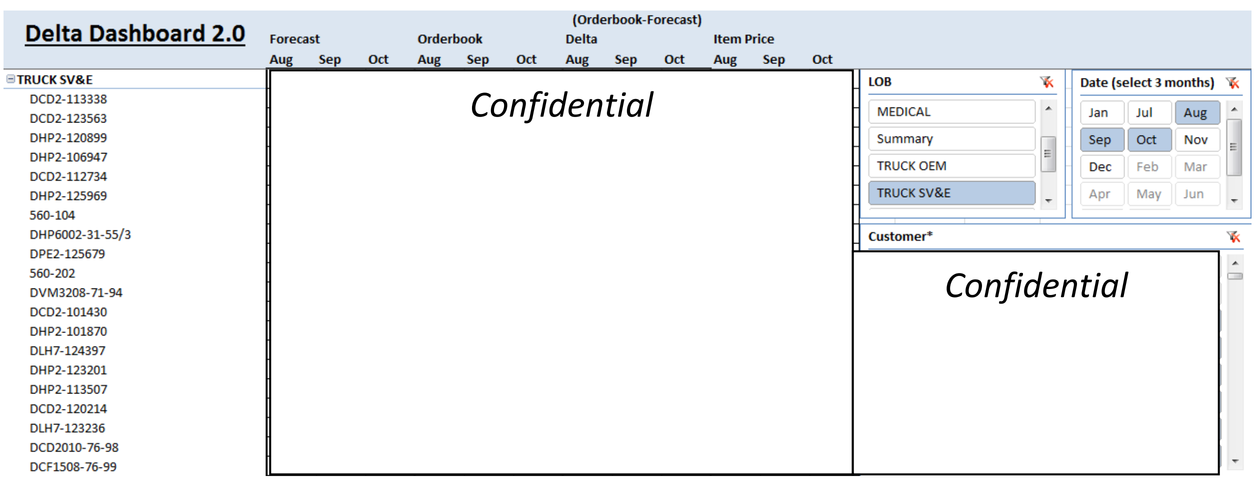


Figure 6-9 Delta Dashboard

9 Although this thesis focuses on the SV&E market, the tool provides an option to select which Line Of Business (LOB) to be reviewed.

2. *Review Top 10 items*

The sales department has insight in which products are the most important for their profitability. Some customers are more demanding with respect to On Time Delivery than others. And some products might require some extra attention due to issues in the past. Therefore the sales department identifies 10 products which are reviewed and discussed in detail to ensure a smooth delivery of these components. This top 10 could be adjusted each month, based on the insights of both sales and other SIOP team members who want to review a certain component in detail.

SIOP Dashboard (Tool)

The SIOP Dashboard (figure 6-10) has been developed to be able to quickly analyze historical, forecast and actual demand patterns. Besides this the Net Stock (current On Hand minus 2 days' supply, which is still in inventory but already reserved for shipping) and System Safety Stock settings of the top 10 products are displayed in the graphs. The Dashboard provides the possibility to search for a specific product to be reviewed in case the Delta Dashboard revealed abnormalities which should be further analyzed. The SIOP Dashboard is a graphical representation of four separate reports. The visualized data is much easier and faster to interpret.

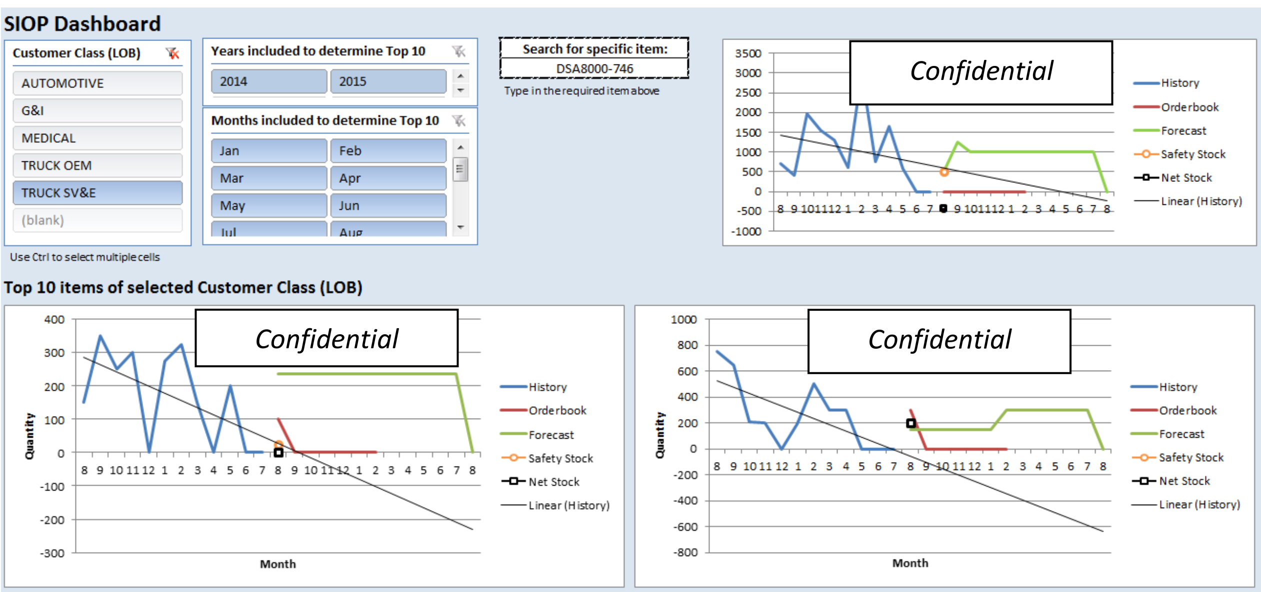


Figure 6-10 SIOP Dashboard

Example: Take the SIOP Dashboard output for product X (figure 6-11), ranked sixed in the top 10. The order book, which displays the actual placed orders, shows twice as much orders than the forecast anticipated (the Order book is empty in the upcoming months due to the single incoming orders with a lead time of 5 weeks). As the Net stock point indicates, there currently seems to be a shortage. Although the Safety Stock of this product should be 100 units, there seems to be no unit available at all. Questions during the SIOP meeting could for example be about possible actions to produce the remaining products on time. Are there enough materials to

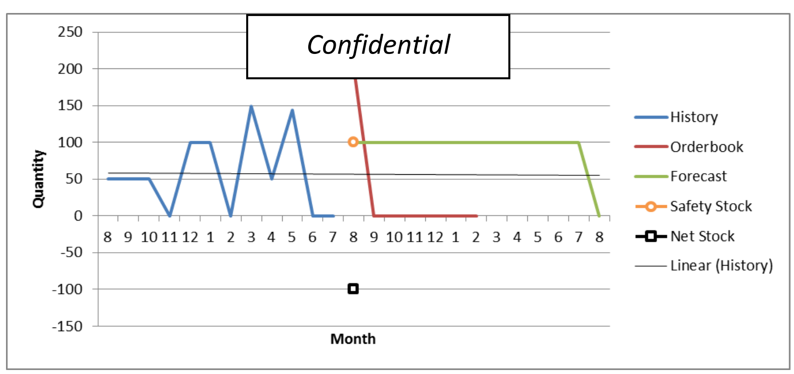


Figure 6-11 SIOP Dashboard output product DPE2-123611

produce the product? If not, is it possible to get material emergency shipments on time to start production? Should the forecast be updated because the demand will also increase in the upcoming months? Should we adjust the inventory settings for the corresponding materials to prevent future shortages?

3. OTD / Overdue

The third topic during a SIOP meeting is the On Time Delivery performance and the (corresponding) overdue performance. The main objectives of the initiatives in this thesis are set up to improve the On Time Delivery performance in the SV&E market. The OTD is measured and the causes of OTD problems are registered by the SOP department and presented in a chart; see figure 6-12. There are predefined root causes on which the SOP department can categorize the cause of the OTD problem. These categories were explained in section 3.1.3.

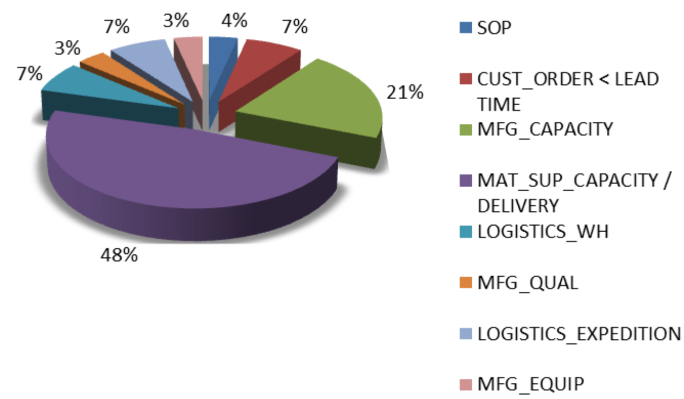


Figure 6-12 Root cause NOTD SV&E May 2015

The SOP department prepares a weekly update of the OTD problems. The departments responsible for the OTD problems should respond to this update if they do not agree with the specified cause. During the SIOP meeting these NOTD causes need to be discussed and appropriate actions should be defined to prevent future occurrences.

For example: A product could not be delivered on time because one of the materials was not present at the start of the production. This results in a "MAT_SUP_CAPACITY/DELIVERY" root cause. During the SIOP meeting it would be interesting to present which component was not available and what actions should be taken to overcome shortage of this component in the future.

The second KPI used by finance and the logistical department is the Overdue. As is discussed extensively in Appendix B, Overdue mainly has the same root causes as mentioned in the OTD problem root causes. The biggest difference is that the Overdue represents the value of the orders which are not delivered on time to the customer. Because most of the root causes are already dealt with during the OTD discussion, the remaining root causes of the Overdue only apply to for example client payment issues or shipping problems

4. Expedited Freight

If the On Time Delivery performance is really good, but this is accomplished by emergency shipments from suppliers and to customers, this means there could still be a problem with the current inventory control parameter settings. This extra cost for emergency shipments is measured as the Expedited Freight. Each month an Expedited Freight report is prepared with the cost incurred for emergency shipments in the previous month. During the SIOP meeting the outliers are discussed. For example, if a certain product shipped from China constantly makes use of emergency shipments, there should be an incentive to look for alternative opportunities. These opportunities could rise from extra safety stock to the selection of a local supplier to overcome the expensive air shipments of heavy raw materials. Of course it is important to discuss the underlying cause for the emergency shipments. The multidisciplinary SIOP team can indicate and discuss what the main underling problems are.

5. Tenders / Big after-market orders

Unusual sales could have a huge impact on the normal material usage and production plan / capacity. Early signs enable the different departments to react on time. Material planners could arrange extra raw materials, production could start producing to stock or hire extra temporary employees. Therefore, each month the sales department prepares a Power-point slide with an update of upcoming tenders, big after-market orders or expected unusual sales amounts. Based on this information all departments define actions to smoothen the delivery of these extra sales volumes.

6. Safety Stock

Safety stock is currently the major buffer against uncertainty. Unfortunately the safety stock is not updated frequently enough, causing excess inventory of end of life products and a shortage for others. Using the new inventory classification model a good baseline is defined to identify demand patterns. The SIOP meeting mainly deals with exceptions. In reality all kinds events could happen which are not modelled. This could relate for example to quality issues or temporarily supplier closedown during holidays. Besides these unknown events there are also cases in which it is known that a certain safety stock amount is necessary, but right communications between Sales and Logistics lacks. A recent issue gives a good example of this communication problem:

In May 2015 the sales department sent an email to the logistical department with the request to increase the safety stock for a certain product. The reason for the increase was not known. The person responsible for updating the safety stock looked at the forecast and did not see any demand until February 2016. So the safety stock setting was scheduled for November 2015. Taking into account the long lead times from China this would seem early enough to build the safety stock on time. What this person did not know was that the Sales department made an agreement with a customer to stock a certain amount of this product which should immediately be available. When a request from this customer came in on July 2015 no safety stock of the products was available, nor were there components present to produce the products.

This example shows that safety stocks based on models which are based on historical demand and future demand could provide a good base-line but of course cannot incorporate vaguely communicated agreements between sales and customers. During the SIOP meeting the Sales department communicates these agreements and these agreements are immediately registered in a “Safety stock agreement form”.

Besides this a review based on demand versus safety stock is done on a regular basis. Decreasing demand for a certain item must be corrected in the safety stock setting. Currently there remains excess inventory for products which are not produced any more while the safety stock setting is not changed!

Finally, planners, sales people, and material planners can request a safety stock increase because they recognize material shortage problems for certain components or products. Main point of discussion will be whether extra safety stock is the solution.

6.2.4 SIOP Implementation plan

Implementation of the SIOP process requires the support of many stakeholders. Higher management support is needed to get the people with the right competencies involved. Reports need to be updated to new standards and people need to be informed about their new responsibilities. To be able to guide the implementation of the SIOP process, the implementation started already during the execution of this master thesis. Figure 6-13 provides the implementation steps.

Figure 6-13 Implementation steps SIOP

After all involved people were informed about their contribution to the SIOP meeting an introduction meeting of 2 hours has been given. During this introduction meeting the SIOP process cycle, depicted in figure 6-8, has been explained. All required actions for the next SIOP meeting were outlined.

During the Pilot SIOP process for the SV&E market the topics discussed could be adjusted based on relevance and timing. A major pitfall during the SIOP meeting is timing. Many topics need to be discussed, but a too detailed discussion consumes valuable time of other important topics. Therefore the process should be evaluated and adjusted if these kinds of pitfalls arise.

Table 6-4 shows the timetable corresponding to the SIOP implementation process. As was mentioned before, the first SIOP meetings were already conducted during the execution of this Master thesis. During these meetings valuable insights and actions were defined and executed, for example the approval and implementation of new Demand Time Fence parameter settings, as discussed in paragraph 6.1.1.

Augustus 15th	**Inform selected people for SIOP**
September 8th	SIOP Introduction presentation
September 15th	1st SIOP meeting
October 13th	2nd SIOP meeting (Evaluation / Adjustments of Topics)
November 10th	3rd SIOP meeting (Evaluation / Adjustments of Topics)
December 15th	4th SIOP meeting (Evaluation / Adjustments of Topics)
January 12th	Evaluation SIOP / decide on continuation of SIOP meetings

Table 6-4 Timetable SIOP implementation

After 4 SIOP meetings an evaluation will take place in order to determine how to proceed.

6.3 Conclusion – Qualitative part

Section 6.2 outlined the Sales Inventory & Operations Planning process implemented at Power-Packer, and answered sub question 6: “What is the appropriate set-up of the Sales Inventor & Operations Planning (SIOP) for Power-Packer Europe in order to be able to increase the On Time Delivery performance in the SV&E market?”

This more qualitative approach to improve the On Time Delivery performance combines the knowledge from people in different departments. The cross functional team reviews current delivery problems and takes action to prevent future On Time Delivery problems. During the SIOP meeting six recurring topics will be discussed which should improve the On Time Delivery. The first two SIOP meetings were already successfully completed. Quantitative inventory models provide a good basis for parameter settings, but the human knowledge and interaction is still insurmountable, the SIOP meetings provide the basis for discussion and agreements about parameter settings. Eventually this must lead to consensus between all stakeholders and improve the On Time Delivery performance in the SV&E market.

7. Conclusion and Recommendations

Each chapter finished with the answer on the corresponding sub-question. Based on these answers, the conclusion in section 7.1 provides the answer on the main research question, which was formulated as follows:

"How can Power-Packer Europe improve the On Time Delivery (OTD) performance in the Special Vehicle & Equipment market, based on a customer lead time which is at maximum 5 weeks?"

In section 7.2 we give recommendations based on the research done in this report. Next section 7.3 deals with the limitations of the research in the discussion part. Finally section 7.4 gives guidelines for possible further research.

7.1 Conclusions

The biggest improvement in the On Time Delivery performance to customers can be gained by improving the availability of components to start production on time. On average one third of the On Time Delivery problems has been caused by a material shortage. The current inventory management system is completely build based on the smooth demand patterns and reliable forecasts in the Automotive and Truck OEM businesses. However, the SV&E business relies on single incoming orders without a reliable forecast. To make a distinction between all these components a new component classification model has been developed.

The new component classification model, which classifies components based on value, supplier lead time and demand pattern, provides a new foundation for setting correct inventory parameter settings per component. Analysis of the internal lead times revealed that, in the worst case scenario, there are 10 workdays left for the supplier to deliver the components on time, so no inventory is needed for components with a lead time of 10 workdays or less. For all other components it is important to be able to distinguish based on the demand pattern. Using the new classification model, the critical components with an intermittent, lumpy or singular demand pattern can now be distinguished from the components with a smooth or erratic demand pattern. The latter two can be managed using the current inventory management system, while the others need a new inventory management strategy.

Croston's forecasting method and de inventory replenishment policy of Teunter et al (2009), which includes a new safety stock calculation, are especially designed to manage components with an intermittent demand pattern. Adjustment of the current forecast method and inventory replenishment policy to these new methods can optimally improve the component availability of components with an intermittent and lumpy demand pattern to more than 95%. Unfortunately, a simulation based on the historical demand data of Power-Packer revealed that this goes along with an increased inventory value of 53% for the 37 components with an intermittent demand pattern and 84% for the 20 components with a lumpy demand pattern. This corresponds to a total increased inventory value of €199,000 (fictitious number). So even when an optimal forecasting method and inventory replenishment policy is used, the inventory value increases significantly. The huge increase is mainly caused by the long lead times of components sourced abroad and the current low safety stock values which were based on safety stock calculations for components with a smooth demand pattern. The safety stock for components with an intermittent and lumpy demand must cover both the uncertain demand quantities and occurrences. The new inventory policy can adequately deal with this uncertainty but at high costs compared to the current situation. To reduce inventory costs, a reduction of the lead times for components with an intermittent or lumpy demand pattern should be a top priority. We performed a sensitivity analysis is section 6.1.4.1 which indicated that the lead time has a significant impact on the required safety stock to obtain the 95% service level.

Besides the quantitative parts described above, a more qualitative approach has been implemented in the form of a Sales Inventory & Operations Planning (SIOP) process. During the SIOP meetings the On Time Delivery performance is reviewed and (corrective) actions are taken to further improve the On Time Delivery. Challenging issues related to the On Time Delivery performance are discussed by a multidisciplinary team in order to reach consensus about the optimal parameter settings. The six recurring topics support a structured meeting. A quantitative inventory model provides a good basis for the On Time Delivery performance, but human knowledge and judgement is still of great value in setting the correct parameter settings.

7.2 Recommendations

Based on the research the following recommendations are formulated:

- The safety stock calculation method should be adjusted based on the demand pattern to avoid underestimation of the safety stock quantity. These demand patterns can be identified by making use of our newly proposed component classification model. The safety stock calculation should be based on the forecast error.
- Save forecast data and corresponding actual demand data on component level to be able to calculate forecast errors, which can then be used to determine appropriate safety stock quantities.
- Reduce supplier lead times of components with an intermittent, lumpy or singular demand pattern to 10 workdays or less to avoid holding a huge amount of inventory to cover for the demand uncertainties. Source local suppliers to increase flexibility, suppliers abroad are not flexible enough to react to changes. This report showed that even with an optimal inventory replenishment policy the inventory holding costs increase if the availability target of 95% must be reached.
- Implement Croston's forecasting method for components with an intermittent demand pattern. Currently the forecast is made on product level, products which show an intermittent demand pattern should be forecasted based Croston's forecasting method. The MRP system will translate this automatically to component demand.
- Implement the new inventory replenishment policy we described in this report after the supplier lead times have been reduced for components with an intermittent, lumpy or singular demand pattern[10]. When the supplier lead times are reduced the new inventory replenishment model calculates optimal stock quantities for the lowest cost at a certain service level.

- Go on with the Sales Inventory & Operations Planning process which has been implemented during this research. Adjust the topics discussed during the SIOP meeting based on experiences. Currently there is a lot to discuss in limited time. Time will tell what the most valuable topics are to discuss during the meeting. The SIOP meetings can also be valuable for the other Lines Of Business (Automotive, Truck OEM and Medical)
- Use data directly from Oracle. The current reports and dashboards which support the SIOP meetings are all based on Excel files. Although the procedures to make these reports and dashboard are strictly defined, mistakes are easily made.
- It is important to set-up a procedure which stores which components caused the On Time Delivery problem of a product. In this case direct action can be taken at the root cause. The running example in section 3.1.2 showed that components with a supplier lead time of 10 workdays caused On Time Delivery problems while this is theoretically impossible. Analyzing On Time Delivery problems on component level could reveal these wrong lead time settings, but are out of scope in this research. However, validation of lead time settings in Oracle is an important action.
- Validate supplier lead times, during the research it became clear the lead time settings are not correct in some cases.

[10] If the supplier lead time is 10 workdays or less no inventory is needed according to the new proposed component classification model. For components with a reduced lead time, but still larger than 10 workdays, the new proposed inventory replenishment policy should be used.

- Ask external customers to provide more insight in there demand, this decreases the forecast error and thus the safety stock quantities needed.

7.3 Discussion / (Limitations)

In this section the limitations of the research and the limitation of the introduced models introduced are discussed.

The On Time Delivery causes are registered by the SOP employees who classify the On Time Delivery cause based on limited information into pre-defined categories. These categories do sometimes not suite the actual root cause which could result in a bias in the root cause data. Just like the OTD root cause analysis unveiled, the interviews also revealed that the material supply was one of the main problems. Based on both the quantitative and qualitative data it can be assumed that mainly the material supply causes the On Time Delivery problems. Besides this, the SOP employees register which product was not delivered on time, but the component which caused the on time delivery problem is not properly registered in most of the cases. This made it impossible to compare current availability performance on component level with the performance of the new inventory replenishment policy.

The number of components with an intermittent (37) and lumpy (20) demand pattern to test the new inventory replenishment policy was limited, as well as the historical demand data of these components. This could bias the results of the simulation. However, the results showed no unexpected extremes.

The demand pattern classification model can give a wrong result if a component is used in a new product or a product in the "End Of Product (EOP)" stage. For example, the demand data used to determine the demand pattern has a time span of one year. A new product only shows demand in the last 10 weeks of this time span. In this case the demand classification will be Lumpy or Intermittent while in reality the products will be ordered each week from now on and the demand pattern should actually be classified as Smooth or Erratic. Therefore an extra parameter must be added to reveal whether the component is used in a new product or in a product which will not be produced anymore in the future.

The data file with de component usage only shows the components used in production, components which are resold directly to the customer and partly used in production show corrupt results in the demand pattern classification. This is a data issue.

The target service level of 95% used in the simulation for components with an intermittent and lumpy demand pattern reflects that on average 95% of the components can be taken directly from stock. However, a product consists of multiple components, which all should be available to start production. Multiplying the availability of all required products would then result in a lower target service level. However, there are also many high volume components used in these products, which are assumed to be always on stock. Therefore a target service level of 95% for the components with an intermittent or lumpy demand seems reasonable.

Forecast data was not saved at Power-Packer[11], which made it also impossible to compare actual demand versus forecasted demand. To be able to calculate a forecast error based on actual demand at Power-Packer, the Croston forecast has been used in the new inventory replenishment policy. Using the Croston forecast is part of the new inventory replenishment policy but is currently not used at Power-Packer. So the simulation results show what

[11] Since September 2015 the sales department started saving the forecast data, which was too late for this research

would have been the inventory value at a certain service level if both Croston had been used as forecasting method and the new inventory replenishment policy we proposed.

The actual achieved service target levels of the new inventory replenishment policy were not completely in line with the target service levels, but this phenomenon was also observed by Teunter et al (2009) in their research. This is caused by the assumption of normally distributed total lead time demand, which in most of the cases is a poor fit for components with an intermittent or lumpy demand. This could be solved if the demand distribution per component is known. However in practice it is impossible to acquire all demand distributions per component. Besides this the supplier lead time was assumed to be fixed without any variation. In practice the supplier lead time shows variation and also this variation should be buffered by safety stock. However, currently the supplier has two weeks to supply the components, while the model assumes the components must be delivered directly from stock when a demand occurs. These two weeks could be used as safety time to buffer against supplier lead time variability.

7.4 Further research

This section provides a guideline for possible further research.

- New forecasting method: In this report the basic Croston forecast has been used for components with an intermittent demand pattern. However, as has also been mentioned in this report, there are several improved forecasting methods which are based on Croston. Teunter et al (2011) tested these adjusted Croston forecast on accuracy, but the two data sets which were used showed different results. So further empirical research is needed to be able to select the best forecast method for component with an intermittent demand pattern.
- Due to the long supplier lead times huge safety stock quantities are required for components with an intermittent demand pattern. Further research should reveal whether local sourcing is cheaper than holding the large amounts of safety stock proposed by the new inventory replenishment model.
- Besides local sourcing, it would be possible to transport some components by air, instead of by boot. This would decrease the supplier lead time and would also decrease the safety stock needed. However, shipping by air is on average ten times more expensive. Further research should reveal whether these high shipping costs outweigh the extra inventory holding costs and the risks of obsolescence.
- Although left out of scope in this report, the correctness of supplier lead times in Oracle must be reviewed. Examples in this report showed that these are not correct in many cases, which could cause serious material supply problems because the MRP system orders components based on the supplier lead times in the system.
- Further research on safety stock quantities for components with a smooth demand pattern could be conducted, although the current safety stock calculation method is build based on the smooth demand patterns, only supplier location and component value are taken into account. It should be better to monitor forecast errors and variation in supplier lead time to determine safety stock quantities. The variation in supplier lead time could also be added to the safety stock calculation proposed in this report for components with an intermittent demand pattern. The supplier lead time was assumed to be fixed without variation.
- Review internal processes and corresponding lead times. The total internal lead time to produce a product requires 3 weeks in the worst case scenario, while the actual production time is not more than one or two days per order.

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Appendix A – Overdue per SV&E customer

Period 31 Dec 2014 - 31 May 2015.

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Appendix B – Overdue Analysis

As has been discussed in section 3.1.1 the Overdue is highly related to the OTD performance. In most of the cases the Overdue has the same causes as the Not On Time Delivered products. Therefore the Overdue will not be handled in the main part of this thesis. Products which cannot be delivered on time become Overdue per definition, the opposite does not hold. Other causes for Overdue could for example be related to the freight terms or payment conditions, but this is only true in a minor number of cases as will be confirmed by the SOP department in de following sections.

Freight terms

Freight terms refer to the Incoterms. These incoterms (International Commercial Terms) clearly define who arranges the transportation and who carries the risks and cost associated with the transportation and delivery of the goods. The International Chamber of Commerce publishes these incoterms. The main incoterms used within the SV&E market are "Ex Works (EXW)", "Free Carrier (FCA)", "Delivery At Place (DAP)" and "Carriage Paid To (CPT)". The description of these incoterms can be found in the table below (International Chamber of Commerce, 2010), for an overview of all incoterms see the website of the International Chamber of Commerce.

Incoterm	Description
EXW	"Ex Works means that the seller delivers when it places the goods at the disposal of the buyer at the seller's premises or at another named place (i.e., works, factory, warehouse, etc.). The seller does not need to load the goods on any collecting vehicle, nor does it need to clear the goods for export, where such clearance is applicable."
FCA	"Free Carrier means that the seller delivers the goods to the carrier or another person nominated by the buyer at the seller's premises or another named place. The parties are well advised to specify as clearly as possible the point within the named place of delivery, as the risk passes to the buyer at that point."
DAP	"Delivered at Place means that the seller delivers when the goods are placed at the disposal of the buyer on the arriving means of transport ready for unloading at the named place of destination. The seller bears all risks involved in bringing the goods to the named place."
CPT	"Carriage Paid To means that the seller delivers the goods to the carrier or another person nominated by the seller at an agreed place (if any such place is agreed between parties) and that the seller must contract for and pay the costs of carriage necessary to bring the goods to the named place of destination."

If a customer receives the products based on the Ex Works freight term, the customer must arrange the transportation. So after Power-Packer has notified the customer that the goods are ready to be shipped, the customer still needs to arrange the transportation. Based on the transportation truck availability, it could be that the goods are picked up couple of days after the due date. This will result in unnecessary Overdue!

Payment conditions

The payment conditions refer to the moment when the ordered products must have been paid. Most customers have a payment term of 30 or 60 days, which means the products must be paid within 30 or 60 days after the products are shipped and thus invoiced. Some customers on the other hand must pay the products before they are produced or shipped. If a customer from one of these last two classes does not pay on time, the products can become Overdue, the products cannot be shipped on the specified due date.

Impact of Overdue

All products in Overdue must stay in the warehouse and thus be financed by Power-Packer. The average Overdue in the SV&E market has been 233,678 euro (fictitious number) in the past half year. The cost of goods sold is on average 80 percent (fictitious number) of the overdue, and with a capital expense rate of 20 percent (fictitious number) the Overdue consumes unnecessary capital which costs on average (233.678 *0.8*0.2) euro per year. This are costs which directly result from products in Overdue, but indirect costs like lost sales due to unsatisfied customers are hard to measure.

As opposed to the Truck market with important clients like X and X, the SV&E markets does not suffer from immense penalties if products are delivered to late. A line stop at X for example will cost around 3500 euro (fictitious number) per truck, in these cases the not on time parts will later be assembled on the truck while it is standing on the finished goods parking lot of X.

Overdue analysis per customer

The Overdue of the last half year was 233.678 euro (fictitious number) on average. In the table below the top 10 out of the 36 Overdue customers can be found. This top 10 accounts for 73 percent of the total Overdue (with 36 customers). The corresponding Freight terms and Payment conditions are added to analyze whether it is possible that the Overdue amount is caused by these terms and conditions. To get a better inside in the Overdue reason per customer the SOP department has been interviewed, see the next paragraph.

Customer	Overdue	Freight Terms	Payment Conditions
Confidential	**€ 233,558.40**	**EXW**	**PREP. ON SHIPM.**
	€ 99,488.75	**EXW**	**30 NET**
	€ 63,964.70	**EXW**	**30 NET**
	€ 58,065.00	**EXW**	**30 NET**
	€ 47,260.00	**FCA**	**30 NET**
	€ 43,580.87	**EXW**	**30 NET**
	€ 83,818.00	**FCA**	**30 NET**
	€ 30,647.50	**FCA**	**30 DS MONTH END**
	€ 30,618.75	**EXW**	**30 NET**
	€ 29,366.04	**DAP**	**30 ME +10**
	€ 20,745.75	**FCA**	**PREP. ON ORDER**
	€28,099.80	**DELIVERY AT PLACE**	**60 NET**
	€18,190.28	**EX WORKS_PPE**	**30 NET**

SOP Overdue interview

The Sales Order Processing department registers and updates all Overdue reasons in textual form in the "Daily report per LOB – Overview overdue detail". There are many possible reasons for the Overdue, for example: missing parts, incomplete orders, payment issues, customer needs to arrange transportation, order is planned within the lead time, administrative problems, parts are ready but need to be rebooked to Finished Good status before they can be released or the supplier of Power-Packer is too late. But the missing parts show-up in all cases. These missing parts do not only cause Overdue costs, but Power-Packer must also arrange the transportation to the customer on their own costs in most of the cases.

If the freight term of a customer is EX Works, the customer needs to arrange the transportation them self. Only after the products are actually finished the SOP department is authorized to inform the customer that they can arrange transportation. Customers like A and B come from the Czech Republic and Russia respectively, in most of the cases it takes some days until their transporter comes to pick up the goods. All this time the goods need to be stored and financially covered by Power-Packer. If Power-Packer arranges the transportation, the goods are shipped just one day after the request in most of the cases.

The Payment conditions refer to whether an order is allowed to be shipped based on the payment status. Currently the payment conditions do not restrict shipping because nearly all customers have a payment term of 30 days or more after the goods were shipped. In the past, customers like A and B had a “Pre Payment on shipping” condition which could cause Overdue. Currently only 4 of the 36 identified customers with overdue have a “Pre Payment” condition. Whether a pre-payment is done is checked by the SOP department themselves. If the customer lacks pre-payment the SOP department is responsible to contact the customer about the payment status.

So, although the “Freight terms” and “Payment conditions” have some impact on the Overdue, the material shortage is the major cause according to the SOP records and interview. This corresponds to the first not On Time Delivery analysis done in section 3.1.4.

Appendix C – Products with OTD problems

A list of the 75 products which caused an OTD problem in the period July 2014 up to and including May 2015.

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Appendix D – Literature search

This appendix shows the search methodology used for the demand classification and the inventory replenishment policy for components with show an intermittent demand pattern.

Start
- Literature search for Intermittent Demand Inventory Control
- TITLE-ABS-KEY (**intermittent demand inventory**)

118 articles
- Search Engine: Scopus
- Search terms: "Intermittent Demand" AND "Inventory"

84 articles
- Litmit number of articles based on Subject Area
- "Business, Management and Accounting", "Engineering"
- TITLE-ABS-KEY (**intermittent demand inventory**) AND) (LIMIT-TO (SUBJAREA , **"BUSI"**) OR LIMIT-TO (SUBJAREA , **"ENGI"**))

7 articles
- Limit by Abstract and Title review
- "Full text must be available"

11 articles
- Backward search

Appendix E – Forecast methods based on Croston

Forecast methods based on Croston's forecasting method for intermittent demand. Although all methods try to overcome the bias of Croston's method, a recent study outlined that the application of the methods depends on the underlying demand distribution and that the empirical test of these forecasting methods on two real data sets came up with different and sometime opposite findings (ZiedBabai , Syntetos, & Teunter, 2014). So before applying one of forecast methods for intermittent demand, empirical test should reveal which method performs best in a certain demand environment. The mathematical expressions of the forecasting methods based on Croston are given below. The notation is based on the work of Babai, Syntetos & Teunter (2014):

$\mathrm{Y}_t = $ demand for an item in period t
$\mathrm{Y}'_t = $ estimate of mean demand per period made in period t for period t + 1
$z_t = demand\ size\ in\ period\ t, when\ demand\ occurs, with\ a\ mean\ u\ and\ variance\ \sigma^2$
$z'_t = estimate\ of\ mean\ demand\ size\ in\ period\ t$
$p_t = estimate\ of\ probability\ of\ demand\ occurrence\ in\ period\ t$
$T_t = actual\ demand\ interval\ in\ period\ t$
$T'_t = estimate\ of\ mean\ demand\ interval\ in\ period\ t$
$\alpha, \beta = smoothing\ parameters\ (0 \leq \alpha, \beta \leq 1)$

Croston

$If\ Y_t = 0: \quad T'_t = T'_{t-1}, \quad z'_t = z'_{t-1}, \quad Y'_t = Y'_{t-1}$

$If\ Y_t = 1: \quad T'_t = T'_{t-1} + \beta(T_t - T_{t-1}), \quad z'_t = z'_{t-1} + \alpha(Y_t - z'_{t-1}), \quad Y'_t = z'_t / T'_t$

SBA method

If $\quad Y_t = 0 : T'_t = T'_{t-1}, \quad z'_t = z'_{t-1}, \quad Y'_t = Y'_{t-1}.$

If $\quad Y_t > 0 : T'_t = T'_{t-1} + \beta(T_t - T'_{t-1}), \quad z'_t = z'_{t-1} + \alpha(D_t - z'_{t-1}),$
$Y'_t = (1 - \beta/2) z'_t / T'_t.$

SY method

If $\quad Y_t = 0 : T'_t = T'_{t-1}, \quad z'_t = z'_{t-1}, \quad Y'_t = Y'_{t-1}.$

If $\quad Y_t > 0 : T'_t = T'_{t-1} + \beta(T_t - T'_{t-1}), \quad z'_t = z'_{t-1} + \alpha(D_t - z'_{t-1}),$
$Y'_t = (1 - \beta/2) z'_t / (\mathrm{T}'_t - \beta/2).$

TSB method

If $\quad Y_t = 0 : p'_t = p'_{t-1} + \beta(0 - p'_{t-1}), \quad z'_t = z'_{t-1}, \quad Y'_t = p'_t z'_t$

If $\quad Y_t > 0 : p'_t = p'_{t-1} + \beta(1 - p'_{t-1}), \quad z'_t = z'_{t-1} + \alpha(z_t - z'_{t-1}),$
$Y'_t = p'_t z'_t$

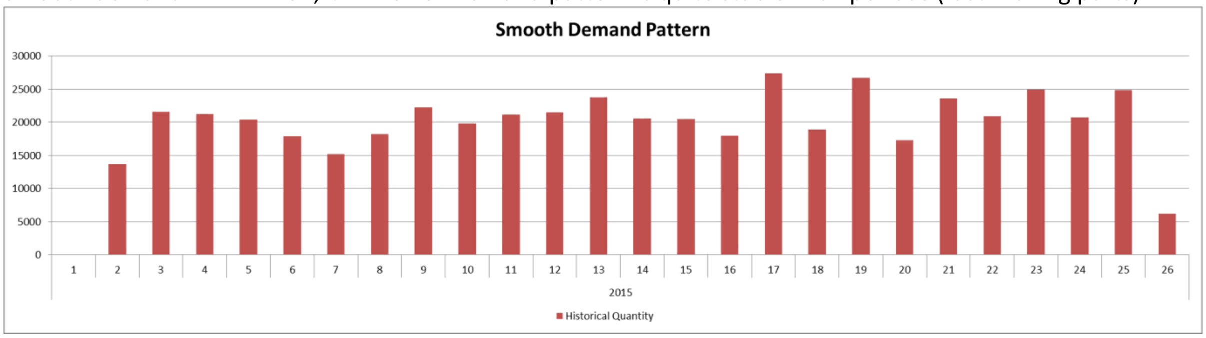
SES method

$Y'_t = Y'_{t-1} + \alpha(Y_t - Y'_{t-1})$ for all t.

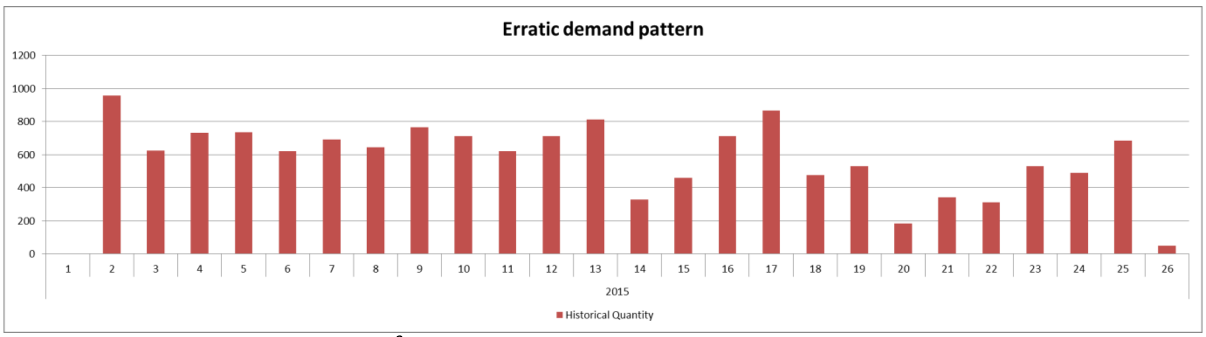
Appendix F – Demand pattern classification

Examples of the demand pattern classification of Syntetos *et al* (2005), based on real data of Power-Packer:

Smooth demand: ADI ≤ 1.32, $CV^2 \leq 0.49$: Demand pattern is quite stable in all periods (fast moving parts)

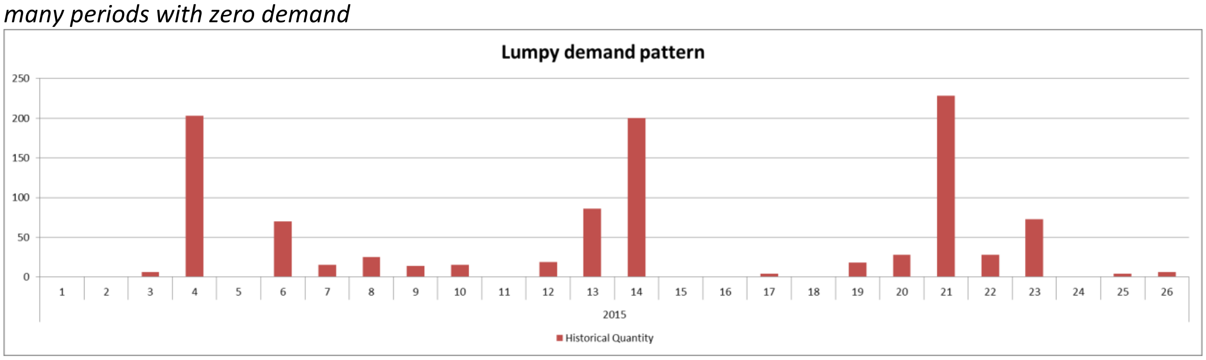


Erratic demand: ADI ≤ 1.32, $CV^2 > 0.49$: Irregular demand pattern with frequent demand occurrences



Intermittent demand: ADI > 1.32, $CV^2 \leq 0.49$: Demand pattern with quite constant demand, but relatively many zero demand periods.

Lumpy demand: ADI > 1.32, $CV^2 > 0.49$: Demand with great differences between demand quantities and relatively many periods with zero demand



Appendix G – Forecast accuracy comparison

Comparison of the forecast accuracy of the current forecasting method Demantra and Croston's forecasting method. The accuracy of Croston's forecast is 10-12% higher based on the Mean Absolute Deviation. Below you can find an example of the forecast accuracy for component X, with α=0.15.

COMPONENT	**X**				
WEEK	**Actual Demand**	**Demantra Forecast**	**Croston Forecast**	**MAD Demantra**	**MAD Croston**
41	0	0.00	20.98	0.00	20.98
42	0	0.00	20.98	0.00	20.98
43	0	0.00	20.98	0.00	20.98
44	0	0.00	20.98	0.00	20.98
45	0	28.50	20.98	28.50	20.98
46	24	28.50	11.86	4.50	12.14
47	0	28.50	11.86	28.50	11.86
48	0	28.50	11.86	28.50	11.86
49	0	12.00	11.86	12.00	11.86
50	60	12.00	12.22	48.00	47.78
51	0	12.00	12.22	12.00	12.22
52	0	12.00	12.22	12.00	12.22
1	0	12.00	12.22	12.00	12.22
2	0	25.00	12.22	25.00	12.22
3	0	25.00	12.22	25.00	12.22
4	0	25.00	12.22	25.00	12.22
5	70	25.00	11.79	45.00	58.21
6	0	40.50	11.79	40.50	11.79
7	0	40.50	11.79	40.50	11.79
8	0	40.50	11.79	40.50	11.79
9	0	40.50	11.79	40.50	11.79
10	0	6.00	11.79	6.00	11.79
11	0	6.00	11.79	6.00	11.79
12	50	6.00	10.94	44.00	39.06
13	0	6.00	10.94	6.00	10.94
14	0	6.00	10.94	6.00	10.94
15	100	15.75	12.83	84.25	87.17
16	0	15.75	12.83	15.75	12.83
17	100	15.75	15.14	84.25	84.86
18	0	15.75	15.14	15.75	15.14
19	0	25.00	15.14	25.00	15.14
20	82	25.00	16.35	57.00	65.65
21	0	25.00	16.35	25.00	16.35
22	0	25.00	16.35	25.00	16.35
23	0	19.00	16.35	19.00	16.35
24	0	19.00	16.35	19.00	16.35
25	50	19.00	15.32	31.00	34.68
26	0	19.00	15.32	19.00	15.32
27	10	19.00	14.59	9.00	4.59
28	0	19.00	14.59	19.00	14.59
Forecast Error: Mean Absolute Deviation (MAD)				**24.60**	**21.97**
	Improved forecast Croston versus Demantra				12%

Appendix H – Simulation output

The simulation (paragraph 6.1.4.1) output of the selected components with an intermittent and lumpy demand pattern based on the new classification model described in section 5.1.5.

Intermittent demand

Simulation of 37 components with an intermittent demand pattern, value >1€, lead time > 10 workdays, selected for master thesis.									
Alpha	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Target Service Level % (used in Simulation)	80.0%	82.5%	85.0%	87.5%	90.0%	92.5%	95.0%	97.5%	99.0%
Actual obtained service level % (new inventory policy)	**84.2%**	**85.8%**	**87.5%**	**89.2%**	**91.0%**	**93.0%**	**95.1%**	**96.4%**	**97.0%**
Total Backorders	120	112	105	93	83	68	49	32	26
Average OTD percentage	**80.4%**	**81.7%**	**82.8%**	**84.8%**	**86.4%**	**88.9%**	**92.0%**	**94.8%**	**95.8%**
Total On Hand Croston	9844	10632	11505	12491	13649	15061	16929	19848	23287
Total On Hand Power-Packer	17362	17362	17362	17362	17362	17362	17362	17362	17362
Total Safety Stock (Teunter et al 2009)	8494	9432	10460	11610	12934	14529	16601	19781	23479
Total System Safety Stock (Power-Packer)	3591	3591	3591	3591	3591	3591	3591	3591	3591
Total Value On Hand Croston	€ 95,075	€ 102,663	€ 111,059	€ 120,525	€ 131,610	€ 145,068	€ 162,703	€ 190,020	€ 222,030
Total Value On Hand Power-Packer	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665	€ 106,665
Total Value Safety Stock (Teunter et al 2009)	€ 76,478	€ 84,926	€ 94,180	€ 104,532	€ 116,454	€ 130,809	€ 149,467	€ 178,101	€ 211,394
Total Value Safety Stock (Power-Packer)	€ 16,641	€ 16,641	€ 16,641	€ 16,641	€ 16,641	€ 16,641	€ 16,641	€ 16,641	€ 16,641
Target Service Level % Power-Packer	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Inventory value using Croston (%)	-11%	-4%	4%	13%	23%	36%	53%	78%	108%
Inventory value using Croston (€)	€ (11,590)	€ (4,002)	€ 4,394	€ 13,860	€ 24,945	€ 38,403	€ 56,038	€ 83,354	€ 115,364

Lumpy demand

Simulation of 20 components with a Lumpy demand pattern, value >1€, lead time > 10 workdays, selected for master thesis.									
Alpha	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Target Service Level % (used in Simulation)	80.0%	82.5%	85.0%	87.5%	90.0%	92.5%	95.0%	97.5%	99.0%
Actual obtained service level % (new inventory policy)	**84.2%**	**85.6%**	**86.6%**	**87.7%**	**88.7%**	**89.7%**	**91.2%**	**92.6%**	**95.6%**
Total Backorders	62	51	47	40	37	34	29	25	14
Average OTD percentage	**80.6%**	**84.0%**	**85.3%**	**87.5%**	**88.4%**	**89.3%**	**90.9%**	**92.2%**	**95.6%**
Total On Hand Croston	9300	9837	10434	11108	11891	12834	14072	16006	18298
Total On Hand Power-Packer	14003	14003	14003	14003	14003	14003	14003	14003	14003
Total Safety Stock (Teunter et al 2009)	5415	6013	6669	7402	8246	9262	10583	12611	14968
Total System Safety Stock (Power-Packer)	3845	3845	3845	3845	3845	3845	3845	3845	3845
Total Value On Hand Croston	€ 46,409	€ 49,267	€ 52,461	€ 56,060	€ 60,221	€ 65,231	€ 71,771	€ 81,908	€ 93,902
Total Value On Hand Power-Packer	€ 50,912	€ 50,912	€ 50,912	€ 50,912	€ 50,912	€ 50,912	€ 50,912	€ 50,912	€ 50,912
Total Value Safety Stock (Teunter et al 2009)	€ 28,797	€ 31,978	€ 35,463	€ 39,360	€ 43,850	€ 49,255	€ 56,280	€ 67,062	€ 79,599
Total Value Safety Stock (Power-Packer)	€ 16,320	€ 16,320	€ 16,320	€ 16,320	€ 16,320	€ 16,320	€ 16,320	€ 16,320	€ 16,320
Target Service Level % Power-Packer	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Inventory value using Croston (%)	-9%	-3%	3%	10%	18%	28%	41%	61%	84%
Inventory value using Croston (€)	€ (4,503)	€ (1,645)	€ 1,549	€ 5,148	€ 9,309	€ 14,319	€ 20,859	€ 30,996	€ 42,990

Appendix I – Sensitivity analysis output

Sensitivity output based on lead time reduction of the 10 selected components with an intermittent demand pattern, which currently have a supplier lead time of 11 weeks:

LEAD TIME (weeks)	11	10	9	8	7	6	5	4	3
Alpha	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Target Service Level	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Average proportion directly delivered from stock	99.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total Backorders	1	0	0	0	0	0	0	0	0
Average weighted OTD percentage	99.3%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total On Hand Croston	6255	5958	5660	5354	5032	4672	4305	3911	3492
Total On Hand Power-Packer	3009	3009	3009	3009	3009	3009	3009	3009	3009
Total Safety Stock (Teunter et al 2009)	4876	4650	4415	4171	3915	3645	3358	3048	2709
Total System Safety Stock (Power-Packer)	50	50	50	50	50	50	50	50	50
Total Value On Hand Croston	€ 86,109.11	€ 82,481.50	€ 78,765.30	€ 74,891.56	€ 70,681.74	€ 65,741.67	€ 60,738.19	€ 55,273.06	€ 49,443.33
Total Value On Hand Power-Packer	€ 34,507.08	€ 34,507.08	€ 34,507.08	€ 34,507.08	€ 34,507.08	€ 34,507.08	€ 34,507.08	€ 34,507.08	€ 34,507.08
Total Value Safety Stock (Teunter et al 2009)	€ 70,324	€ 67,034	€ 63,623	€ 60,070	€ 56,349	€ 52,424	€ 48,246	€ 43,741	€ 38,797
Total Value Safety Stock (Power-Packer)	€ 1,349	€ 1,349	€ 1,349	€ 1,349	€ 1,349	€ 1,349	€ 1,349	€ 1,349	€ 1,349
Safety Stock decrease % compared to lead time = 11		-4.7%	-9.5%	-14.6%	-19.9%	-25.5%	-31.4%	-37.8%	-44.8%

Sensitivity output based on lead time of component X, with an intermittent demand pattern:

LEAD TIME (weeks)	11	10	9	8	7	6	5	4	3
Alpha	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Target Service Level	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Average proportion directly delivered from stock	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total Backorders	0	0	0	0	0	0	0	0	0
Average weighted OTD percentage	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total On Hand Croston	1273	1218	1161	1102	1039	964	888	806	717
Total On Hand Power-Packer	329	329	329	329	329	329	329	329	329
Total Safety Stock (Teunter et al 2009)	995	948	899	848	795	739	680	616	545
Total System Safety Stock (Power-Packer)	0	0	0	0	0	0	0	0	0
Total Value On Hand Croston	€ 54,404.39	€ 52,053.95	€ 49,615.83	€ 47,113.07	€ 44,384.58	€ 41,182.71	€ 37,952.35	€ 34,427.22	€ 30,650.07
Total Value On Hand Power-Packer	€ 14,059.96	€ 14,059.96	€ 14,059.96	€ 14,059.96	€ 14,059.96	€ 14,059.96	€ 14,059.96	€ 14,059.96	€ 14,059.96
Total Value Safety Stock (Teunter et al 2009)	€ 42,504	€ 40,498	€ 38,418	€ 36,253	€ 33,986	€ 31,595	€ 29,049	€ 26,304	€ 23,289
Total Value Safety Stock (Power-Packer)	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Safety Stock decrease % compared to lead time = 11	0.0%	-4.7%	-9.6%	-14.7%	-20.0%	-25.7%	-31.7%	-38.1%	-45.2%

Sensitivity output based on lead time of component X, with an intermittent demand pattern:

LEAD TIME (weeks)	11	10	9	8	7	6	5	4	3
Alpha	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Target Service Level	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Average proportion directly delivered from stock	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total Backorders	0	0	0	0	0	0	0	0	0
Average weighted OTD percentage	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total On Hand Croston	290	278	266	253	241	228	214	198	181
Total On Hand Power-Packer	207	207	207	207	207	207	207	207	207
Total Safety Stock (Teunter et al 2009)	274	261	248	234	220	205	189	171	153
Total System Safety Stock (Power-Packer)	0	0	0	0	0	0	0	0	0
Total Value On Hand Croston	€ 3,254.73	€ 3,118.92	€ 2,981.95	€ 2,838.94	€ 2,704.85	€ 2,556.37	€ 2,398.68	€ 2,222.29	€ 2,034.39
Total Value On Hand Power-Packer	€ 2,323.00	€ 2,323.00	€ 2,323.00	€ 2,323.00	€ 2,323.00	€ 2,323.00	€ 2,323.00	€ 2,323.00	€ 2,323.00
Total Value Safety Stock (Teunter et al 2009)	€ 3,071	€ 2,929	€ 2,782	€ 2,629	€ 2,468	€ 2,299	€ 2,119	€ 1,925	€ 1,711
Total Value Safety Stock (Power-Packer)	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Safety Stock decrease % compared to lead time = 11	0.0%	-4.6%	-9.4%	-14.4%	-19.6%	-25.1%	-31.0%	-37.3%	-44.3%

Appendix J – RASCI

The RASCI provides an overview of the responsibilities and actions everybody needs to perform before a predefined deadline.

Confidential

SIOP team members
Data / Report support members

SV&E SIOP meeting 2nd Tuesday of the month 13:30 - 15:00

Task	Deadline	Input	Output	LSE	SOP	Expeditor	Planning	SSM	Product.	SSM	LSE	LSE
Chairman SIOP meeting				R	S	S	S	S	S	S	S	S
ACTION BEFORE THE START OF THE SIOP MEETING												
Adjust monthly Sales Forecast SV&E in Demantra	3rd week of the month	Historical data / Customer schedules	Consencus Forecast Report	S				R		S		
Prepair Slide with unusual upcoming sales (Tenders etc)	SIOP MEETING - 4 days	Customer information	PowerPoint Slide	I				R				
Place updated **Forecast report** in correct folder each month	3rd week of the month	Demantra Forecast	Forecast Report	A						R		
Place updated **Sales & Backlog** report in correct folder	2nd Tuesday of the month	Oracle Data	Sales and Backlog Report	A							R	
Place updated **Sales History** report in correct folder each month	1st (work)day of the month	Historical Sales	Sales History Report	A							R	
Place updated **Inventory Strat** report in correct folder each month	2nd Tuesday of the month		Inventory Strat Report	A							R	
Produce **NOTD report** with root cause analysis	SIOP MEETING - 2 workdays	Forecast Delivery List	NOTD Report		R	S	S					
Send main NOTD root causes to SIOP team members	SIOP MEETING - 2 workdays	NOTD Report	Underlying root causes		R	S	S	S				
Prepair PowerPoint slide with main problems / possible actions / recommendations to improve NOTD	SIOP MEETING - 2 workdays	Underlying root causes	Powerpoint Slide	I	R							
Produce **Expedited Freight** report	SIOP MEETING - 2 workdays	QD-445	Expedited Freight Report	I	S	S						R
Analyse Expedited Freight report	SIOP MEETING - 2 workdays		Root Causes Exp. Freight		R							S
Deliver Expedited Freight PowerPoint slide	SIOP MEETING - 2 workdays	Expedited Freight Report	PowerPoint slide	I	R							S
Produce **Overdue** Report	SIOP MEETING - 2 workdays	Sales & Backlog report	Overdue report	I							R	
Make Overdue PowerPoint slide with month review	SIOP MEETING - 2 workdays	Overdue Report	PowerPoint Slide	I	R							
Safety Stocks Versus Forecast	SIOP MEETING - 2 workdays	Inventory strat. Report		R								
ACTIONS DURING THE SIOP MEETING												
Check whether actions of previous SIOP meeting are excecuted	SIOP MEETING	Action plan previous SIOP	Updated Action plan	R								
Forecast versus Orderbook Review and come up with Corrective actions for the products which show a big difference in. What causes this big differences?	SIOP MEETING	Delta Dashboard	Corrective actions: Limit forecast error, reschedule in, reschedule out etc.	R	S	S	S	S	S			
Review the Top 10 products (selection based on historical turnover)	SIOP MEETING	SIOP Dashboard	Corrective actions to assure we can deliver these most important products on time	R	S	S	S	S	S			
NOTD Root-Cause Review and come up with corrective actions	SIOP MEETING	NOTD Analysis Report	Corrective actions to prevent further NOTD hit	S	R	S	S	S	S			
Expedited Freight Review and come up with corrective actions to decrease costs	SIOP MEETING	Expedited Freight Report	Corrective actions to decrease Expedited Freight costs	S	R	S	S	S	S			
Inform about unusual upcoming sales (Tenders)	SIOP MEETING	PowerPoint	Actions to be able to supply on time	S	S	S	S	R	S			
Safety Stock review / agreements with Sales				R				S				
ACTIONS AFTER SIOP MEETING												