RESEARCH TO THE LEAD TIME PERFORMANCE IN AN UNCERTAIN MAKE-TO-ORDER ENVIRONMENT

A Master Thesis conducted at DAP Technology B.V.

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Preface

This thesis is the end product of the master program Industrial Engineering and Management with specialization track Production & Logistics Management at the University of Twente. I'm satisfied with my choice to go for this master program with a focus on the technical side. During my study, I have gained valuable knowledge which I hope to apply during my working career. I am very proud to finally obtain my master's degree.

I would like to take the opportunity to thank a few people who made this project possible. First of all, I would like to thank my supervisor from the University of Twente: IR. W.J.A. Van Heeswijk. I'm grateful for the guidelines and feedback you provided. It was definitely not easy to formulate a suitable graduation assignment, but you helped with the brainstorm sessions and steering me in the right direction.

Furthermore, I want to thank the people at DAP Technology for making this project possible. I want to thank Jan de Vries for supervising the research. I'm grateful for the fact that you kept believing in a valuable graduation project despite the problematic start. I enjoyed working on the assignment and discussing the results. I want to thank Frank Maasdam and Peter van Gaal for the great support in the time-consuming data collection phase. I hope this thesis will provide valuable insight and contributes to a bright future for the company.

Thijs Jeurissen
Enschede, December 2019

Summary

This master thesis is about the improvement of the delivery reliability and delivery speed at DAP Technology.

- **Delivery Reliability**: Percentage of total number of Production Orders (POs) that is delivered within the quoted lead time.
- **Delivery Speed:** Percentage of total number of POs that is delivered within 4 weeks, when the customer prefers to receive the products as soon as possible.

The motivation of research is founded by the fact that DAP Technology wants to offer a good service to its customers, to keep a leading position in the IEEE-1394 industry. The management team currently has insufficient insight into the order delivery performance. They want to know if there are aspects of the organization that need to be improved to achieve a delivery speed and delivery reliability of at least 95%. Furthermore, the management team wants to know how these improvements could be realized. The main research question is formulated as follows:

How can DAP Technology achieve a delivery reliability and delivery speed of at least 95%?

We identify that, from 2017 on, DAP was able to deliver 80.9% of its orders within the targeted lead time (delivery speed) and 82.6% of the orders within the quoted lead time (delivery reliability). This means that the feeling of the management team was right that improvements need to be made to achieve the desired performance. In the current situation, the information systems do not provide enough support for the sales, purchasing and order processing departments to properly manage inventory. With better support from information systems, Sales and Purchasing might better anticipate inventory shortages and improve the delivery performance.

To design a solution, we make a conceptual design for an IT system in which broad outlines of function and processes are described. The organization should adopt a centralized inventory management tool, in which crucial information of the three departments can be combined. Information regarding upcoming customer demand, that is currently stored in Customer Relationship Management (CRM) system Goldmine, should be linked with information regarding the inventory status of components, that is currently stored in information system Minox. Moreover, information about supplier lead times should be added, which the organization currently does not register. This combined information can be used to make inventory forecasts to better anticipate inventory shortages.

Using the centralized tool, various purchasing policies and due date quotation policies can be applied. Our goal is to find purchasing policies that result in a delivery speed of at least 95% with a low average value of components on stock. Furthermore, we want to find due date quotation policies that result in a low average quoted lead time, while a delivery reliability of 95% will be achieved. We simulate the order delivery process when the centralized tool would have been implemented and the departments therefore have full information availability. We conduct experiments for various future scenarios, in which we vary the number of opportunity arrivals. Opportunities are customers that show concrete interest in one of DAP's products and are possibly going to place a PO in the near future. Conducting simulation experiments, we identify that the best way to achieve a delivery speed of 95% is by using a purchasing policy that categorizes the inventory components into two categories:

- Category A: Components with a low expected demand (demand score < 8)
- Category B: Components with a high expected demand (demand score ≥ 8)

Since it is not easy to predict future scenarios, we choose for a policy that performs well under all tested scenarios for the opportunity arrival frequency. The following purchasing policy seems to be the most robust for various future scenarios:

Category A components:	*Fixed re-order level; Fixed order quantity*
Category B components:	*Fixed re-order level; Variable order quantity based on inventory forecast*

Furthermore, we identify that the best way to achieve a delivery reliability of 95% is by using the following due date quotation policy:

Category A+B components:	*Moment of quoting extra lead time based on inventory forecast; Fixed quantity of extra lead time*

This means that the organization does not have to distinguish between components for this policy. The same policy can be applied for all inventory components.

To conclude, using the centralized tool, the delivery speed and delivery reliability are likely to improve because it enables the purchasing and sales departments to better anticipate inventory shortages. The simulation study shows that various purchasing policies and due date quotation policies can be applied to achieve a delivery reliability and delivery speed of at least 95%. This means that the current performance regarding delivery speed and delivery reliability of respectively 80.9% and 82.6% can be improved. The research shows that various steps need to be taken to improve the delivery speed and delivery reliability. On the short term the organization should internally discuss if they are willing to invest in additional IT. This research provides guidelines to implement additional IT that can improve the delivery reliability and delivery speed. Moreover, the organization should start better registering and monitoring data that is crucial for analyzing the order delivery process. In the current situation, data is often difficult to obtain and sometimes scarce. Better registering and monitoring crucial data of the sales, purchasing and order processing departments will make it easier to analyze the order delivery process and find future bottlenecks. The sales department should better register and monitor the arrival behavior of opportunities. This information can help to better anticipate potential POs. The purchasing department should accurately register and monitor price specifications and supplier lead times for each inventory component, to make a well-founded purchasing decision. The order processing department should register the delivery reliability and delivery speed for each delivered PO. It becomes easier to monitor the performance when this information will be centrally registered. On the long term, various organizational aspects could be investigated more extensively if better data becomes available. Further research could be conducted to further analyze the arrival behavior of opportunities or to zoom in on the performance of suppliers. Moreover, the organization should learn how to work with the simulation model and include more accurate input data on the long term. When the organization is willing to adopt a centralized inventory management tool, the simulation model can be used to maximize the expected effectiveness of the tool.

There are some limitations that the organization should be aware of, when interpreting the results of this research. The quality of input data is sometimes limited. For example, we used triangular distributions for supplier lead times and production times, based on best guesses. When the quality of input data improves, better decisions can be made. Furthermore, the simulation model is just a simplification of reality in which we made assumptions about various aspects of the order delivery process. The goal of the simulation study is to explore if there are possibilities for the organization to improve its current way of working by adopting a centralized inventory management tool. Because the organization does currently not work with a centralized inventory management tool, the obtained sub-optimal configurations are not directly applicable for the current way of working.

Contents

Preface 1

Summary 2

Chapter 1: Introduction 7

1.1) Description of the Company 7

1.2) Research Plan 7

1.2.1) Problem Description and Problem Cluster 7

1.2.3) Motivation of Research & Research Objective 9

1.2.4) Research Scope 9

1.2.5) Research Framework and Questions 9

1.2.6) Deliverables 10

Chapter 2: Context analysis 11

2.1) Process description: How is the PO delivery process currently arranged? 11

2.1.1) Which processes occur in the sales department and how do they interact with other departments? 11

2.1.2) Which processes occur in the purchasing department and how do they interact with other departments? 14

2.1.3) Which processes occur in the order processing department and how do they interact with other departments? 17

2.2) Performance measurement: What is the current performance regarding delivery reliability and delivery speed? 20

2.2.1) What is the total lead time of production orders? 21

2.2.2) What is the current performance regarding delivery speed? 22

2.2.3) What is the current performance regarding delivery reliability? 23

2.3) Overview of problems: What are main reasons that DAP is not able to improve its delivery reliability and delivery speed? 24

2.3 A) Internal shortcomings of the current way of working 25

2.3 B) Lack of knowledge of how the organization can anticipate external uncertainties 27

Chapter 3: Literature review and Solution Design 32

3.1) How can relevant inventory management aspects be properly included? 36

3.1.1) Which functionalities should the tool contain to improve monitoring available stock and upcoming customer demand? 36

3.1.2) Which information needs to be centrally registered? 40

3.2) Which organizational aspects should be taken into account when adopting a centralized inventory management tool? 41

3.2.1) Literature: What does literature say about business IT alignment? 41
3.2.2) What organizational aspects should DAP pay attention to when adopting a centralized tool? 42
3.3) What are possibilities for the purchasing department to use the tool in order to improve the delivery speed? 44
3.3.1) Literature: what can be suitable purchasing policies when customer demand is uncertain? ... 44
3.3.2) Which purchasing policies could be interesting for DAP and how can they be included? 48
3.4) What are possibilities for the sales department to use the tool in order to improve the delivery reliability? 49
3.4.1) Literature: what can be suitable due date quotation policies? 49
3.4.2) Which due date quotation policies could be interesting for DAP and how could they be included? 51
3.5) How can we build a conceptual design for a centralized inventory management tool? 52
3.5.1) Literature: How can a conceptual design for IT systems be created? 52
3.5.2) What does the conceptual design of the centralized inventory management tool look like? .. 52
Chapter 4: Solution Test 56
4.1) How can we test what the expected effectiveness of the tool could be and how the tool should be used? 56
4.1.1) Literature: What type of model can be suitable to evaluate the expected effectiveness of the inventory management tool? 56
4.1.2) Literature: How can we use historical data to simulate the order delivery process based on real life properties? 57
4.1.3) How can we simulate the order delivery process, when the tool would have been implemented? 59
4.1.4) What does the simulation model look like? 74
4.1.5) Which experiments can be conducted? 79
4.2) What is the best way to use the tool to achieve a delivery speed and delivery reliability of at least 95%? 91
4.2.1) What are the best purchasing policies to achieve a delivery speed of at least 95%? 91
4.2.2) What are the best due date quotation policies to achieve a delivery reliability of at least 95%? 94
Chapter 5: Conclusions, Implementation Plan and Recommendations, Limitations 98
5.1 Conclusions 98
5.2 Implementation Plan and Recommendations 100
5.3 Limitations 103
References 104

Appendices 106
Appendix 1: List of Figures & Tables 106
Appendix 2: Goldmine pipeline overview 107
Appendix 3: Arrival frequency of COTS products 108
Appendix 4.1: Sub-optimal configuration Purchasing λ=0.4 (Exp 1 - 8) 109
Appendix 4.2: Sub-optimal configuration Purchasing λ=0.4 (Exp 9 – 16) 110
Appendix 5.1: Sub-optimal configuration Purchasing λ=1 (Exp 1 - 8) 111
Appendix 5.2: Sub-optimal configuration Purchasing λ=1 (Exp 9 – 16) 112
Appendix 6.1: Sub-optimal configuration Purchasing λ=1.6 (Exp 1 - 8) 113
Appendix 6.2: Sub-optimal configuration Purchasing λ=1.6 (Exp 9 – 16) 114
Appendix 7: Sub-optimal objective values Purchasing 115
Appendix 8.1: Sub-optimal configuration Due date Quotation λ=0.4 (Exp 1 - 8) 116
Appendix 8.2: Sub-optimal configuration Due date Quotation λ=0.4 (Exp 9 – 16) 117
Appendix 9.1: Sub-optimal configuration Due date Quotation λ=1 (Exp 1 - 8) 118
Appendix 9.2: Sub-optimal configuration Due date Quotation λ=1 (Exp 9 – 16) 119
Appendix 10.1: Sub-optimal configuration Due date Quotation λ=1.6 (Exp 1 - 8) 120
Appendix 10.2: Sub-optimal configuration Due date Quotation λ=1.6 (Exp 9 – 16) 121
Appendix 11: Sub-optimal objective values Due date Quotation 122

Chapter 1: Introduction

This chapter introduces the research performed at DAP Technology to obtain my master's degree Industrial Engineering and Management. The research analyses the current performance of the organization regarding delivery reliability and delivery speed, and seeks ways to improve this performance. Section 1.1 provides a description of the company. Section 1.2 describes the research plan.

1.1) Description of the Company

DAP Technology is an internationally represented company that is specialized in products, systems and solutions based on IEEE-1394 and AS5643 standards. IEEE-1394 is an interface standard for high-speed communication and real-time data transfers between connected devices in a network. AS5643 are the IEEE-1394 interface requirements for Military and Aerospace vehicle applications. Several products of DAP are globally accepted with applications mainly in the Aerospace and Defense industry. DAP Technology is well known for its "IEEE-1394 Protocol Analyzer" product line. With this product line, DAP responds to the market's need for IEEE-1394 test tools. Furthermore, DAP offers products in the following categories: Interface Solutions, Connectivity devices, IP cores, Software and Accessories. The majority of the products fall in the "commercial off-the-shelf" (COTS) category, such that they can be easily installed and interoperate with customer's existing system components. This thesis focuses on COTS hardware products that must be assembled.

DAP is a knowledge company that collaborates closely with standard's development organizations. These organizations establish and maintain policies, guidelines and procedures that help ensure the integrity of IEEE standards that are generated. The company also attaches great importance to a close collaboration with strategic partners and key customers. The main goal is to develop world-class IEEE-1394 and AS5643 enabled products through a successful combination of skilled staff, project management and the right test- & development tools. With a specialized team of Hardware and Software engineers, DAP is striving for a continuous improvement of key technology elements for AS5643 and IEEE-1394.

DAP was founded in 1998 in Nijmegen and currently operates from various locations in the Netherlands, UK, Canada and US. DAP has 3 facilities. DAP's headquarter is located in Oldenzaal and the R&D and production facility is located in Nijmegen. DAP also has a facility in Arizona (US) to be able to offer local product and sales support to key customers in the US. Furthermore, DAP's CEO and sales manager operate externally from respectively the UK and Canada.

1.2) Research Plan

This section contains the research plan. First, Section 1.2.1 describes the problem as presented by DAP Technology. From this problem description, we derived the problem cluster. After that, the motivation and objective of the research (1.2.3) and the research scope (1.2.4) are described. Finally, the research questions are worked out (1.2.5) and the deliverables are listed (1.2.6).

1.2.1) Problem Description and Problem Cluster

DAP Technology is, with a small organization, a big player in the IEEE-1394 industry. To be able to keep this leading position, the management team feels the need for making improvements to serve customers better. It is important for DAP to offer a good service to its customers. Two important customer service aspects are delivery reliability and delivery speed:

- **Delivery Reliability**: Percentage of total number of Production Orders (POs) that is delivered within the quoted lead time.
- **Delivery Speed:** Percentage of total number of POs that is delivered within 4 weeks, when the customer prefers to receive the products as soon as possible.

We distinguish three departments that are together responsible for a smooth order delivery process: Sales, Purchasing and Order Processing. The sales department is responsible for managing customer contacts from the moment that a customer shows interest in DAP's products until the customer places a PO. The purchasing department is responsible for anticipating potential POs and managing inventory in such a way that as many orders as possible can be assembled and delivered directly from stock, without keeping too much inventory. Finally, the Order Processing department is responsible for processing the PO from the moment that Sales communicates a received PO until the moment of delivery. This includes activities like administration, assembly, testing, sending and invoicing. Figure 1 displays the connection between these 3 departments and thereby the scope of this research.

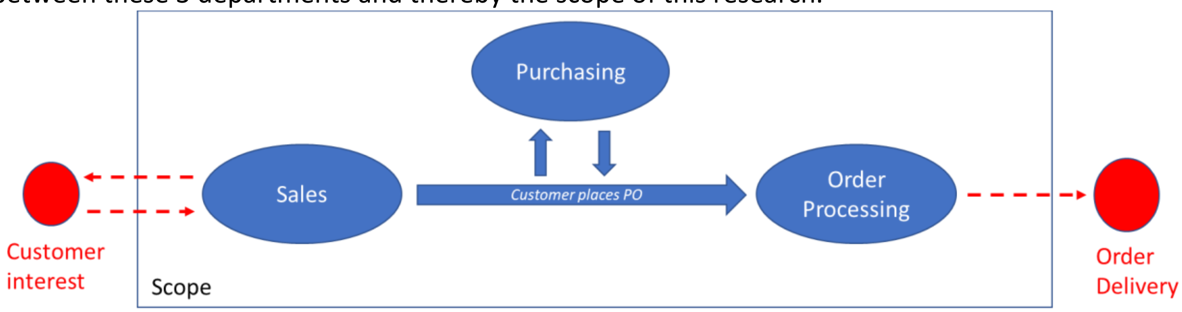

Figure 1: Scope of research

DAP's management team experiences that the alignment between the three departments is currently inadequate, which can have an influence on the order delivery performance. DAP wants to achieve a delivery speed and delivery reliability of at least 95%. The management team believes that, if customers are not satisfied enough, it can cause customers walking away, competitors coming closer, or DAP will be forced to drop prices. Moreover, the chance of attracting new customers will be smaller. The management team thinks that it currently happens too often that DAP is not able to deliver fast enough, and that DAP is not able to realize the lead times they quote to the customer. At the moment, DAP does not have any performance measures that confirm these feelings. The management team wants to know what the seriousness of the problem is, and what possibilities to improve are.

DAP operates from various locations over the world. The sales department operates from an external location in Canada. The purchasing department operates from the Headquarter in Oldenzaal. Order Processing takes place in both the Headquarter and the R&D and production facility in Nijmegen. In the current way of working, it is hard to analyze the current order performance. The management team currently has a deficient overview of the performance of the current way of working, which makes it difficult to find out if DAP needs to improve and how the organization can improve. The problem cluster as described above, is presented in Figure 2. The problem cluster schematically displays the relation between the above-mentioned problems.

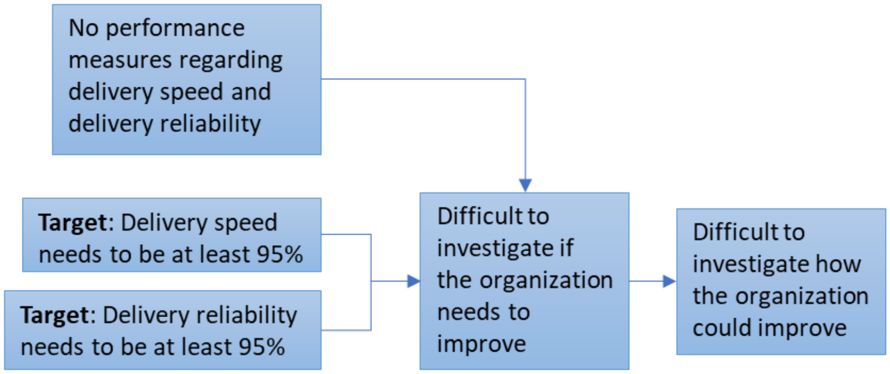

Figure 2: Problem Cluster

1.2.3) Motivation of Research & Research Objective

The motivation of research is founded by the fact that DAP Technology wants to offer a good service to its customers, to keep a leading position in the IEEE-1394 industry. The management team currently has insufficient insight into the order delivery performance. They want to know if there are aspects of the organization that need to be improved to achieve a delivery speed and delivery reliability of at least 95%. Furthermore, the management team wants to know how these improvements could be realized.

The research goal is to identify what the current performance regarding delivery reliability and delivery speed is, and what the main problems are why the organization is currently not able to improve this performance. After that, the objective of the research is to provide DAP Technology with a plan to improve the current order delivery process to achieve the targeted delivery speed and delivery reliability of 95%.

1.2.4) Research Scope

As mentioned in the problem description above (1.1.2), and as displayed in Figure 2, the focus in this research will lay on the sales, purchasing and order processing departments, which are together responsible for delivering customer orders.

1.2.5) Research Framework and Questions

To reach the described research objective, we try to answer the following main research question:

How can DAP Technology achieve a delivery reliability and delivery speed of at least 95%?

To formulate an answer to the main research question, we split the research into two parts. In the first part we investigate if the organization needs to improve. If the organization indeed needs to improve, we investigate how the organization could improve in the second part of the research. The first part of the research is worked out in Chapter 2. The second part starts in Chapter 3.

Research Part 1

To investigate if the organization needs to improve, we perform a context analysis in Chapter 2. The context analysis consists of a process description, performance measurement and overview of problems. The first part of the context analysis consists of a **process description**. We explore the current state to get insight into the current way of working and into the way how departments are interacted to deliver customers. The goal is to accurately map the relevant processes that lead to the delivery of POs. We hold interviews with employees that play an important role in the sales, purchasing and order processing departments. With this information we give a full description of the relevant processes and the interaction between departments in the form of a flowchart.

Question 1) How is the PO delivery process currently arranged?

1.1) Which processes occur in the sales department and how do they interact with other departments?

1.2) Which processes occur in the purchasing department and how do they interact with other departments?

1.3) Which processes occur in the order processing department and how do they interact with other departments?

The second part of the context analysis consists of a **performance measurement**. After mapping the current way of working in Question 1, we know how and where we can collect data to delve deeper into relevant processes. We collect PO delivery data of the 187 most recently delivered POs (March 2017 till June 2019). We delve deep into the information systems Minox (Oldenzaal), Fogbugz (Nijmegen) and Goldmine (Oldenzaal) to collect dates regarding quotation, ordering, production, shipping and delivery. This is a time-consuming task, because data is hard to track down and it is hard to combine data of one specific PO. Moreover, information systems can only be accessed from specific locations. Relevant stored data from information systems on various locations must be collected and put together manually. We combine and analyze data of the delivered POs to get insight into the delivery speed and delivery reliability in the current way of working.

Question 2) What is the current performance regarding delivery reliability and delivery speed?

2.1) What is the average lead time of production orders in the current situation?

2.2) What is the current performance regarding delivery speed?

2.3) What is the current performance regarding delivery reliability?

The third part of the context analysis consists of an **overview of problems**. We want to zoom in on problems that occur in the sales, purchasing and order processing departments. We want to explore why the organization currently lacks the insight on how to improve its delivery speed and delivery reliability. We look at the process descriptions in Question 1 in combination with the collected data in Question 2 to identify the main problems of the current way of working.

Question 3) What are the main reasons that DAP is not able to improve its delivery reliability and delivery speed?

Research Part 2

In Questions 1 till 3 we investigate if the organization needs to improve to achieve a delivery reliability and delivery speed of at least 95%. If the organization indeed needs to improve, we will construct a number of sub questions to investigate how the organization can be improved in the second part of the research. These sub-questions are worked out in Chapter 3.

1.2.6) Deliverables

The main deliverables of the first part of the research project are:

- Insight into the current performance regarding delivery speed and delivery reliability (Question2)
- Insight into the major problems of the current way of working (Question 3)

Chapter 2: Context analysis

Chapter 2 contains a context analysis of the current order delivery process. First, we give a description of the processes that occur in the sales, purchasing and order processing departments (2.1). Subsequently, we analyze the current performance (2.2). Thereafter, we zoom in on the problems that occur in the three departments to create an overview of problems, which can explain why the organization is currently not able to improve the delivery speed and delivery reliability (2.3).

2.1) Process description: How is the PO delivery process currently arranged?

The scope of the research consists of 3 departments: Sales, Purchasing and Order Processing. In this section, we explore the current way of working. Open interviews with employees that play an important role in relevant processes that lead to the delivery of POs are conducted to get a better insight into the three departments. The department make use of several different information/registration systems to capture processes. The company uses Customer Relationship Management (CRM) system 'Goldmine' to support sales management in managing customer data. 'Fogbugz' is used to monitor development, production and customer support processes. 'Minox' is the administration system that is used for financial administration and to keep track of inventory, while Microsoft Office is used for several other processes. In the process descriptions below, we refer to these information systems.

2.1.1) Which processes occur in the sales department and how do they interact with other departments?

First, we investigate the processes that occur in the sales department. The sales department is responsible for selling DAP's products. The process runs from the moment a (potential) customer has interest in one of DAP's products until the customer places a PO. The goal of the sales department is to quote reliable lead times to customers, that are preferably as short as possible. The process is displayed in the following flowchart (Figure 3):

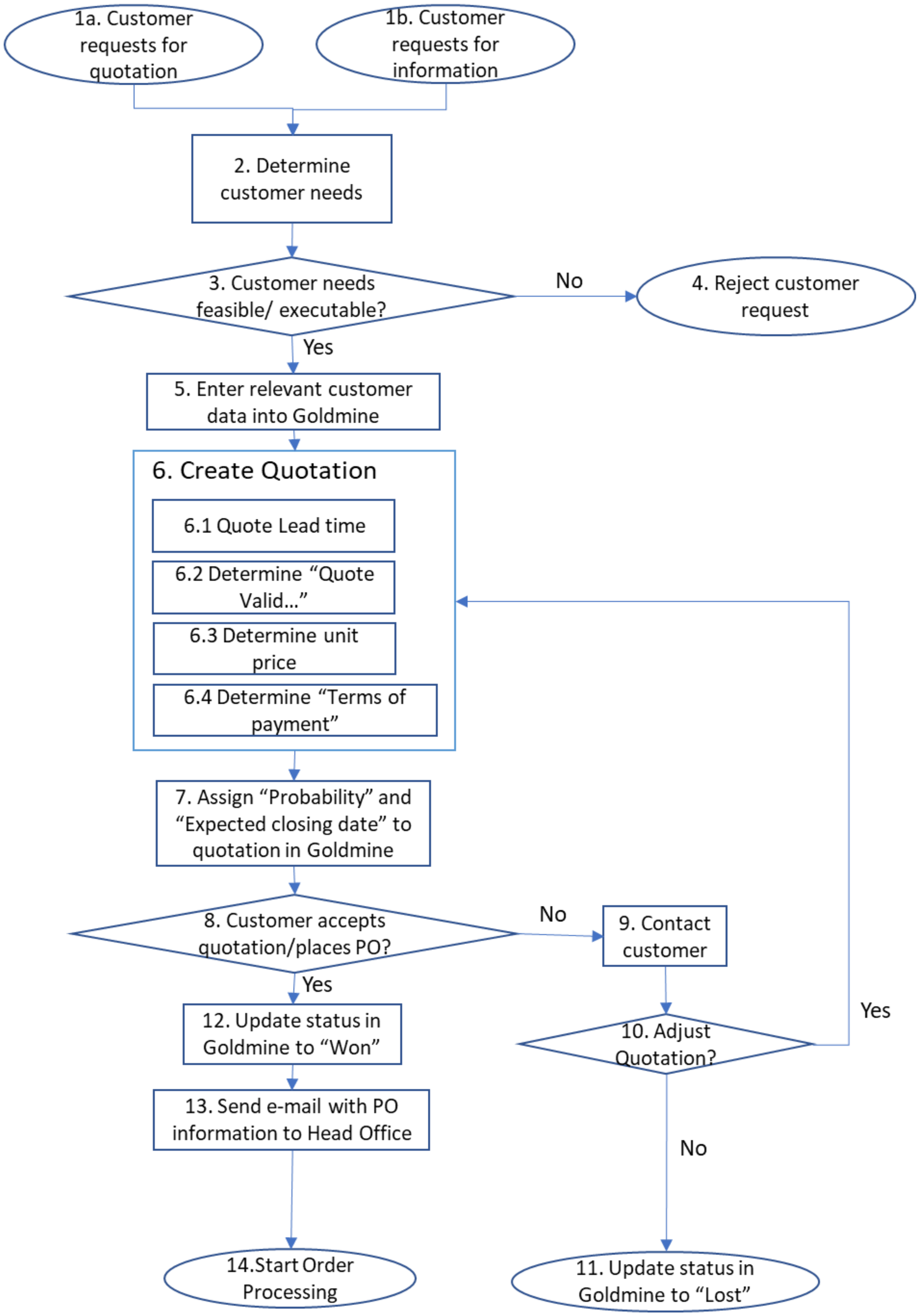

Figure 3: Sales flowchart

The various process steps are numbered. An explanation of each numbered step is given in Table 1.

Table 1: Sales flowchart steps

	Activity	Description
1a+1b	Triggers: Customer requests for quotation/information	Customer has interest in DAP's products and contacts the sales department
2	Determine customer needs	The sales department collaborates with the customer to determine what the customer exactly wants/needs
3	Customer needs feasible/executable	The sales department makes a decision whether DAP wants to/ is able to fulfill customer needs
4	Reject customer request	The sales department determines that DAP is not going to fulfill customer needs
5	Enter relevant customer data into Goldmine	Customer data regarding correspondence is entered into the customer relationship management (CRM) system Goldmine
6	Create quotation	The sales department tries to translate customer needs into a concrete quotation
6.1	Quote lead time	The sales department quotes a lead time to the customer, within which DAP thinks it is able to deliver the products
6.2	Determine "Quote Valid"	The sales department sets a deadline for the customer before which the customer has to inform DAP whether it accepts the quotation
6.3	Determine unit price	The sales department quotes a price for the offered products
6.4	Determine "Terms of payment"	The sales department sets a term of payment within which the customer has to pay the invoice
7	Assign "Probability" and "Expected closing date" to quotation in Goldmine	The sales department tries to make an estimate of the likelihood that the customer will place a PO in response to the offered quotation on the expected closing date
8	Customer accepts quotation/ places PO?	The customer makes a decision whether it places a PO in response to the offered quotation
9	Contact customer	The sales department contacts the customer to get insight into why the customer does not accept the quotation/ does not place a PO
10	Adjust Quotation?	In consultation with the customer, the sales department makes a decision whether it is necessary to adjust the existing quotation to persuade the customer
11	Update status in Goldmine to "Lost"	When the customer does not place a PO within the "Quote Valid" time, the quotation is considered to be lost, or the opportunity is shifted into the future
12	Update status in Goldmine to "Won"	When the customer places a PO, the quotation is considered to be won
13	Send e-mail with PO information to Head Office	The placed PO will be communicated via e-mail to the head office in Oldenzaal
14	Start Order Processing	The order processing department can start processing the PO

Figure 3 and Table 1, give a global overview of the tasks and responsibilities of the sales department. It provides insight into the processes that occur in the sales department, and how they interact with other departments.

2.1.2) Which processes occur in the purchasing department and how do they interact with other departments?

Subsequently, we look into the processes of the purchasing department. The goal of the purchasing department is to place purchase orders in such a way that products can be assembled directly from inventory as much as possible, without holding too much inventory. The purchasing department deals with the ordering of components needed for fabrication of the hardware products. The process runs from triggers to order components until the receipt of goods. The processes are displayed in Figure 4.

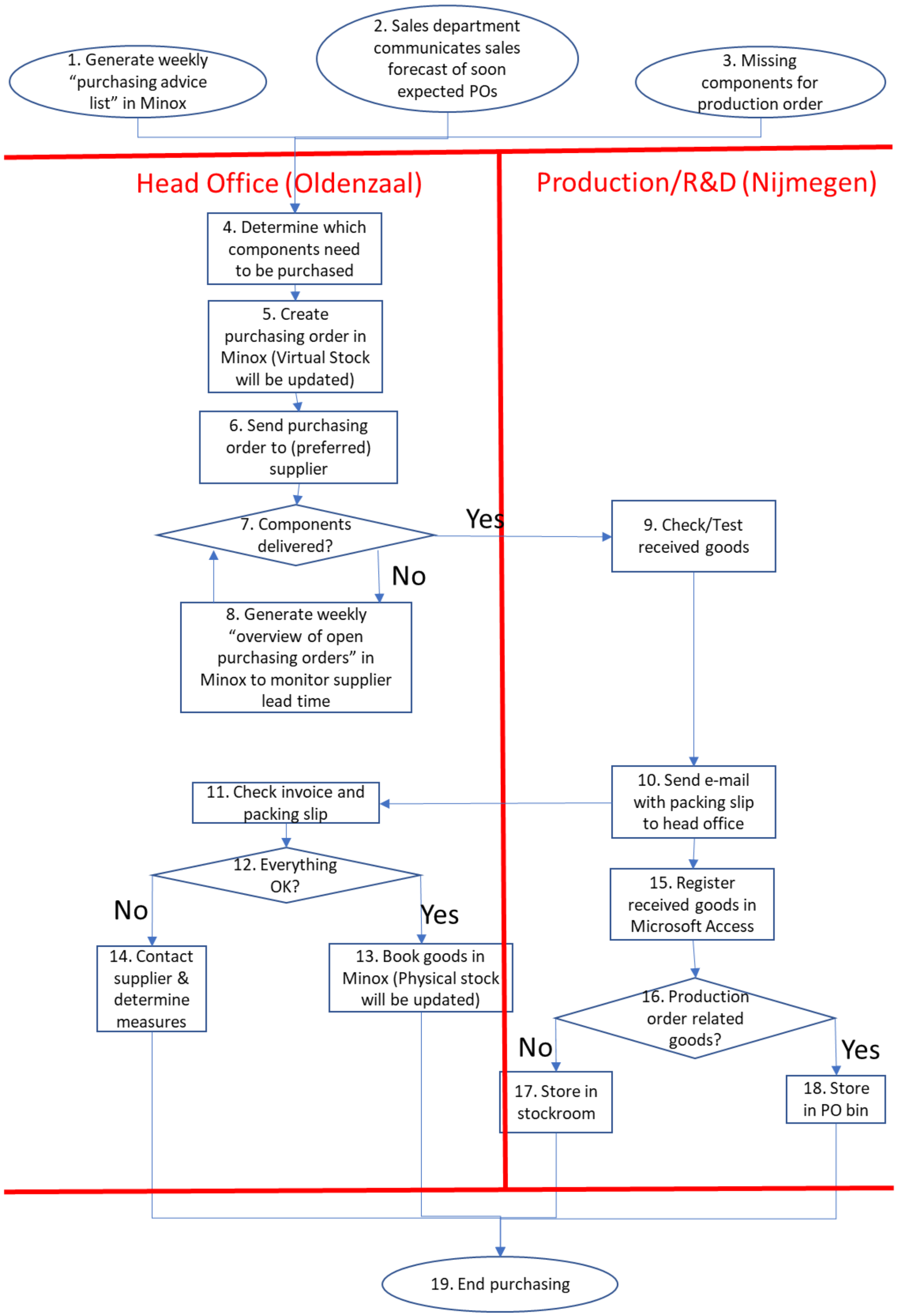

Figure 4: Purchasing flowchart

An explanation for the numbered process steps is given in the Table 2.

Table 2: Purchasing flowchart steps

	Activity	Description
1	Trigger: Generate weekly "purchasing advice list" in Minox	For critical stock components, a minimum stock level has been determined. When the virtual stock (=physical stock + open purchase orders – reserved components) of the component gets below that level, it appears on the "purchasing advice list". The system advices to place an order such that the virtual inventory is equal again to the minimum stock level.
2	Trigger: Sales department communicates sales forecast of soon expected POs	When Sales communicates that there are many potential orders of a specific type in the pipeline, this can be a trigger to place a purchase order for corresponding frequently asked components.
3	Trigger: Missing components for production order	When a customer places a PO for which the corresponding components are not all available, it triggers the purchasing process to order missing components
4	Determine which components need to be purchased	The purchasing departments tries to make a good estimate of how many components need to be purchased to meet potential customer demand
5	Create purchasing order in Minox (virtual stock will be updated)	The purchasing department creates a purchasing order in Minox. The virtual stock for these components will be updated, causing them to disappear from the "purchasing advice list"
6	Send purchasing order to (preferred) supplier	Most stock components have a preferred supplier where purchase orders will be placed if the inventory level gets below the minimum. For some parts there are alternative suppliers.
7	Components delivered?	The purchasing department monitors whether the purchase order already has been delivered
8	Generate weekly "overview of open purchasing orders" in Minox to monitor supplier lead time	The purchasing department keeps track of open purchasing orders, to see if suppliers will meet their promised lead time
9	Check/Test received goods	Upon delivery, the goods will be checked and tested at the production/R&D facility in Nijmegen
10	Send e-mail with packing slip to head office	The packing slip will be sent to the head office, such that office management can complete the administration
11	Check invoice and packing slip	Office management checks if the invoice and packing slip are correct according to the placed purchasing order
12	Everything OK?	Invoice and packing slip correct?
13	Book goods in Minox (physical stock will be updated)	Office management books the received goods in Minox such that the physical stock will be updated
14	Contact supplier & determine measures	When something is wrong with the delivered goods, the purchasing department will contact the supplier & determine measures to solve the problem(s)
15	Register received goods in Microsoft Access	The batches of received goods will be registered in a Microsoft access database with the corresponding batch number at the production and R&D facility

16	Production order related goods?	Are the received goods already needed for a production order?
17	Store in stockroom	Stock components will be stored in the stock room
18	Store in project bin	Received components which are already ordered are stored in the corresponding PO bin
19	End purchasing	

By following Figure 4 and Table 2, this section (2.1.2) gives a first insight into the tasks and responsibilities of the purchasing department and into how the purchasing processes interact with other departments.

2.1.3) Which processes occur in the order processing department and how do they interact with other departments?

As final part of the process description, we investigate the processes that occur in the order processing department. The order processing department is responsible for processing the PO from the moment that the PO has been received until the moment of delivery. This includes activities like administration, assembling, testing, sending and invoicing.

For the order processing process, it is important to know what the structure of a PO looks like, and what terms like “production article”, “production component” and “stock article” mean. The PO structure is explained in Figure 5.

Product 1			**Product 2**		
	Production Article 1			Production Article 1	
		Production component 1			Production component 1
		Production component 2			Production component 2
		Production component 3			Production component 3
		Production component 4			Production component 4
		Production component 5			Production component 5
		Production component 6			Production component 6
		Production component 7			Production component 7
		Production component 8			Production component 8
		Production component 9			Production component 9
	Production Article 2			Stock article 1	
		Production component 1		Stock article 2	
		Production component 2			
	Stock article 1				
	Stock article 2				
	Stock article 3				
	Stock article 4				

Figure 5: PO structure

A PO consists of one or more products that the customer orders. A product consists of production articles and stock articles. Production articles need to be assembled from production components. Stock articles do not undergo processing and will be delivered along with the production articles. In the remainder of the report, the terms “Production Article”, “Production component” and “Stock article” will be kept using. The order processing processes are displayed in Figure 6.

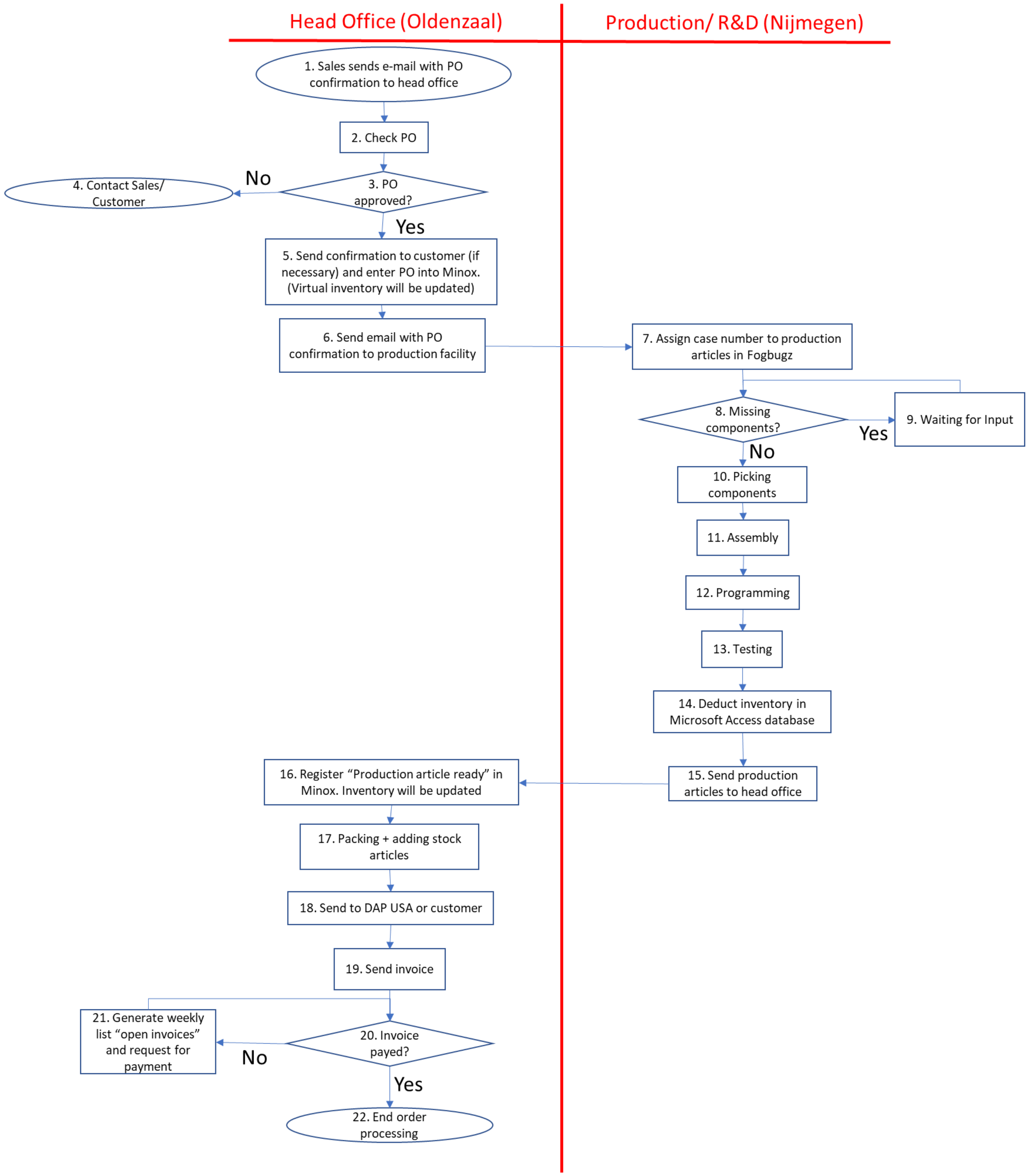

Figure 6: Order Processing flowchart

An explanation for the numbered processes is given in Table 3.

Table 3: Order Processing flowchart steps

ID	Activity	Description
1	Trigger: Sales sends e-mail with PO confirmation to head office	When a customer places a PO, Sales informs office management via e-mail, and the order processing process will be triggered
2	Check PO	Office management checks if the PO information is correct and corresponds to the quotation
3	PO approved?	Office management makes a decision whether the PO is approved
4	Contact Sales/ Customer	Office management contacts the sales department or customer to find a solution if the PO is not approved
5	Send confirmation to customer (if necessary) and enter PO into Minox (Virtual inventory will be updated)	Office management enters the PO into Minox. The virtual inventory for corresponding products will be updated
6	Send e-mail with PO confirmation to production facility	Office management notifies the production facility regarding the placed PO
7	Assign case number to production articles in Fogbugz	Production enters the production articles of the PO into Fogbugz and assigns a case to each line item
8	Missing components?	Production checks whether all components are available to start producing
9	Waiting for Input	If there are still components missing, production cannot start producing
10	Picking components	Production picks the components of the production article according to the Bill of Materials (BOM) overview in Excel
11	Assembly	Production assembles the ordered product
12	Programming	If necessary, the products will be programmed by the software department
13	Testing	Production tests the functionality of the products and fixes problems that occur
14	Deduct inventory in Microsoft Access database	Production registers the used components in a Microsoft access database
15	Send production articles to head office	Production sends the produced products to the head office in Oldenzaal via UPS or PostNL
16	Register "Production article ready" in Minox. Inventory will be updated	Office management books that the production article is ready to be shipped in Minox. The inventory of corresponding components will be updated in Minox.
17	Packing + adding stock articles	Office management packs the ordered items and adds documentation/attributes
18	Send to DAP USA or customer	Office management sends the package via UPS to DAP USA or directly to the customer
19	Send invoice	Office management creates an invoice and sends it to the customer
20	Invoice payed?	Office management checks if the invoice has already been payed

21	Generate weekly list "open invoices" and request for payment	Office management monitors the open invoices in Minox, and requests customers to pay if necessary
22	End Order Processing	

Section 2.1.3 provides insight into the tasks and responsibilities of the order processing department. Sections 2.1.1 till Section 2.1.3 provide a complete process description that provides insight into Research Question 1: “*How is the PO delivery process currently arranged?*”

2.2) Performance measurement: What is the current performance regarding delivery reliability and delivery speed?

To get insight into the seriousness and the nature of the problems regarding delivery reliability and delivery speed, in Section 2.2 we analyze delivered orders from the past 2 years. This time span is chosen because of the availability of accurate data regarding internal lead times. From March 2017 on, the data of the production process has been kept up in Fogbugz. From before this date, one cannot track down lead times in the production process without quite a lot of additional work. In the analysis, production orders consisting of more than one product type, are split up in different production orders, since that’s the way they are entered into Fogbugz. This means that, in the analysis, every production order consists only of one product type. Data of the 187 most recently delivered hardware production orders has been collected. It is a time-consuming task to collect the relevant data of the 187 POs. Data from various information systems has been combined. The collected data is displayed schematically in Figure 7.

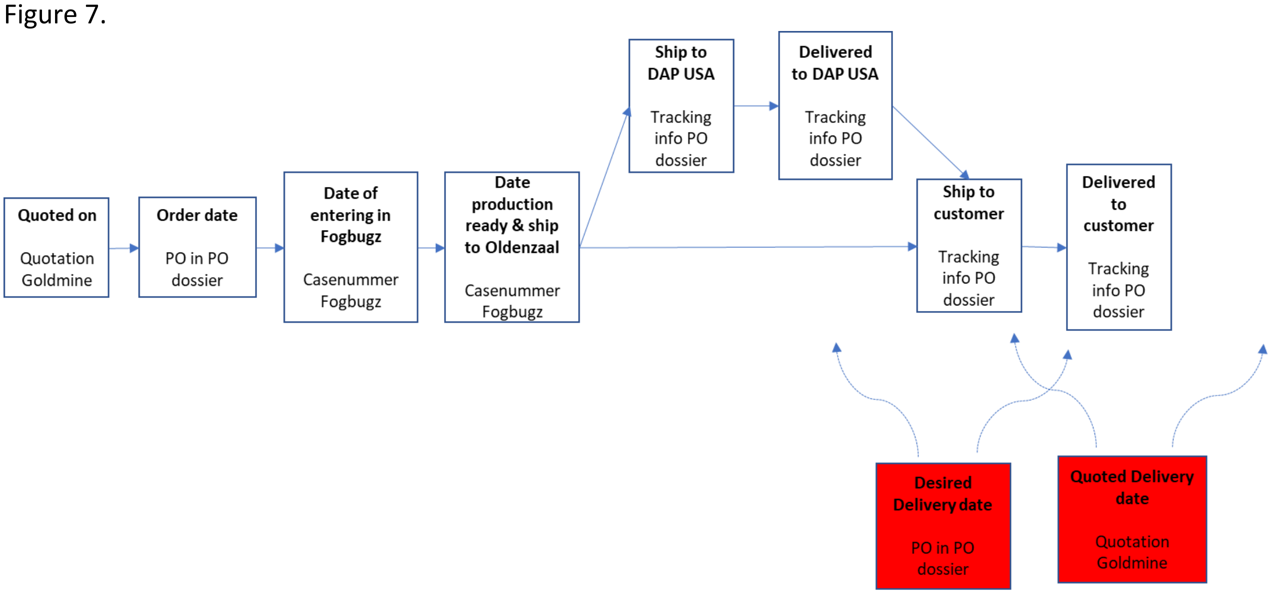

Figure 7: Collected data

An explanation of the dates displayed in Figure 7 is given in Table 4.

Table 4: Explanation collected data

Date	Explanation
Quoted on	Date that DAP sends a quotation to the customer
Order date	Date that the customer places a production order
Opened in Fogbugz	Date that a case number has been assigned to the production article in Fogbugz. This is a unique identifier, by which one can track down production information in Fogbugz

Date production ready and ship to Oldenzaal	Date that the production is finished and shipped to Oldenzaal. It is assumed that products are directly shipped to Oldenzaal after finishing production.
Ship to DAP USA	Date of shipping to DAP USA. Most of the times, DAP uses transport carrier UPS for this shipment.
Delivered to DAP USA	Date that DAP USA has received the products.
Ship to Customer	Date that DAP USA has shipped the products to the customer
Delivered to Customer	Date that the customer has received the products
Desired delivery date	The “required date” that the customer mentions in the PO. This can be either the date that the customer would preferably receive the products, or customer has taken over the quoted delivery date.
Quoted delivery date	Date that DAP promised to deliver. This can be either the mentioned lead time in the corresponding quotation, or the agreed lead time at the moment the customer places a PO

The above-mentioned dates are used in Sections 2.2.1 till 2.2.3 to analyze the current performance.

2.2.1) What is the total lead time of production orders?

First, the total lead time of production orders has been analyzed. Total lead time is defined as the number of days between the order date and the date that the customer has received the products. Figure 8 displays the distribution of lead times of the 187 most recently delivered POs.

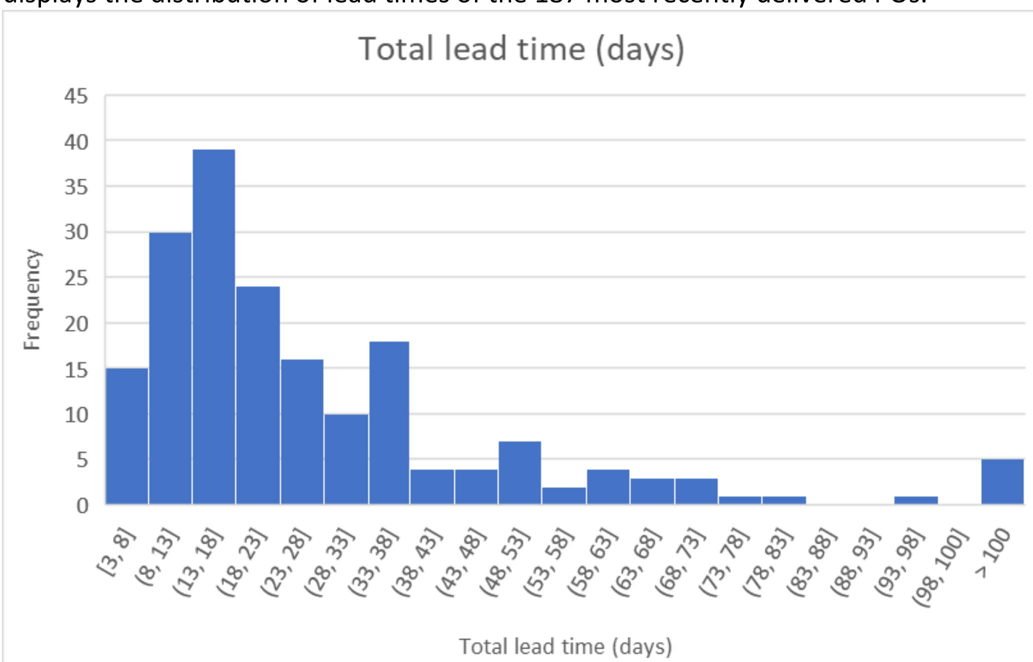

Figure 8: Total lead time distribution

DAP aims to deliver its COTS products within 4 weeks (28 days). For the 187 most recently delivered POs, DAP has delivered 66.1% within 28 days. However, this does not mean by definition that DAP was not able to deliver on time in the remaining 33.69% of the cases. There are situations in which the customer only needs the products later than 28 days. Therefore, to get a better insight into the lead time performance, it is necessary to zoom in further on orders where the customer requires a specific “required date” in the PO and orders for which DAP has quoted a concrete lead time.

For the orders from which the desired or quoted lead time has not been met, the following reasons (A, B & C) can be inferred from the data:

A The desired lead time is unreasonable:

The customer wants to receive the products within 7 days. Given the geographical distance and production time, DAP is typically not going to meet this deadline. This happens when customers would like to receive their products as soon as possible. Typically, DAP will quote verbally a more reasonable lead time in these cases. However, sometimes this quoted lead time has not been registered. These failures will be disregarded, since it is almost impossible for DAP to deliver within 7 days and it is no objective for the organization to be able to deliver within one week.

B Production not finished on time:

The production has not been finished enough days before the deadline (desired date or quoted date) to meet the deadline, taking into account the required shipping time. This happens when the production cannot start on time because they are waiting for required production components or stock components that should be on stock. It is assumed the production capacity and production time are never the bottleneck for not getting the production finished on time, since the number of orders is relatively low and we deal with standard products, for which the way of producing is more or less a routine operation.

C Products have not been shipped on time:

The production was finished on time, but the products were not shipped on time to the customer, taking into account the required shipping time. This happens when office management decides to combine two or more shipments. Most of the times, this is the case for relatively cheap products, for which it is significantly cheaper to combine shipments. It can also happen that DAP does not want to ship the products before the invoice has been paid. These failures will also be disregarded, since they are easy to solve if DAP would want to.

This section (2.2.1) provides insight into the total lead time of delivered POs. In Section 2.2.2 and 2.2.3 we zoom in on delivery speed and delivery reliability to get a better insight in the current performance.

2.2.2) What is the current performance regarding delivery speed?

In Section 2.2.2, we focus on delivery speed: "Percentage of total number of orders that DAP is able to meet the desired lead time". Orders for which customers mention a concrete "required date" in their PO are taken into account. The obtained results are displayed in Table 5.

Table 5: Delivery speed performance

	Number of Orders	Desired Lead time not met	A: Desired lead time unreasonable (<= 7 working days)	B: Production not finished on time	C: Not shipped on time
Delivery speed	**178**	**63**	17	34	12

As mentioned before in Section 2.2.1, the lead time failures of A and C will be disregarded. Therefore, based on the collected data the current delivery speed performance is that DAP is able to meet the desired customer lead time in (178-34)/178*100= 80.9% of the cases. In practice, this percentage is likely to be lower since there are customers who take over the quoted lead time as "required date" in their PO, even if they preferably would like to receive the products earlier. Figure 9 provides insight into the violation of the 34 lead time failures.

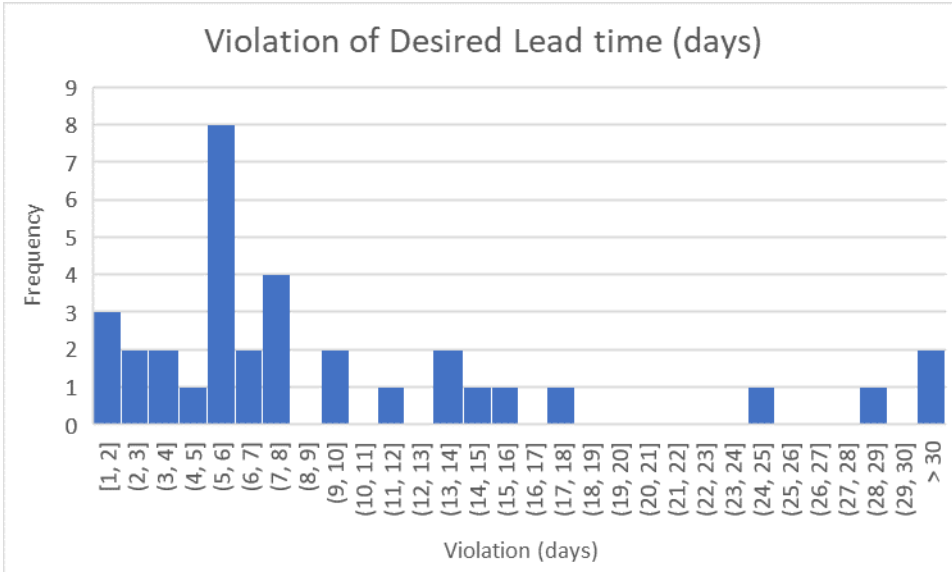

Figure 9: Violation of desired lead time

Currently, most of the failures have a violation of less than one week. In 47.1% of the desired lead time failures the violation is more than a week (7 days).

Section 2.2.2 provides insight into the current performance regarding delivery speed. To get an even better insight into the performance, the delivery reliability will be analyzed in Section 2.2.3.

2.2.3) What is the current performance regarding delivery reliability?

In Section 2.2.3, we focus on delivery reliability: "Percentage of total number of orders that DAP is able to meet the quoted lead time". Orders for which DAP has quoted a concrete lead time, where the quoted lead time is not smaller than the desired lead time, have been taking into account. Namely, if the customer would like to receive its products only after the quoted lead time, it does not say anything whether DAP would be able to meet the quoted lead time. The obtained results are displayed in Table 6.

Table 6: Delivery reliability performance

	Number of Orders	Quoted Lead time not met	A: Quoted lead time unreasonable (<= 7 working days)	B: Production not finished on time	C: Not shipped on time
Delivery speed	**178**	**52**	11	31	10

Again, the failures in category A and C will be disregarded, leading to a delivery reliability of (178-31)/178*100= 82.6%. Figure 10 provides insight into the violation of the 31 quoted lead time failures.

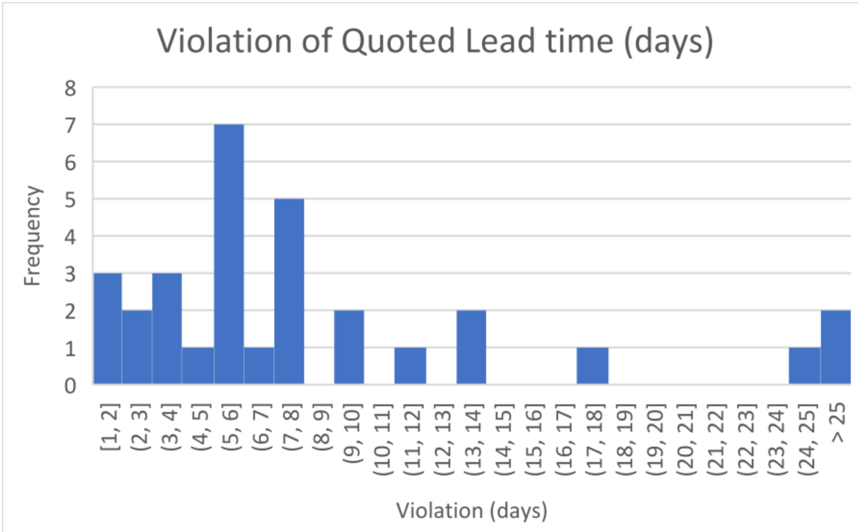

Figure 10: Violation of quoted lead time

Currently most of the quoted lead time failures have a violation of less than one week. In 45.2% of the quoted lead time failures, the violation is more than a week (7 days).

Section 2.2.3 together with the previous Sections 2.2.1 and 2.2.2 provide insight into the current performance of DAP regarding order delivery, and provide insight into Research Question 2: "What is the current performance regarding delivery reliability and delivery speed?". Due to the limited amount of registered data, it is not easy to give accurate performance measures regarding order delivery. However, the following performance measures give a valuable impression of how the organization currently performs:

- DAP delivers 66.31% of the production orders within 4 weeks (28 days)
- The percentage of total number of POs that is delivered within 4 weeks, when the customer prefers to receive the products as soon as possible is 80.9%. This means that the performance regarding delivery speed is 80.9%, assuming that the registered "required date" in the PO is an accurate representation of what the customer really prefers.
- The percentage of total number of POs that is delivered within the quoted lead time is 82.6%. This means that the performance regarding delivery reliability is 82.6%.

2.3) Overview of problems: What are main reasons that DAP is not able to improve its delivery reliability and delivery speed?

In this section (2.3) of the context analysis, we investigate the problems that occur in the sales, purchasing and order processing departments, which can explain that the performance regarding delivery speed and delivery reliability are both below the targeted 95%. After zooming in on the sales, purchasing and order processing departments, several related problems can be identified. Figure 11 provides an overview of the identified problems.

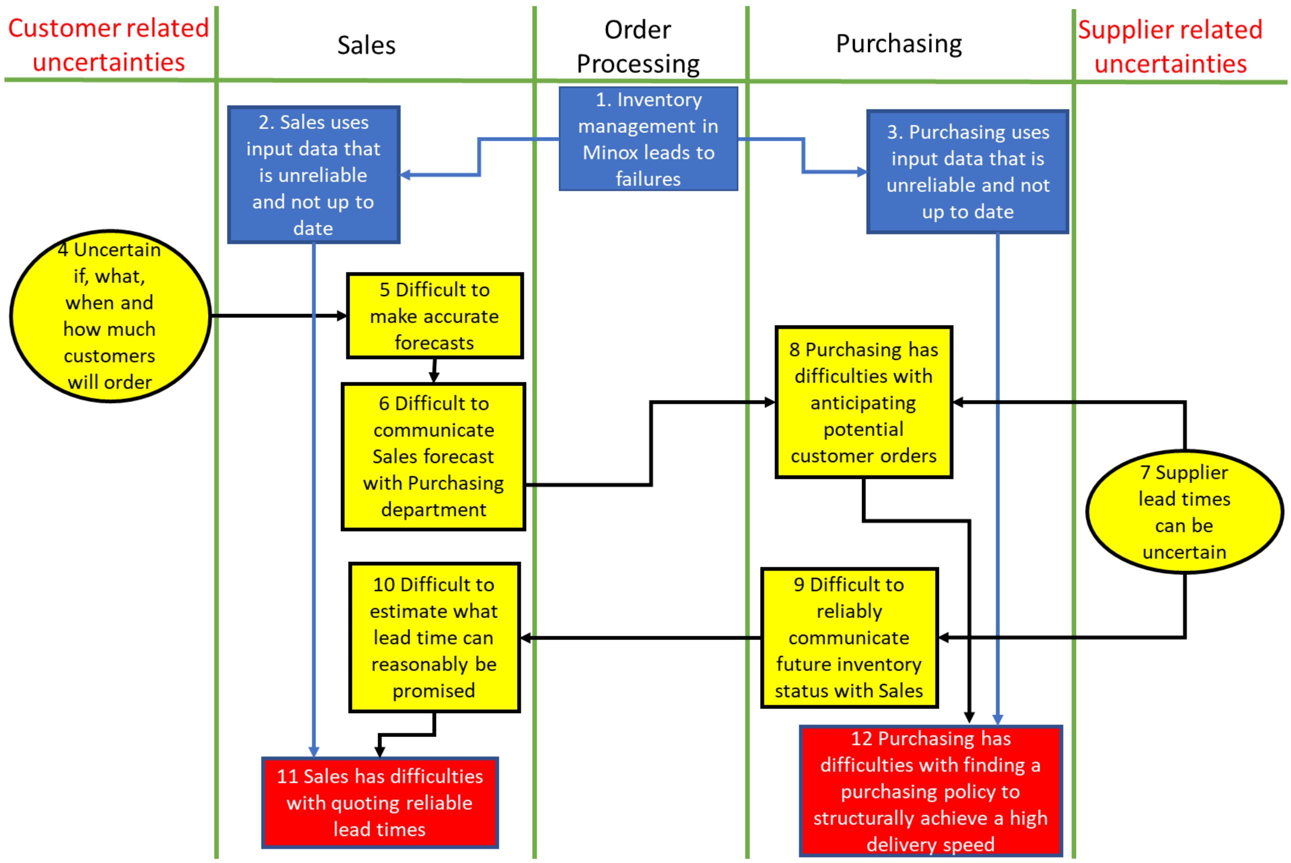

Figure 11: Overview of problems

One can distinguish two types of problems why the lead time performance is not good enough in the current situation. The first type is "**Internal shortcomings of the current way of working**", highlighted in blue. These problems are worked out in Section 2.3 A. The second type is "**Lack of knowledge of how the organization can best anticipate external uncertainties**", highlighted in yellow. These problems are worked out in Section 2.3 B. In the figure above, the problems are numbered. These numbers are used in the Sections 2.3 A and 2.3 B to refer to the problems of Figure 11.

2.3 A) Internal shortcomings of the current way of working

The way the current processes in the sales, purchasing and order processing departments are arranged lead to lead time problems. In this section, the problems 1,2 and 3 of the overview of problems (highlighted in blue) are worked out.

<u>Problem 1: Inventory Management in Minox leads to failures:</u>
Currently, the status of inventory is kept up in information system Minox, which can only be accessed from the head office in Oldenzaal. The production team in Nijmegen uses picking lists that are not connected with the bill of materials in Minox. Sometimes, the product composition of standard products can undergo small changes, because particular components are not available anymore and production needs to find a solution for that. Every time a product gets sold, the exact structure of the product needs to be communicated to the Head Office (Oldenzaal), where the inventory status is updated in Minox by office management. When the bill of materials of the produced products in Minox is not completely correct, stock differences will arise between the actual level of inventory and the inventory level in Minox. Moreover, it takes a relatively long time before the inventory status in Minox will be

updated after the production has been finished. Figure 12 displays schematically how the inventory levels in Minox are updated during the delivery process. The average waiting time until the next operation is displayed in red.

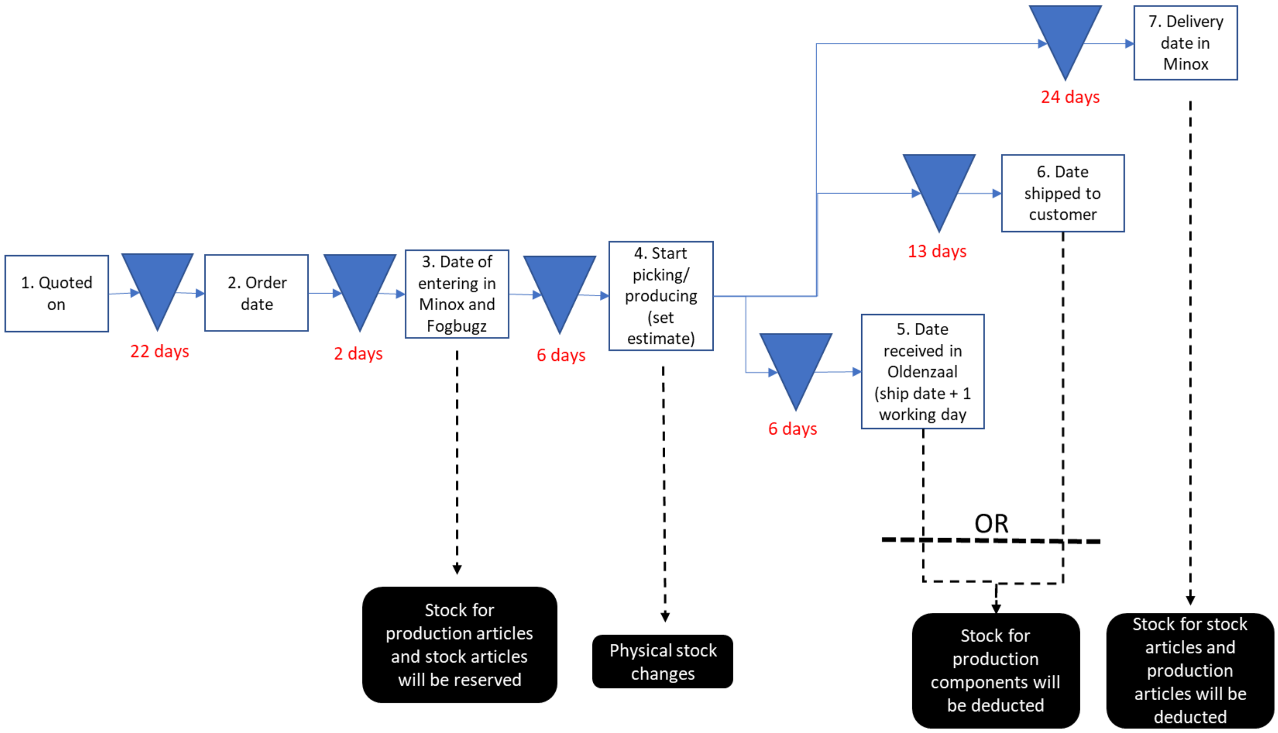

Figure 12: Updating Minox inventory levels

At the moment a customer places a PO, only a reservation on production articles and stock articles takes place. The virtual inventory of production components won't be updated. The inventory level only gets updated when office management books the products "ready". Preferably, this happens at the moment that the products are received in Oldenzaal, but sometimes it only happens at the moment the products are shipped from Oldenzaal. This means that the inventory level of production components in Minox has on average a 6-day lag on the physical inventory if products are booked ready at the moment of reception, and a 13-day lag if products are booked ready at the moment of shipping. Sales and Purchasing use this Minox overview as input information for quoting lead times and determining purchasing requirements. Moreover, the stock for stock components and production articles will only be updated on the delivery date that is entered in the system. This takes on average 24 days after the production has started.

<u>Problem 2: Sales uses input data that is unreliable and not up to date:</u>
When a customer requests for quotation/information, Sales uses the Minox overview of inventory of production components to check whether there is enough inventory to assemble the desired products for the potential customer directly from stock. As mentioned before, this overview is not completely reliable and not completely up to date. The sales department asks office management approximately once a month to send a new overview of inventory, since Sales cannot access Minox from external locations. This means that the input information that Sales uses can have a lag on the physical inventory that goes up to one month and 13 days on average at the end of the month. Currently the production engineers are often asked to do a physical check of the inventory before quotes are sent out.

Problem 3: Purchasing uses input data that is unreliable and not up to date:
Purchasing uses the Minox overview of inventory to check whether it is assumable that there is still enough inventory to fulfil potential customer demand fast enough, or that a new purchase order needs to be placed for production components or stock articles. Approximately once a week, a purchasing advice list is generated, based on the Minox overview of inventory. When the inventory level of a component gets below the minimum defined level, the system advices to place a purchase order. This minimum level serves as support for the purchasing department to be informed on time if the inventory level gets low, but it is more or less “guesswork”. As mentioned before, the Minox overview of inventory is not completely reliable and has a lag on the physical inventory level. This means that the purchasing triggers are not always reliable and up to date. The purchasing advice list will therefore be adapted manually by the purchasing department. The purchasing department just uses the Minox purchasing advice list as input information and eventually makes a final decision regarding what and how much to order.

2.3 B) Lack of knowledge of how the organization can anticipate external uncertainties

The organization currently does not know what is the best way to deal with customer related and supplier related uncertainties. In this section, the problems 4 till 12 of the overview of problems (highlighted in yellow), are worked out.

Problem 4: Uncertain if, what, when and how much customers will order:
DAP operates in a market where demand is typically not easy to predict. It is uncertain (A) if, (B) what, (C) when and (D) how much customers will order.

4A)

A customer that shows interest in DAP’s products does not always actually place a PO.

4B)

It is difficult to predict what are the upcoming needs of customers in the aerospace and defense industry or other potential markets. Moreover, customers do not always know upfront which product will be suitable to fulfil their needs. Often, they go in conversation with the DAP’s sales department to find a suitable solution.

4C)

Customers use DAP’s products for complex engineering and production projects. When the customer shows interest in DAP’s products, it can take some time before the customer organization gives approval and releases budget to place a PO. This is typically the most uncertain factor. For 70 orders from which the quotation could be linked to the PO, the distribution of the time between the quotation date and the order date is displayed in Figure 13.

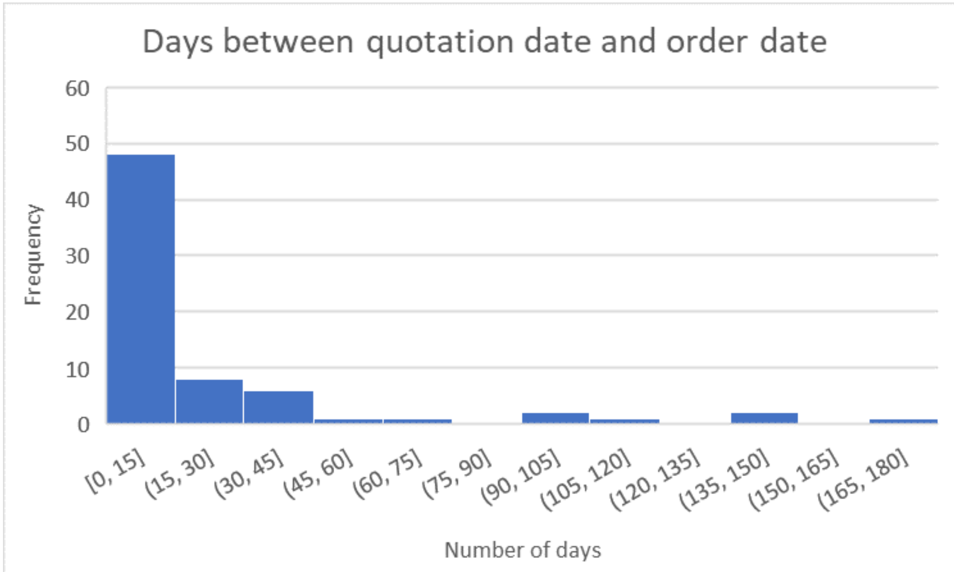

Figure 13: Distribution of time between quotation and order date

From the figure above follows that in 20% of the cases, it takes longer than a month before a customer places a PO in correspondence to a quotation.

4D)

For customers with complex production projects, it is not easy to predict if and when they are going to scale up production. Therefore, the order quantities are difficult to predict.

Problem 5: Difficult to make accurate forecasts:

The sales department currently tries to make forecasts about if, what, when and how much customers will order, using information system Goldmine. When a customer shows interest in DAP's products, this is stored as opportunity for a specific month in Goldmine. Each opportunity gets a status assigned, representing the probability that the customer will place a PO in that specific month. These probabilities are just estimations and not based on actual data. Table 7 gives an overview of the Goldmine statuses.

Table 7: Statuses Goldmine

Status	**Probability of placing PO**	**Explanation**
Interest unconfirmed	20%	Customer contacted the sales department but has not officially confirmed its interest in DAP's products
Confirmed interest	30%	Customer has confirmed its interest in DAP's products
Selected for Evaluation	40%	Customer has received a quotation from DAP, which need to be evaluated within the customer organization
Evaluation INP	50%	The evaluation of DAP's quotation at the customer organization has been started
Evaluation Good	60%	The customer informs DAP that the evaluation process goes well, and that there are no additional questions
Passed evaluation	70%	The quotation has been evaluated

Final approval INP	80%	The quotation needs to be approved definitively by the customer management team
PO INP	90%	The customer is working on a production order that they want to place
PO received	100%	DAP has received the placed production order

The numbers in the second column of Table 7 represent a probability that the customer will place a PO in a specific month. If the customer does not place a PO in that month, the opportunity shifts forward in time and the probability will be updated. This process goes on until the validity of an opportunity has expired. Opportunities in Goldmine typically are valid for 60 days. If the customer has not placed an order by then, the opportunity is considered as “lost”, or DAP decides to keep it open (dormant) for a longer period, if the sales department expects that the customer still has interest.

<u>Problem 6: Difficult to communicate sales forecast with purchasing department:</u>
Currently, DAP has not really found a suitable way to communicate sales forecasts with the purchasing department. Sales forecasts are communicated in two ways: The purchasing department uses the above-mentioned (A) forecast in Goldmine as input information, and the sales department provides the purchasing department with a (B) “Hardware Forecast” of all soon to be expected open hardware opportunities.

<u>6A) Forecast in Goldmine:</u>

Currently, this forecast is especially used for informing the management team about what the expected turnover per month is going to be. The forecast is currently not really useful for the purchasing department for determining purchasing need. An opportunity only appears in one specific month with a given probability. Therefore, it won’t be taken into account for next months, while the actual probability of placing an order most of the times only increases for next months. That’s why Goldmine offers deficient support to really look forward in time and anticipate future bottlenecks in the inventory levels.

<u>6B) Hardware Forecast:</u>

This is an overview of all open hardware opportunities in Goldmine. However, this forecast lacks information about when the expected order date will be, and what the probability is that the customer actually places an order.

<u>Problem 7: Supplier lead times can be uncertain:</u>
DAP orders, among other things, printed circuit boards (PCBs) for which components that the supplier does not have on stock need to be imported, before the supplier can assemble the PCBs. The moment the supplier can start assembling depends on the lead time of the components to be imported as well as the supplier capacity. These two aspects are not easy to predict, and can vary considerably from the lead time of previously placed purchase orders. Moreover, there a few unique components, that are purchased directly, which are indispensable for many of DAP’s products and sometimes can have unforeseen longer lead times than normal.

<u>Problem 8: Purchasing has difficulties with anticipating potential customer orders:</u>
The purchasing department experiences difficulties in translating the available input information to make a well-founded decision regarding when and how much to order.

<u>8A) How to use sales input information?</u>

As mentioned before, the purchasing department gets informed about the sales forecast by means of the Goldmine forecast and the “Hardware Forecast”. The purchasing department currently does not know how to use this input information. Both ways entail some disadvantages why they cannot really serve as suitable input information for the purchasing department.

8A1) Goldmine forecast:

Currently, the organization has no information about:

- Which percentage of all opportunities do actually lead to a production order?
- Do the ordered products/ quantities deviate from the initial quoted products/quantities?
- How accurate are the mentioned Goldmine probability estimations to predict when a customer places a PO?
- How long do opportunities typically stay in the pipeline before an order is placed

8A2) Hardware forecasts:

As mentioned before, the hardware forecast is an overview that the sales department creates to inform the purchasing department about all open hardware opportunities that are currently in the pipeline. However, this forecast lacks information about when the expected order date will be, and what the probability is that the customer actually places an order. It is economically not feasible to completely anticipate all open opportunities and put on stock all required components for the open opportunities. Moreover, the risk of ordering too much is high, leading to an increasing risk of stock that cannot be sold anymore. Therefore, the purchasing department has doubts to which extend it should anticipate open opportunities.

8A1+8A2)

Both the Goldmine forecast and Hardware forecast are only available on product level, not on component level. The purchasing department has to translate the sales forecast by manually from product level to component level to see if the inventory is high enough. This way, there is a chance that bottlenecks in the inventory levels will be overlooked.

8B) How to use supplier input information?

Currently, the purchasing department does not have a clear overview of what the expected lead time is going to be for stock articles and production components. The purchasing department can check previously placed purchase orders, to see how long previous lead times were. However, this gives no guarantee for potential purchase orders. The purchasing department can also contact the supplier, but it is not easy to predict if the supplier quotes a reliable lead times and how much the actual supplier lead time can deviate from the quoted lead time.

Problem 9: Difficult to reliably communicate future inventory status with Sales:

The uncertainty in supplier lead times makes it difficult to reliably inform Sales. The sales department wants to know when open purchase orders will be received, to make an estimation about how fast DAP will be able to deliver, and quote a reliable lead time to the customer.

Problem 10: Difficult to estimate what lead time can reasonably be promised:

There are two aspects which make it difficult for the sales department to estimate what lead time can reasonably be promised for a new opportunity: (1) There are a number of open opportunities in the pipeline, possibly requiring the same components as the new entering opportunity. For these open opportunities it is difficult to estimate if, what, when and how much customers will order. (2) In addition, there can be a number of open purchase orders, for which it is uncertain when they will be received. Therefore, it is difficult to estimate what the inventory level status will be at the moment that the new opportunity places a PO.

In Section 2.3.1 and 2.3.2 the problems related to respectively “Internal shortcomings of the current way of working” and “Lack of knowledge of how to deal with external uncertainties” are worked out, and give answer to Research Question 3: “What are the main reasons that DAP is not able to improve its delivery reliability and delivery speed?”. Namely, the worked-out problems in Section 2.3.1 and 2.3.2 together lead to the two main reasons why DAP is not able to improve its delivery speed and delivery reliability, highlighted in red in Figure 11:

- **Problem 11**: Sales has difficulties with quoting reliable lead times such that DAP can structurally meet the promised lead time: The internal shortcomings in combination with external uncertainties makes it difficult to structurally quote reliable lead times.
- **Problem 12**: Purchasing has difficulties with finding a suitable purchasing policy to structurally achieve a high delivery speed against the lowest possible costs: The internal shortcomings in combination with external uncertainties makes it difficult to anticipate potential customer orders well to structurally achieve a high delivery speed.

When we look at the two main problems above, we need to develop a solution that can offer support to the sales department in quoting reliable lead times and to the purchasing department in anticipating potential POs. A solution should tackle both the internal shortcomings and the lack of knowledge as well as possible. In the current way of working, the information systems do not provide enough support to achieve a delivery speed and delivery reliability of at least 95%. Various aspects of managing inventory are problematic in the current way of working. From the process descriptions in Section 2.1, it follows that the departments are in need of the following aspects of inventory management, that cannot be completely fulfilled in the current way of working when we look at the overview of problems in Figure 11:

- **Order Processing**: Monitor available stock to know what can be produced and shipped.
- **Sales**: Monitor available stock and forecast upcoming customer demand to make a well-founded decision about which lead time can reasonably be promised to new arriving customers.
- **Purchasing**: Monitor available stock and forecast upcoming customer demand to make a well-founded decision regarding when and how much to purchase.

We need to find a way to align the sales, purchasing and order processing departments, such that the departments will be provided by more reliable and up to date inventory information, and that based on this information, the organization can anticipate external uncertainties as well as possible. A solution should provide better support to fulfill the above-mentioned needs, such that the sales and purchasing departments will be able to better foresee bottlenecks in the inventory. In the continuation of the research we will explore what can be a suitable solution to improve the delivery reliability and delivery speed.

Chapter 3: Literature review and Solution Design

In the first part of the research (Chapter 2), we identified that the organization needs to improve to achieve a delivery reliability and delivery speed of at least 95%. The current performance is respectively 80.9 and 82.6%. In the second part of the research we will investigate how the organization could improve to achieve the target of at least 95%. The second part of the research consists of a Literature Review and Solution Design (Chapter 3), Solution Test (Chapter 4) and Conclusions, Implementation Plan and Recommendations, Limitations (Chapter 5).

Literature Review and Solution Design (Chapter 3)

In Chapter 2, we identified that the current information systems do not provide sufficient support for the sales, purchasing and order processing departments. The departments are in need of the following aspects of inventory management, that cannot be completely fulfilled in the current way of working:

- **Order Processing**: Monitor available stock to know what can be produced and shipped.
- **Sales**: Monitor available stock and forecast upcoming customer demand to provide reliable lead times to potential customers.
- **Purchasing**: Monitor available stock and forecast upcoming customer demand to make a well-founded decision regarding when and how much to purchase.

In Section 2.2.3 we identified the following reasons why the above-mentioned needs cannot completely be fulfilled in the current way of working:

- **Monitor available stock**: The three departments currently use information system Minox to monitor the available stock. The current way of managing inventory leads to overviews of inventory that are not reliable and not up-to-date. The purchasing department uses these unreliable overviews as input to decide when and how much to purchase. Moreover, the sales department uses these overviews as input to quote lead times for potential customers. Therefore, the sales department and purchasing department cannot directly use Minox and have to make poorly informed decisions leading to underperformance.
- **Forecast upcoming customer demand**: The organization currently tracks upcoming customer demand by storing opportunities in Customer Relationship Management (CRM) system Goldmine. Opportunities are customers that show concrete interest in DAP's products and possibly are going to place a PO in the near future. These opportunities are stored in the Goldmine Opportunity pipeline. Currently, there is no connection between potential customer demand in Goldmine and the inventory status in Minox. Therefore, it is currently difficult to identify upcoming inventory shortages. Again, the sales department and the purchasing department cannot directly use the opportunity pipeline information as input, and have to make their decisions to a great extent based on feeling.

With better support from information systems, Sales and Purchasing might better anticipate inventory shortages and improve the delivery performance. An additional inventory management tool would be needed, in which crucial information of the three departments is combined. In the continuation of the research, we explore if and how the performance can be improved, when crucial information of the three departments would be linked into a centralized tool that can be used by all three departments. The goal is to create a conceptual design for a tool that can help Sales, Purchasing and Order Processing to achieve a better delivery reliability and delivery speed. The centralized inventory management tool is an IT system that requires data input from the three departments and returns advice for the sales and purchasing departments. The conceptual design for the tool should contain broad outlines of function and processes. It involves the understanding of the departments' needs, and how to meet them with the tool. We answer the following question:

> *Question 4) What could be a suitable inventory management tool to improve the delivery reliability and delivery speed?*
> *4.1) How can relevant inventory management aspects be properly included?*
> > *4.1.1) Which functionalities should the tool contain to better monitor available stock and upcoming customer demand?*
> > *4.1.2) Which information needs to be centrally registered?*
>
> *4.2) Which organizational aspects should be taken into account when adopting a centralized inventory management tool?*
> > *4.2.1) Literature: How can a better business IT alignment be achieved?*
> > *4.2.2) What organizational aspects should DAP pay attention to when adopting additional IT?*
>
> *4.3) What are possibilities for the purchasing department to use the tool in order to improve the delivery speed?*
> > *4.3.1) Literature: What can be suitable purchasing policies when customer demand is uncertain?*
> > *4.3.2) Which purchasing policies could be interesting for DAP and how could they be included?*
>
> *4.4) What are possibilities for the sales department to use the tool in order to improve the delivery reliability?*
> > *4.4.1) Literature: What does literature say about due date quotation?*
> > *4.4.2) Which due date quotation policies could be interesting for DAP and how could they be included?*
>
> *4.5) How can we build a conceptual design for a centralized inventory management tool?*
> > *4.5.1) Literature: How can a conceptual design for IT systems be created?*
> > *4.5.2) What does the conceptual design of the centralized inventory tool look like?*

To find an answer to Research Question 4, we construct 5 sub-questions as shown above (4.1 till 4.5). Question 4.1 investigates the company specific inventory management aspects of the tool, and does not contain literature. Thereafter, Questions 4.2 till 4.5 all start with a literature review in the first part and continue with an application of the literature to DAP in the second part.

First of all, in Section 4.1 we identify how relevant inventory management aspects can be included in the tool. In Chapter 2, we identified that the relevant aspects that we want to include are "Monitor available stock" and "Forecast upcoming customer demand". We look at the mentioned problems in the context analysis (Chapter 2) and determine which functionalities the tool should contain to better monitor available stock and forecast upcoming customer demand (4.1.1). Eventually, we determine which information needs to be centrally registered to include the identified functionalities (4.1.2).

In Question 4.2, we investigate which organizational aspects should be taken into account when adopting a centralized inventory management tool. To explore how an IT system can provide a better support for the sales, purchasing and order processing departments, we consult literature about business IT alignment (4.2.1). We want to investigate what DAP should pay attention to when adopting additional IT. Based on the identified IT problems in the context analysis (Chapter 2), we determine which risks from literature the organization should take into account when adopting a centralized inventory management tool (4.2.2).

In Question 4.3, we investigate how the purchasing department could use the inventory management tool to improve the delivery speed. When the department is able to accurately monitor available stock and forecast upcoming customer demand, various purchasing policies could be applied. First, we consult literature to explore what could be suitable purchasing policies to apply in an uncertain environment (4.3.1). After that, we determine which purchasing policies are applicable for DAP and how they could be included in the tool (4.3.2).

In Question 4.4 we explore how the sales department could use the inventory management tool to improve the delivery reliability. When the department is able to accurately monitor available stock and forecast upcoming customer demand, various due date quotation policies can be applied. First, we consult literature to explore what can be suitable due date quotation policies (4.4.1). After that, we determine which due date quotation policies can be interesting for DAP and how they can be included in the tool (4.4.2).

Eventually, in Question 4.5, we explore how we can build a conceptual design for the centralized inventory management tool. First, we consult literature to investigate how a conceptual design for IT systems can be created (4.5.1). After that, we use the guidelines from literature and the information of Questions 4.1 till 4.4 to create a conceptual design for the tool (4.5.2).

Solution Test (Chapter 4)

As mentioned before, in Chapter 3 we explore how a centralized inventory management tool should be shaped to improve the delivery reliability and delivery speed. We make a conceptual design for a tool in which broad outlines of functions and processes are described. The conceptual design describes which input of the three departments will be transformed by the tool. The tool provides purchasing advice and due date advice. In Chapter 4, we want to explore if we can test what the expected effectiveness of the inventory management tool is. Using the tool, various purchasing policies and due date quotation policies can be applied. To get insight into the most promising policies, we want to simulate the order delivery process when the tool would have been implemented.

Question 5) How can we test what the expected effectiveness of the inventory management tool could be and how the tool should be used?

- *5.1) Literature: What type of model can be suitable to evaluate the expected effectiveness of the inventory management tool?*
- *5.2) Literature: How can we use historical data to simulate the order delivery process based on real life properties?*
- *5.3) How can we simulate the order delivery process when the tool would have been implemented?*
- *5.4) What does the simulation model look like?*
- *5.5) Which experiments can be conducted?*
  - *5.5.1) How can purchasing policies be evaluated?*
  - *5.5.2) How can due date quotation policies be evaluated?*

First, in Question 5.1 we want to get insight in possibilities to evaluate the expected effectiveness of the tool. Additional literature will be consulted regarding evaluation methods that can be used in operations research to optimize a stochastic and dynamic problem. We try to identify what type of model we can use in this context.

In Question 5.1, we identify that a simulation model can be used to evaluate the expected effectiveness of the tool. We want to build a discrete-event simulation model that can be used to simulate the order delivery process when the tool would have been implemented and all departments therefore have full information availability. In Question 5.2, we consult additional literature to explore how we can use historical data to simulate the order delivery process based on real life properties.

In Question 5.3, we explore how we can simulate the order delivery process, when the tool would have been implemented. We apply the consulted literature of Question 5.2.

In Question 5.4, we show how we build the simulation model using Siemens Plant simulation. We give a description of the used frames and explain their functionality. Furthermore, we explain which roles the sales, purchasing and order processing departments play in the simulation.

In Question 5.5, we want to explore which experiments we can conduct to evaluate purchasing policies and due date quotation policies. We give an explanation of the used experimental design. In 5.5.1 we explain how we try to evaluate purchasing policies. In 5.5.2 we explain how we evaluate due date quotation policies.

As mentioned above, the simulation model can be used to simulate the order delivery process, when the tool would have been implemented. Experiments can be conducted to sub optimize the various purchasing policy alternatives and due date quotation policy alternatives that can be applied using the tool. After sub optimizing the various alternatives, we can evaluate which purchasing policies and due date quotation policies are likely to be the most suitable to apply for DAP, when the inventory management tool would be implemented. We try to answer the following question:

> *Question 6) What is the best way to use the inventory management tool to achieve a delivery speed and delivery reliability of at least 95%?*
>
> > *6.1) What are the best purchasing policies to achieve a delivery speed of at least 95%?*
> > *6.2) What are the best due date quotation policies to achieve a delivery reliability of at least 95%?*

In Question 6.1 we investigate which purchasing policies seem to be the most promising to achieve a delivery speed of at least 95%. We conduct simulation experiments as described in Question 5.5. First, we sub optimize various purchasing policy alternatives. Thereafter, we try to determine what the best purchasing policies are to achieve a delivery speed of at least 95%.

In Question 6.2 we try to get insight into which due date quotation policies seem to be the most promising to achieve a delivery reliability of at least 95%. We conduct simulation experiments as described in Question 5.5. First, we sub optimize the various due date quotation alternatives. Thereafter, we try to determine what the best due date quotation policies are to achieve a delivery reliability of at least 95%.

Conclusions, Implementation Plan and Recommendations, Limitations (Chapter 5)

Finally, the main research question will be answered: “How can DAP Technology achieve a delivery reliability and delivery speed of at least 95%?”. The findings and possibilities for organizational implementation will be worked out. We provide the organization with a plan on which steps have to be taken to improve the delivery speed and delivery reliability. The plan consists of steps to take on the short to long term. Finally, the limitations of the research are listed.

Deliverables of the second part of the research

The main deliverables of the second part of the research project are:

- A conceptual design for a centralized inventory management tool that can be used by the sales, purchasing and order processing departments. It is a design for an IT system in which broad outlines of function, processes and strategies are described. The inventory management tool should be able to provide support for the three departments to improve the delivery reliability and delivery speed (Chapter 3).
- A simulation model that simulates the order delivery process when the tool would have been implemented by DAP. We perform experiments to identify the most promising due date quotation policies and purchasing policies that can be applied using the tool (Chapter 4).
- An implementation plan to provide Dap Technology with advice on how to improve the current order delivery process in order to achieve better delivery reliability and delivery speed. The plan consists of steps to take on the short to long term (Chapter 5).

As mentioned above, in this chapter (Chapter 3) we explore how a centralized inventory management tool should be shaped to improve the delivery reliability and delivery speed. We create a conceptual design for an IT system in which broad outlines of function and processes are described. The following main research question will be answered:

"What could be a suitable inventory management tool to improve the delivery reliability and delivery speed?"

In Section 3.1, we explore how relevant aspects of inventory management can be included in the tool. Thereafter, in Section 3.2 we investigate which organizational aspects should be taken into account when adopting a centralized inventory management tool. Subsequently, we investigate how the purchasing department could use the inventory management tool to improve the delivery speed in Section 3.3. In Section 3.4, we investigate how the sales department could use the inventory management tool to improve the delivery reliability. Eventually, in Section 3.5 we use the information of Sections 3.1 till 3.4 to create a conceptual design for the tool.

3.1) How can relevant inventory management aspects be properly included?

In this section we try to explore how relevant inventory management aspects can be properly included. The aspects that we want to include are: "Monitor available stock" and "Forecast upcoming customer demand". We determine which functionalities the tool should contain to better monitor available stock and forecast upcoming customer demand (3.1.1). Eventually, we determine which information needs to be centrally registered to include the desired functionalities (3.1.2).

3.1.1) Which functionalities should the tool contain to improve monitoring available stock and upcoming customer demand?

In this section, we determine which functionalities the tool should contain to better monitor available stock and forecast upcoming customer demand. First, we identify which functionalities could be useful for the three departments. Thereafter, we create a flowchart of all functionalities of the centralized inventory management tool.

First of all, we need to explore which functionalities we want to include in the tool to better align the sales, purchasing and order processing departments:

- **Functionalities that could be useful for the sales department:** As mentioned in Chapter 2, the sales department experiences difficulties in quoting lead times that are preferably as short as possible, and that can structurally be met. Therefore, the tool should provide advice regarding which lead time can reasonably be promised for a new arriving hardware opportunity.
- **Functionalities that could be useful for the purchasing department:** From the context analysis in Chapter 2 it follows that the purchasing department has difficulties in placing purchase orders in such a way that the delivery speed is high enough against the lowest possible costs. The tool should provide advice regarding when to order and how much to order.
- **Functionalities that could be useful for the order processing department:** In the context analysis in Chapter 2, we identified that the order processing department is currently not able to manage inventory administratively well. It could be useful if the tool could enable them to keep inventory administratively up to date and reduces the risk of making errors.

To fulfill the above-mentioned desired functionalities for the three departments, the functionalities in Figure 14 should be included in a centralized inventory management tool:

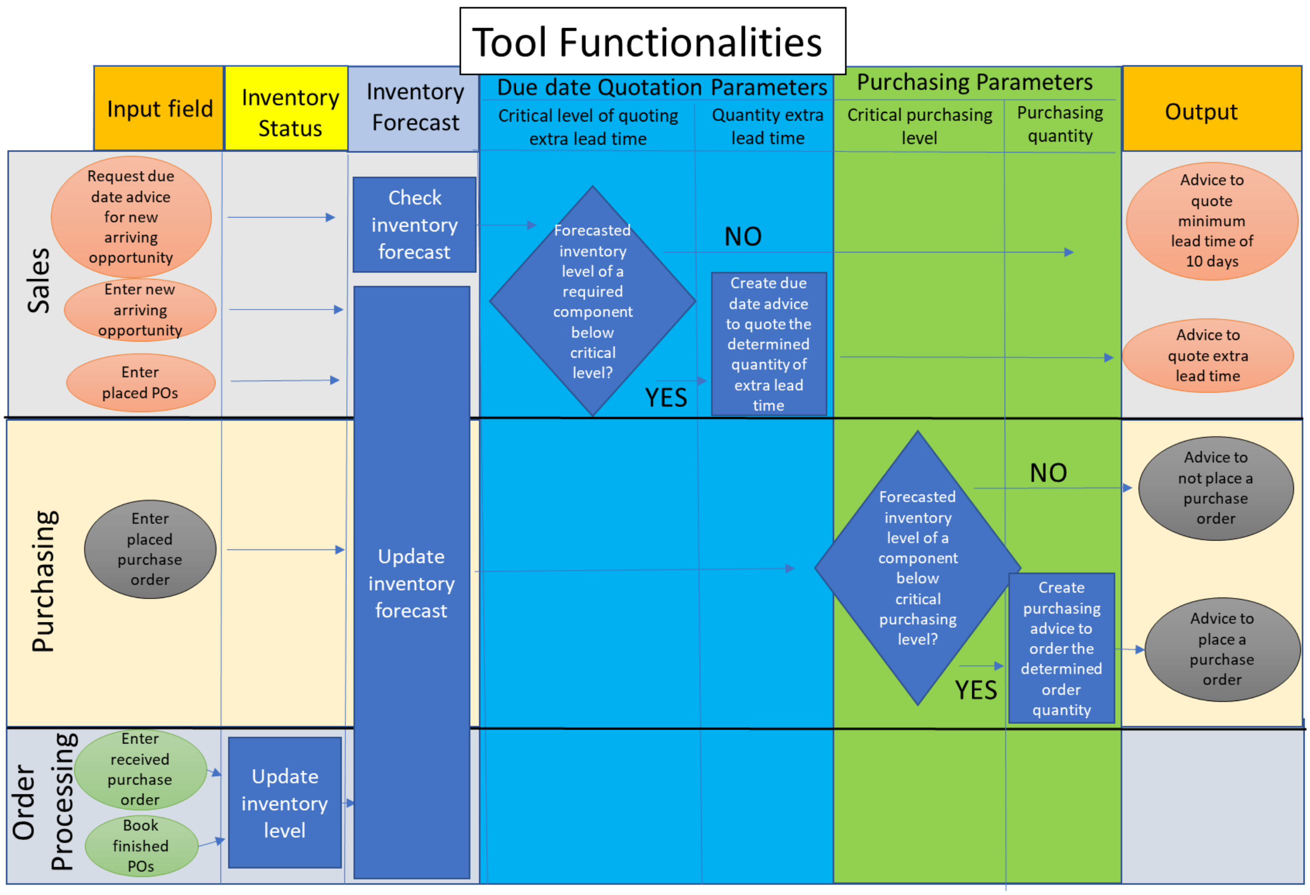

Figure 14: Tool Functionalities

The input of the three departments will be transformed by the tool, leading to output that can be used by the sales and purchasing department. The displayed functionalities are worked out below:

Input Field

The sales, purchasing and order processing departments provide input for the tool. To ensure that the departments can properly monitor available stock, it is important that all departments can directly access the tool and enter their input.

Sales:

- Request due date advice for new arriving opportunity: When a new customer arrives, the sales department has to quote a lead time. The tool can provide support for the sales department regarding which lead time can reasonably be promised for new arriving opportunities.
- Enter new arriving opportunity: When the sales department has quoted a lead time, a new opportunity will be entered with an expected closing date and probability status. New arriving opportunities will be registered in the same way as in the Goldmine opportunity pipeline (described in problem 5 of the overview of problems in Chapter 2.3). The assigned probability status represents the probability that the customer will place a PO on the expected closing date. If the customer does not place a PO in that month, the expected closing date of the opportunity shifts forward in time and the probability status will be updated.
- Enter placed POs: When a customer places a PO, the sales department can directly communicate this to the order processing and purchasing departments. The PO consists of the products that need to be produced, the quoted lead time and the desired lead time. The required components for producing the PO will be marked as reserved stock.

Purchasing:

- Enter placed purchase order: The purchasing department can directly enter placed purchase orders with the expected receival date, such that the other departments know when and how much new components are expected to become available.

Order Processing:

- Enter received purchase order: The order processing departments can enter the received purchase orders such that the physical stock will be directly updated. The corresponding open purchase order will be closed.
- Book finished POs: When production is finished, the used components will be directly deducted from the available stock.

Inventory status

The tool keeps track of the inventory level of all components. At the moment that the physical stock changes, the inventory status will be updated immediately. This functionality enables the departments to continuously monitor available stock.

Inventory forecast

The tool makes inventory forecasts of all components. The forecasted inventory levels will be calculated as follows:

$$ForecastedInventoryLevel_{i,t} = InventoryLevel_{i,0} - ReservedStock_{i,0} + \sum_{j=1}^{t} ExpectedReceivedPurchaseOrders_{i,j} - \sum_{j=1}^{t} ExpectedOpportunityDemand_{i,j}$$

$ForecastedInventoryLevel_{i,t} = Forecasted\ inventory\ level\ of\ component\ i\ at\ time\ t$

$InventoryLevel_{i,0} = Current\ Inventory\ level\ of\ component\ i$

$ReservedStock_{i,0} = Current\ reserved\ stock\ of\ component\ i\ for\ POs\ that\ still\ need\ to\ be\ produced$

$\sum_{j=1}^{t} ExpectedReceivedPurchaseOrders_{i,j} = Expected\ number\ of\ components\ i\ that\ will\ be\ received\ until\ time\ t$

$\sum_{j=1}^{t} ExpectedOpportunityDemand_{i,j} = Expected\ demand\ for\ component\ i\ until\ time\ t\ based\ on\ the\ opportunity\ pipeline$

The expected demand for a component based on the opportunity pipeline will be calculated as follows:

$$\sum_{j=1}^{t} ExpectedOpportunityDemand_{i,j} = \sum_{k=1}^{NumOpportunities} (RequiredComponents_{i,k} * ProbStatus_k)$$

$NumOpportunities = Number\ of\ opportunities\ in\ the\ pipeline\ with\ expected\ closing\ date \leq t$

$RequiredComponents_{i,k} = Number\ of\ components\ of\ type\ i\ that\ are\ required\ for\ producing\ opportunity\ k$

$ProbStatus_k = Probability\ status\ of\ opportunity\ k$

Due date Quotation Parameters

When the sales department asks for due date advice for a new arriving opportunity, the inventory forecasts of all required components will be checked. If the forecasted inventory level of one of the required components is below a specified critical level, the tool advices to quote a specified quantity of extra lead time. Thus, for each component, the following two due date quotation parameters will be stored:

- Critical level of quoting extra lead time
- Quantity extra lead time

In Chapter 4, we will try explore how to obtain suitable values for the due date quotation parameters of each inventory component.

Purchasing Parameters

The tool stores the following two purchasing parameters for each inventory component:

- Critical purchasing level
- Purchasing quantity

When the forecasted inventory level of a component changes, the tool checks if it gets below a specified minimum level. If the forecasted level is below the specified minimum level, the tool advices to place a purchase order the size of the specified purchasing quantity. In Chapter 4, we will try explore how to obtain suitable values for the purchasing parameters of each inventory component.

Output

The tool generates output for the sales and purchasing department. For the sales department it provides advice on which lead time can reasonably be promised for new arriving opportunities. For the purchasing department the tool generates advice regarding when and how much to order.

The worked-out functionalities give answer to the question: “Which functionalities should the tool contain to better monitor available stock and forecast upcoming customer demand?”. In the next section, we explore which information needs to be centrally registered to include these functionalities.

3.1.2) Which information needs to be centrally registered?

In this section we look at the desired tool functionalities of Section 3.3.1 and determine which information needs to be centrally registered to fulfill the functionalities.

When we look at the desired tool functionalities (3.1.1), it is necessary to keep track of the following information in a centralized tool (Table 8):

Table 8: Information to combine

Department	Information that needs to be centrally registered?
Sales	1) Open hardware opportunities with expected closing date, assigned probability status and quoted lead time
	2) Placed POs with desired lead time and quoted lead time
Purchasing	3) Specification of order costs, unit price and MOQ for all inventory components
	4) Up-to-date supplier lead time estimates for all inventory components
	5) Open purchase orders with expected supplier lead time
Order Processing	6) Up-to-date BOM for all COTS products

1) Open hardware opportunities with expected closing date, assigned probability status and quoted lead time: For the tool, this information is needed to make inventory forecasts. It can help the purchasing and order processing departments in anticipating potential POs, when accurate information is available regarding the status of opportunities in the pipeline.

2) Placed POs with desired lead time and quoted lead time: This information is needed to calculate the reserved stock. When a customer places a PO, the sales department can efficiently communicate it in such a way that both the purchasing and order processing departments will be notified regarding the desired lead time, and can immediately place a purchase order or start production when necessary.

3) Specification of order costs, unit price and MOQ for all inventory components: For the tool, it is important to have an overview of the order costs, unit price and minimum order quantity (MOQ) for inventory components to provide a well-founded advice regarding when and how much to purchase.

4) Up-to-date supplier lead time estimates for all inventory components: It is important to have an overview of supplier lead time estimates of all inventory components to give well-founded due date advice to the sales department and purchasing advice to the purchasing department when stock is almost running out. The supplier lead times can change over time. Therefore, it is important to keep the estimates up-to-date.

5) Open purchase orders with expected supplier lead time: This information is needed to make inventory forecasts. For both the order processing department and sales department it can be useful to know when missing components will arrive. For Order Processing, it can be useful to know when they can start producing such that they can plan capacity. Moreover, Sales can easily communicate the status of the PO when a customer asks for it.

6) Up-to-date BOM for all COTS products: For the tool, it is important to have a clear overview of the bill of materials (BOM) for all COTS products. This information is needed to administratively deduct the right components from stock when production is finished. Moreover, this information is needed to forecast potential component demand based on the customer interest for a specific product.

The worked-out parts of information give answer to the question: “Which information needs to be centrally registered?”. Together with the desired functionalities of Section 3.2.1, this provides insight into how relevant inventory management aspects can be properly included in the centralized inventory management tool.

3.2) Which organizational aspects should be taken into account when adopting a centralized inventory management tool?

In this section we explore which organizational aspects should be taken into account when adopting a centralized inventory management tool. First, we consult literature about business IT alignment in Section 3.2.1. Thereafter, we identify which organizational aspects DAP should take into account in Section 3.2.2.

3.2.1) Literature: What does literature say about business IT alignment?

In this section we consult literature about business IT alignment (B/I alignment). B/I alignment is a process in which an organization uses information technology (IT) to achieve business objectives. First, we investigate why B/I alignment is important and we explore how a good alignment can be achieved. Eventually, we investigate how the extent of alignment can be determined.

B/I alignment is very important for almost all businesses. Information systems are the ‘muscles’ of an organization. According to Laudon et al. (2018), a good integration of basic business functions using IT leads not only to a good organizational efficiency, but it improves management decision making, the quality of the process increases and it can help the organization achieve competitive advantages. Moreover, IT helps ensure control over strategy implementation (Johnson, 2016). However, to achieve a good integration, companies should not underestimate the work that is needed to analyze what are alternative solutions to achieve their objectives.

To explore how IT can ensure that a company’s objectives can be achieved, we consult literature about Business IT alignment (B/I alignment). The focus of B/I alignment lays on the harmony between IT and business decision-makers. B/I alignment integrates information technology to the goals, strategy and mission of the organization (Nawas et al., 2006). To achieve a good B/I alignment, businesses must make decisions that take into account both business and IT disciplines. There is no single strategy or single combination of activities that a firm should follow to achieve and sustain alignment, because technology and business climate are changing far too quickly (Luftman et al., 1999). However, various alignment models can provide support to link business and technology layers of the organization over common threads.

We first need guidance to the question how companies can achieve a good alignment. According to Laudon et al. (2018), an important first step in managing a better B/I alignment is taking into account the main risks associated with IT projects:

- Technical Risk: will the system function as it should?
- Organizational Risk: will the individuals within the organization use the system as they should?
- Business Risk: will the adoption of the system translate into business value?

The objective is to manage three main risks associated with IT projects. If the organization is able to successfully exclude and manage the above-mentioned risks, there will be a good chance of a successful IT investment.

Subsequently, we want to explore how the extent of alignment can be determined. According to Ullah et al. (2013) The Strategic Alignment Model of Henderson et al. (1999) is widely used as the base of B/I Alignment theories. The model is especially suitable to assess the way business and IT are aligned. The Strategic Alignment model distinguishes four domains as displayed in the Figure 15:

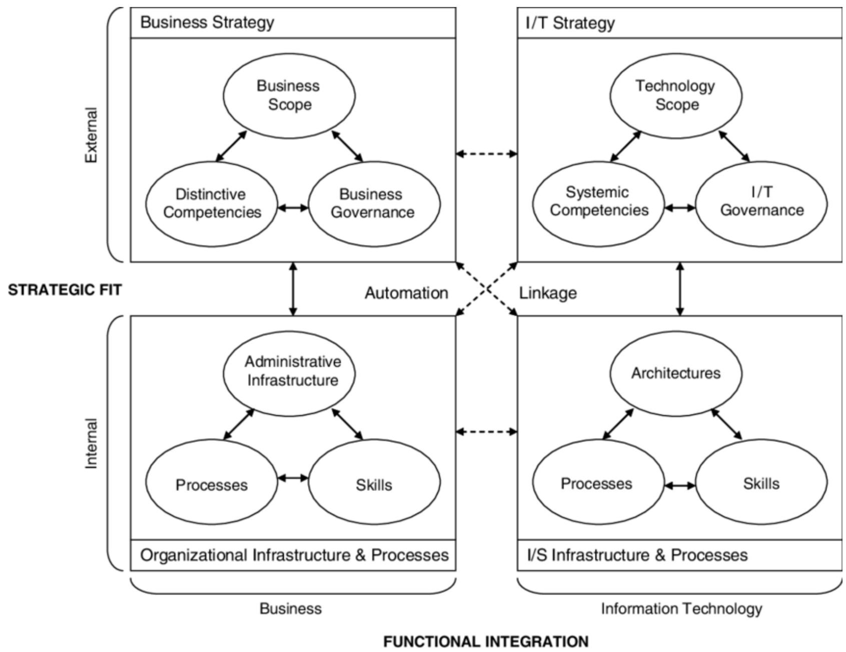

Figure 15: Strategic Alignment Model [Henderson et al., 1999]

The key message of the model is that a company should make sure that the IT strategy is fully aligned with business strategy. The extent of alignment is determined by all domains working together. The model shows that all four domains should be balanced in order to achieve a good alignment.

In this section we identified that B/I alignment is very important for almost all businesses. According to Laudon et al. (2018), a good integration of basic business functions using IT improves organizational efficiency, management decision making, the quality of the process and it can help the organization achieve competitive advantages. We identified that, to successfully adopt IT projects, it is crucial to anticipate the main risks associated with IT projects: Technical, Organizational and Business risk (Laudon et al., 2018). Furthermore, to achieve a good alignment, the organization should ensure that the following four components are balanced: Business strategy, IT strategy, Organizational infrastructure & processes, IS Infrastructure & Processes (Henderson et al., 1999).

3.2.2) What organizational aspects should DAP pay attention to when adopting a centralized tool?

In Section 3.2.1, we consulted literture about business IT alignment. In this section we will identify which organizational aspects from Section 3.2.1 DAP should pay attention to when adopting a centralized tool.

In Section 3.2.1, we saw that, to increase the chance of a succesful IT investment, it is crucial to anticipate the main risks assosiated with IT projects (Laudon et al., 2018):

- **Technical Risk:** The organization should prevent that technical failures occur. For DAP the following technical risks can be relevant:

- Technical failures: Computer crashes, software bugs or a complete failure of a computer component should be prevented. Technical failures can be catastrophic if, for example if crucial data cannot be retrieved anymore.
- Electronic threats: hackers could get access to the IT system or the system could be infected by a computer virus.
- Infrastructure failures: risks that can completely interrupt the business should be taken into account. For example, the loss of internet connection.

DAP employs various skilled hardware and software engineers that have to deal with these kinds of technical risks on a regular basis. Therefore, we will disregard the technical risks in the continuation of the research.

- **Organizational Risk:** The organization should not underestimate the time that is needed to ensure that all employees use the IT-system properly. Taking into account that departments operate from separate locations, this can be challenging. If employees do not use the tool in the right way, it can cause data to not be reliable anymore. Human errors should be avoided. This is a major treat because someone might accidentally delete important data, or does not follow security procedures properly. All departments should be aware of the fact that the tool contains sensitive information, such as customer details and product compositions. Unauthorized access to confidential data by an outsider needs to be prevented.

- **Business Risk:** The organization should pay attention to the fact that they have to monitor if business objectives will be met using the tool. This means that, in this case, the delivery reliability and delivery speed need to improve. The tool should enable the management team to easily monitor the performance regarding delivery reliability and delivery speed. For DAP, it can take a long time before the management team can conclude if a certain way of working leads to a good delivery reliability and delivery speed, because of the limited number of customer orders.

Furthermore, in Section 3.2.1 we saw that, to achieve a good alignment, the organization should take into account the following four components (Henderson et al., 1999):

- **Business Strategy**: long term plan of action designed to achieve a set of objectives. These can be business-wide objectives, broader than only improving delivery reliability and delivery speed.
- **IT Strategy**: plan of action to create an information technology capability to maximize value for an organization. The total of implemented IT should maximize DAP's organizational value. It can therefore be wise to have a critical look at the added value of current information and registration systems.
- **Organizational Infrastructure**: systems, processes and protocols that give structure to the organization. The organization should implement IT that supports the organizational structure, and not adapt processes and protocols to the implemented IT.
- **IT Infrastructure**: composite of hardware, software and network resources/services for the existence, operation and management of a business IT environment. The IT infrastructure should provide support for the existence, operation and management of a smooth order delivery process.

DAP should take into account that all the above-mentioned components should be balanced in order to achieve a good alignment.

This section gives answer to the question "What organizational aspects should DAP pay attention to when adopting a centralized tool?". Based on the literature review in Section 3.2.1, we identified that it is important to anticipate the three main risks associated with IT projects: Technical, Organizational and Business risk. Furthermore, to achieve a good alignment, the organization should ensure that the following four components are balanced: Business strategy, IT strategy, Organizational infrastructure & processes, IS Infrastructure & Processes.

3.3) What are possibilities for the purchasing department to use the tool in order to improve the delivery speed?

In this section, we try to explore how the purchasing department could use the inventory management tool to improve the delivery speed. In Section 3.1, we saw that the tool should provide purchasing advice. Using the tool, various purchasing policies could be applied. First, we consult literature to explore what could be suitable purchasing policies to apply in an uncertain environment (3.3.1). After that, we determine which purchasing policies could be interesting for DAP and how they can be included in the tool (3.3.2).

3.3.1) Literature: what can be suitable purchasing policies when customer demand is uncertain?

As mentioned in Section 3.1, the tool should be able to provide purchasing advice. In this section (3.3.1) we consult literature to explore how we can include purchasing advice in the tool. According to Slack et al. (2013), the following main questions regarding purchasing policies need to be answered:

A) How can inventory be controlled?
B) How can the order size be determined?
C) How can the order moment be determined?

In the continuation of this section, we consult literature to get insight into the above-mentioned questions.

A) How can inventory be controlled?

Inventory control refers to the process of effectively managing inventory items. Inventory control mainly focusses on monitoring item consumption and reducing the time spent on managing inventory items. Managing inventory is a complex and dynamic task. It can be challenging to control such complexity. In this section we consult literature to explore how this complexity can be controlled.

According to Slack et al. (2013), often organizational adaptations are necessary to improve and control inventory. The maintenance of data accuracy is crucial for the effectiveness of inventory management systems. Errors in recording transactions and handling the physical inventory need to be prevented. Moreover, even when a company has an inventory management system with accurate data, it can still be challenging to manage and control an extensive range of inventory items. Nahmias et al. (2005) mentions that it can be helpful to discriminate between inventory items. Some items are more important than others for the business performance. By discriminating, one can apply a degree of control to each inventory item, appropriate to its importance. An ABC classification can be applied such that a company can concentrate its efforts on controlling the most important items on stock. This is a categorization method which divides inventory items into various categories, to draw managers' attention on most critical items and not on the trivial items. Various criteria can be used to classify the stock items. The most often used criterion is dollar-usage (value times usage). However, according to Flores et al. (1998), for many items, there may be other criteria that represent important management considerations regarding inventory. Flores et al. (1998) identifies several non-cost criteria that can be important in the management of inventories such as lead time, obsolescence, availability, substitutability, and criticality. The ABC theory can be expanded to incorporate multiple criteria.

To conclude, in this section we identified two important aspects regarding inventory control that businesses can pay attention to. First of all, it is important that data accuracy of an inventory management system can be maintained (Slack et al., 2013). Errors in recording transactions and handling the physical inventory need to be prevented. Second, it can be helpful to discriminate between inventory items, such that a company can concentrate its efforts on controlling the most important items on stock (Nahmias et al., 2005).

B) How can the order size be determined?

Every time a replenishment order is placed, a decision needs to be made regarding the volume of the order. For managers, it can be challenging to determine appropriate order quantities. In this section, we consult literature to explore which aspects should be taken into account to determine the order size. First, we explore which costs can be relevant to take into account. Thereafter, we focus on lot size models that can be used to determine the order quantity.

Various costs can be crucial to make a well-founded decision regarding the order quantity. Slack et al. (2013) and Ghiani et al. (2013) identify cost components that can be relevant to take into account:

- Cost of placing a purchase order: the expenses to create and process an order to a supplier.
- Price discount costs: Suppliers often offer discounts for large quantities and cost penalties for small quantities.
- Stock-out costs: penalty of failing to supply customers fast enough
- Working capital cost: opportunity costs of not investing it elsewhere.
- Storage costs: costs of storing the goods (insuring the inventory).
- Obsolescence costs: risk that items become obsolete.
- Operating inefficiency costs: high inventory levels can prevent the management from seeing the full extent of problems.
- Transport Costs: the expenses to move products or assets to a different place.
- Plant and equipment costs: the expenses associated with fixed assets used to produce goods for a company.

The mentioned cost components are not always equally relevant for businesses. According to Ghiani et al. (2013), managers should ensure that they have a clear overview of company specific cost components per category to make sure that relevant cost components will not be overlooked.

After determining the relevant cost components, a decision regarding how much to order needs to be made, taking relevant cost components into account. In literature, there are many well-known lot sizing models that could be applicable. We first focus on lot sizing techniques for steady demand, with the economic order quantity (EOQ) model as classical example. Thereafter, we zoom in on lot sizing techniques that can be used when demand is more variable over periods. Eventually, we zoom in on models that can be used for intermittent demand.

There are many lot sizing techniques that can be used to determine batch sizes for purchased items. The economic order quantity (EOQ) approach, presented by Harris (1913), is in practice the most common approach to decide how much to order when stock needs replenishing. The goal of this approach is to find the optimal order quantity (Q_o) by finding the best balance between advantages and disadvantages of holding inventory. The following input needs to be determined: Holding costs (C_h), Order costs (C_o) and Annual demand quantity (D). Then the EOQ can be calculated using the following formula:

$$Q_o = \text{EOQ} = \sqrt{\frac{2C_oD}{C_h}}$$

Even though it is in practice often difficult to determine holding costs and order costs accurately, the EOQ is typically quite robust, such that small deviations from the EOQ will not increase total costs significantly. The EOQ approach is in practice especially suitable for products with steady demand. It is inappropriate to use EOQ models in case demand is highly variable over periods. Moreover, for components that deteriorate or go out of fashion, the EOQ model can result in excess of inventory.

For situations where demand is more variable over periods, and the EOQ model is therefore unsuitable, Baciarello et al. (2013) tested lot sizing algorithms which all use different criteria to determine lot sizes, as summarized in Table 9:

Table 9: Lot sizing methods [Baciarello et al., 2013]

Method	**Criterion to determine lot size?**
Least unit cost (LUC)	Lowest unit cost
Silver Meal (SM)	Average cost per period
Groff's Method (GM)	Stopping criterion when inventory carrying cost are lower than order costs
Freeland and Colley (FC)	Demand in the analyzed period multiplied by the number of periods of storage
Part period simplified (PPS)/ Least total costs	Ratio between order costs and inventory carrying cost
Part period balancing (PPB)	Ratio between order costs and inventory carrying cost
McLauren's order moment (MOM)	Combining the part-period techniques mentioned above and the economic order quantity
Maximum part period gain	Part-period techniques mentioned above. This is distinct from the previous heuristics because it does not follow a forward procedure
Wagner Whitin algorithm (WW)	Calculating all possible solutions when future demand is known (optimal)

The investigated lot sizing methods, all anticipate forecasted demand in a different way. The algorithms' target is to find lot sizing solutions that minimize the inventory holding costs and ordering costs. When demand is perfectly predictable, the exact algorithm of Wagner Whitin gives the optimum solution. However, it is typically not easy to determine which method is the most suitable for a specific situation. The algorithms' performance is strongly dependent of the variation and the predictability of demand.

The above-mentioned lot sizing techniques are especially suitable in situations where demand is fairly predictable. In situations where demand is intermittent, it becomes even more complex to optimize lot sizes. Intermittent means that demand appears at random, with most time periods having no demand. In such situations it can be challenging to find a control rule that minimizes the expected costs. There exist forecasting techniques to forecast products with intermittent demand. The Croston Method can be applied to determine the expected demand per period (Croston, 1972). Croston (1972) makes forecasts using the following 3 steps:

- Determine the average demand level when there is a demand occurrence
- Determine the average time between two demand occurrences
- Forecast the expected demand: demand level (when there is an occurrence) multiplied by the probability to have an occurrence

The Croston method predicts future demand following the above-mentioned steps. The predicted future demand can be used to determine suitable order sizes for products with intermittent demand.

In this section, we explored how the order size could be determined. First of all, it is important for businesses to identify company specific relevant costs when determining the lot size. Company specific cost components from various main categories should be taken into account (Ghiani et al., 2013). When the relevant cost components are determined, various lot sizing techniques could be applied. In situations of steady demand, the EOQ model can be used (Harris, 1913). When demand is more variable over periods, there are various heuristics that could be applied (Baciarello et al.,2013). In situations where demand is intermittent, with most time periods having no demand, forecasting techniques could be applied to predict future demand (Croston, 1972). Therefore, it is very important to get insight into a product's demand pattern before an appropriate lot sizing technique can be chosen.

C) How can the order moment be determined?

In this section we want to explore how the order moment can be determined. We consult literature to identify which factors can be taken into account when determining an appropriate moment to place an order.

First of all, the moment of placing an order depends on the frequency of reviewing (Slack et al., 2013). One can choose to use a continous review approach. The stock levels are reviewed constantly, and an order is placed when the stock level reaches its re-order level. This requires a lower level of safety stock. A company should choose for a continuous review approach when it is easy to check inventory levels. When the inventory levels are not accurately stored by computer, checking inventory levels can be time consuming. In such cases, one can often better choose for a periodic review system. Using this approach, orders can only be placed at fixed points in time. It reduces time for checking inventory levels, but a higher level of safety stock is required.

When the frequency of reviewing has been determined, the moment of placing an order depends on the level of safety stock that a company wants to hold. Demand and supplier lead time are never perfectly predictable. This means a safety stock needs to be held such that the probability is low that the stock will run out before the replenishment order arrives. To determine the safety stock, the variability of demand and supplier lead time is often combined into a lead-time usage distribution (Nahmias et al., 2005). According to Ruiz-Torres et al. (2010) in many situations where demand and lead times are variable, companies hold more safety stock than necessary leading to high inventory costs. In such situations, companies often incorrectly assume that demand during lead time follows a normal distribution. It is therefore important for businesses to get insight into the distribution of the demand over supplier lead time.

In this section we identified that the order moment depends on the frequency of reviewing and the level of safety stock that a company wants to hold. To choose an appropriate level of safety stock, businesses should have a clear overview of the distribution of the demand over supplier lead time.

3.3.2) Which purchasing policies could be interesting for DAP and how can they be included?

In this section we determine which purchasing policies could be interesting for DAP and how they can be included in the tool. First, we explore how inventory can be controlled. Thereafter, we determine which configurations for the order moment and order quantity could be applied.

In Section 3.3.1, we saw that managing inventory is a complex and dynamic task. It can be challenging to manage and control an extensive range of inventory items. It can be helpful to discriminate between inventory items, such that a company can concentrate its efforts on controlling the most important items on stock (Nahmias et al., 2005). An ABC-classification could be applied to control this complexity. We will apply an ABC classification using non-cost criteria, as mentioned by Flores et al. (1998). Since we are interested in improving the delivery reliability and delivery speed, we split up the components based on the expected total demand. We will use this classification in such a way that the same purchasing policy will be applied for inventory components in a specific category. The classification will be worked out in Section 4.1.5.

In Section 3.3.1, we saw that a policy consists of a combination of an order moment (X) and order quantity (Q). The order moment depends on the frequency of reviewing and the level of safety stock that DAP wants to hold. We assume that, using the tool, inventory levels will be real-time and online available in the future. Therefore, we can best use a continuous review approach (Slack et al., 2013). This means that a purchase order can directly be placed if the inventory level gets below a specified minimum. To determine the safety stock, the variability of demand and lead time is often combined into a lead-time usage distribution (Nahmias et al., 2005). For most of DAP's components it is not possible to collect accurate information regarding the variability of demand and supplier lead time. Namely, DAP receives a limited number of customer orders per year and many new developed products have hardly been sold so far. This means that most of the components are not often purchased, leading to limited information regarding supplier lead times. Moreover, most of the components are not often used for customer orders, leading to limited information regarding component demand. This means that we have to find other ways to determine a suitable order moment. We choose for a fixed level of safety stock for each inventory component, that we try to optimize gradually in Chapter 4. Using the tool, the following fixed levels can be used:

Order Moment (X):
A) Do not anticipate potential POs: Place purchase order when inventory level gets below a minimum level (X1)

Order moment: when Inventory Level < X1

B) Anticipate potential POs: Make forecast over worst case estimate of supplier lead time. Place purchase order when forecasted inventory level gets below a minimum level (X2)

Order moment: when forecasted inventory level < X2

Then, we need to identify which methods for determining the order quantity can be interesting for DAP. We saw that the EOQ model (Harris, 1913) is the most common model that companies deal with. However, the EOQ model is not applicable in situations where demand not steady. We have to deal with situations in which demand is intermittent and therefore hardly predictable. This means that the mentioned heuristics of Baciarello (2013) do also not seem to be suitable for DAP's purchasing department. For the mentioned heuristics in Baciarello (2013), the forecasted demand needs to reasonably match the actual demand, which is definitely not the case for DAP's situation. Also forecasting techniques for intermittent demand, as mentioned by Croston (1972), cannot be used, since we have very limited information regarding the average level of demand and the average time between demand occurrences of most of the components. Therefore, we do not use historical data to make forecasts. As mentioned in Section 3.1.1, we try to make forecasts based on the opportunity pipeline. Opportunities are customers that show concrete interest in DAP's products and possibly are going to place a PO in the near future. Using the tool, we can choose for a fixed quantity or a quantity based on the forecasted opportunity pipeline demand. We try to gradually optimize the order quantities in Chapter 4:

Order Quantity (Q)
1) Do not anticipate potential POs: Always order a fixed quantity (Q1)
Order quantity: MOQ+ Q1

2) Anticipate potential POs: Make forecast over worst case estimate of supplier lead time. Order a quantity (Q2) based on the total forecasted demand
Order quantity: MOQ+ Forecasted demand during worst case supplier lead time + Q2

Each combination of order moment X and order quantity Q is a purchasing policy that can be evaluated. Using the tool, the organization can set a purchasing policy for each individual inventory component. For each inventory component we try to gradually optimize the values for X and Q in Section 4.2.1.

This section gives answer to the question "What are possibilities for the purchasing department to use the tool in order to improve the delivery speed?". Based on the literature review in Section 3.3.1, we identified that various purchasing policies could be applied using the tool. A policy consists of two aspects: "Order Moment" and "Order Quantity".

3.4) What are possibilities for the sales department to use the tool in order to improve the delivery reliability?

In Section 3.1, we saw that the tool should provide advice regarding which lead time can reasonably promised under various circumstances. To be able to design an intelligent tool that creates valuable output regarding due date advice, we first consult literature about due date quotation in Section 3.4.1. After that, we determine which due date quotation policies could be interesting for DAP and how they can be included in the tool (3.4.2).

3.4.1) Literature: what can be suitable due date quotation policies?

In this section, we consult literature about "due date quotation". Due date quotation means that a supplier has to quote due dates to arriving customers. First, we explore which characteristics should be taken into account when quoting a lead time. Thereafter, we investigate how the performance of a due date quotation policy can be evaluated. Eventually, we explore what the effect of due date quotation can be on the performance of a company.

First of all, we explore which characteristics can be taken into account when quoting a lead time. Keskinocak et al. (2003) indicates that no single due date quotation policy performs well under all environments. In general, due date policies that take into account job and shop characteristics perform better than the policies that only consider job characteristics. A job shop is a small company that makes specific products for one customer at a time. The following job shop characteristics can be important:

- Layout and routing: the order travels throughout the various areas according to the sequence of operations.
- Capacity: machine capacity or employee capacity is needed to process the order
- Resource Availability: the resources needed to process the order must be available

When firms quote lead times, taking into account relevant job shop characteristics, the performance is likely to be better than when firms only take into account characteristics of the job.

Subsequently, we want to get insight into how the performance of a due date quotation policy can be evaluated. Keskinocak et al. (2003) examines the performance of well-known due date quotation policies. Although the mentioned models are especially focused on multi-machine environments, they can give valuable insight into due date quotation problems where orders arrive over time and lead times are uncertain. The goal of the policies is optimizing one or a combination of the following objectives:

- minimizing quoted due dates
- minimizing average tardiness
- minimizing the fraction of tardy jobs

When minimizing one or a combination of the above-mentioned objectives, service level constraints need to be taken into account to ensure lead time reliability. The models impose service level constraints such as “maximum fraction of tardy jobs” or “maximum average tardiness”. Keskinocak et al. (2003) indicates that it is very important for firms to understand what kind of service level constraints are appropriate in different business environments. A firm should only commit hard to meet service guarantees if such a guarantee would positively impact demand. Ghiani et al. (2013) also mentions that a company should target service levels for which a maximum profit can be achieved. In general, the maximum profit will be obtained for high but less than maximum values for the service level. When a company has determined appropriate service level constraints, the performance of due date quotation policies can be evaluated by minimizing one or a combination of the above-mentioned objectives, while the chosen service level needs to be met.

Eventually, we want to get insight into the effect of quoting lead times on the performance of a company. Wu et al. (2012) investigates, among other things, lead time quotation under lead time and demand uncertainty. The article shows that quoted lead times affect customer satisfaction and therefore affect company broad aspects as pricing, stocking decisions, average demand and the associated expected profit. This means that customer satisfaction is very important for a firm’s performance. A good customer satisfaction can lead to an increase in a company’s profit. Wu et al. (2012) distinguish two types of customers: price sensitive customers and lead-time sensitive customers. Price sensitive customers don’t mind long due dates as long as the price is favorable. Lead time sensitive customers want their products as fast as possible and don’t mind paying a higher price. Especially when demand is uncertain, it is difficult to quote reliable lead times. In such cases, quoting short lead times can lead to a lower customer satisfaction for customers who are lead-time sensitive but price insensitive. It is therefore important for businesses to have an overview of customers that are more price sensitive and of customers that are more lead time sensitive when quoting a lead time.

In this section, we identified that, in general, due date policies that take into account job and shop characteristics perform better than the policies that only consider job characteristics. A firm should identify what company specific relevant job shop characteristics are to take into account. Furthermore, we saw that there are several ways to evaluate the performance of due date policies. One or a combination of following objectives can be used: minimizing quoted due dates, minimizing average tardiness and/or minimizing the fraction of tardy jobs. To ensure lead time reliability, one of the following service level constraints need to be met: maximum fraction of tardy jobs or maximum average tardiness. Eventually, we identified that quoting lead times can have a broad effect on the performance of the company. Especially customer satisfaction is important factor that influences a company's profit. A firm should quote lead times such that a good customer satisfaction will be achieved. Therefore, a firm should take into account if the customer is price sensitive or lead time sensitive, when quoting a lead time.

3.4.2) Which due date quotation policies could be interesting for DAP and how could they be included?

In Section 3.4.1, we consulted literature to get insight into due date quotation policies. In this section, we determine which due date quotation policies could be interesting for DAP and how they could be included in the tool.

First of all, according to Wu et al. (2012), a firm should take into account if the customer is price sensitive or lead time sensitive, when quoting a lead time. DAP is a specialist company that asks standard prices for their products, regardless of the lead time. In this research, customer satisfaction is therefore determined by the length of the lead time and we do not take into account product prices. This means that customers are lead time sensitive, and quoted due dates need to be preferably as short as possible. We saw that, according to Keskinocak et al. (2003), various job shop characteristics can be taken into account when quoting lead times. For DAP, especially resource availability is important. DAP has no separate areas where the order should flow, and DAP has no machines or scarcity in employee capacity. Therefore, we take into account resource availability with a focus on component availability. As described in Section 3.1.1, the tool takes two factors into account for each component: "When to quote extra lead time?" and "How much extra lead time to quote?".

<u>When to quote extra lead time (K)?</u>

A) Do not anticipate potential POs: Quote extra lead time if the physical stock of a required component is below a fixed level (K1) at the moment of opportunity arrival.

Extra lead time if: Physical Stock < K1

B) Anticipate potential POs: Make inventory forecast over worst case estimate of supplier lead time. Quote extra lead time if forecasted inventory level gets below a fixed level (K2)

Extra lead time if: Forecasted inventory level < K2

<u>How much extra lead time to quote? (Y)</u>

1) Do not anticipate supplier lead time: Quote fixed amount of extra lead time (Y1) on top of the minimum lead time of 10 days. We choose 7 days as minimum lead time because DAP has worldwide customers for which it can take up to 7 days to ship orders and add 3 days to take into account supplier lead times of order specific purchases and production times

Lead time to quote: 10 days + Y1

2) Anticipate potential supplier lead time: Quote extra lead time based on supplier lead time of components. Multiply the most likely supplier lead time by a factor Y2.

*Lead time to quote: 10 days + Y2*Most likely supplier lead time*

Each combination of K and Y is a due date quotation policy that can be evaluated. In Section 3.4.1, we saw that various objectives and service level constraints can be used to evaluate the performance of a due date quotation policy. We will zoom in on the used objectives and service level constraints in Section 4.2.2, where we try to evaluate the performance of various due date quotation policies.

This section gives answer to the question “What are possibilities for the sales department to use the tool in order to improve the delivery reliability?”. Based on the literature review in Section 3.4.1, we identified that various due date quotation policies could be applied using the tool. A policy consists of two factors: “when to quote extra lead time” and “how much extra lead time to quote”.

3.5) How can we build a conceptual design for a centralized inventory management tool?

In this section we try to explore how we can build a conceptual design for a centralized inventory management tool. First, we consult literature to investigate how a conceptual design for IT systems can be created (3.5.1). Thereafter, we work out the conceptual design for the centralized inventory management tool (3.5.2).

3.5.1) Literature: How can a conceptual design for IT systems be created?

In this section we consult literature to explore how a conceptual design for IT systems can be created. We want to investigate which steps of conceptual design need to be worked out to successfully construct an information system.

For the design of an information system, conceptual design is the centerpiece of the process. Only after the conceptual design is completed, it can be sure that information systems can be successfully constructed. In a conceptual design of information systems, a broad picture of the system is worked out. According to Amaechi (2013), the following main steps should be worked out in a conceptual design:

- **Define problem**: An organization should clearly understand and define the problem to be solved.
- **Set system objectives**: An organization should clearly define the targeted result that a system aims to achieve.
- **Identify constraints**: Constraints may be imposed on hardware, software, data, operational procedures or interfaces. Establishing constraints will help to ensure that the system design is realistic.
- **Determine information needs and information sources**: An organization should identify what are the items of information that are needed to achieve predetermined objectives.
- **Document the conceptual design**: The overall system flow should be documented. An organization should clearly define system input and output.

According to Amaechi (2013), it is important to accurately work out the above-mentioned steps of a conceptual design to increase the chance of a successful IT system construction.

In this section, we identified that a conceptual design is the centerpiece of the information system design process. For a successful construction of an IT system, several main steps need to be accurately worked out (Amaechi,2013). In the next section (3.5.2), we try to work out these main steps.

3.5.2) What does the conceptual design of the centralized inventory management tool look like?

In this section, we want to create a conceptual design for the centralized inventory management tool. With the information from Sections 3.1 till 3.4, we work out the main steps of conceptual design that we identified in Section 3.5.1 (Amaechi, 2013).

Step 1: Define problem

The organization should clearly understand and define the problem to be solved. We focus on the following problem to be solved: The alignment between the sales, purchasing and order processing departments is not good enough to achieve a delivery speed and delivery reliability of at least 95%. The current information systems do not provide sufficient support to fulfill the needs of the departments. Various aspects of managing inventory are problematic in the current way of working. The departments are in need of the following aspects of inventory management, that cannot be completely fulfilled:

- Order Processing: Monitor available stock to know what can be produced and shipped.
- Sales: Monitor available stock and forecast upcoming customer demand to make a well-founded decision about which lead time can reasonably be promised to new arriving customers.
- Purchasing: Monitor available stock and forecast upcoming customer demand to make a well-founded decision regarding when and how much to purchase.

The organization needs additional IT in the form of a centralized inventory management tool to better align the sales, purchasing and order processing departments.

Step 2: Set system objectives

The organization should clearly define the targeted result that an IT system aims to achieve. The centralized inventory management tool should be able to help the sales, purchasing and order processing departments to achieve a delivery reliability and delivery speed of at least 95%. In order to achieve this, the information systems should provide better support to fulfill the needs mentioned in Step 1, such that the sales and purchasing departments will be able to better foresee bottlenecks in the inventory. The tool should combine crucial information of the three departments to create more openness in the order delivery process.

Step 3: Identify constraints

Various constraints may be imposed on the tool. Establishing constraints will help to ensure that the system design is realistic. In Section 3.2.2, we identified that the organization should take into account various constraints and risks, when implementing the tool. The system should be accessible for all departments form various locations. Furthermore, human errors should be avoided. The organization should not underestimate the time that is needed to ensure that all employees use the IT-system properly. All departments should be aware of the fact that the tool contains sensitive information, such as customer details and product compositions. Unauthorized access to confidential data by an outsider needs to be prevented. Moreover, the organization should pay attention to the fact that they have to monitor if business objectives will be met using the tool. For DAP, it can take a long time before they can conclude if a certain way of working leads to a good delivery reliability and delivery speed, because of the limited number of customer orders.

Step 4: Determine information needs and information sources

The organization should identify what are the items of information that are needed to achieve predetermined objectives. In Section 3.1.2, we identified that, for a centralized inventory management tool, it is necessary to centrally register the following information (Table 10):

Table 10: Information needs and information sources

Department	Information that needs to be centrally registered?	Current way of registering
Sales	1) Open hardware opportunities with expected closing date, assigned probability status and quoted lead time	Goldmine opportunity pipeline
	2) Placed POs with desired lead time and quoted lead time	Fogbugz
Purchasing	3) Specification of order costs, unit price and MOQ for all inventory components	Minox

	4) Up-to-date supplier lead time estimates for all inventory components	Not registered
	5) Open purchase orders with expected supplier lead time	Minox
Order Processing	6) Up-to-date BOM for all COTS products	Minox

As displayed in the third column, the most parts of information are already registered in one of the current information systems. Only information regarding supplier lead times of inventory components is not registered yet.

Step 5: Documentation of the conceptual design

The overall system flow should be documented. The organization should clearly define system input and output. The overall system flow is displayed in Figure 14 of Section 3.1. The tool contains the following functionalities:

- **Input Field**: The sales, purchasing and order processing departments provide input for the tool. It is important that all departments can directly access the tool and enter their input.
- **Inventory Status**: The tool keeps track of the inventory level of all components. At the moment that the physical stock changes, the inventory status will be updated immediately. This functionality enables the departments to continuously monitor available stock.
- **Inventory forecast:** The tool makes inventory forecasts of all inventory components. It takes into account the expected customer demand based on the opportunity pipeline and the expected receival of components based on open purchase orders.
- **Due date Quotation Parameters:** For each component, the following two due date quotation parameters will be stored: “Critical level of quoting extra lead time” and “Quantity of extra lead time”. When the sales department asks for due date advice for a new arriving opportunity, the inventory forecast of all required components will be checked. If the forecasted inventory level of one of the required components is below the specified critical level, the tool advices to quote the specified quantity of extra lead time. Using the tool, various due date quotation policies can be applied. A policy consists of a combination of “when to quote extra lead time” and “how much extra lead time to quote”:

  <u>When to quote extra lead time (K)?</u>

  - **Do not anticipate potential POs:** Quote extra lead time if the physical stock of a required component is below a fixed level (K1) at the moment of opportunity arrival.
    Extra lead time if: Physical Stock < K1

  - **Anticipate potential POs:** Make inventory forecast over worst case estimate of supplier lead time. Quote extra lead time if forecasted inventory level gets below a fixed level (K2)
    Extra lead time if: Forecasted inventory level < K2

  <u>How much extra lead time to quote? (Y)</u>

  - **Do not anticipate supplier lead time:** Quote fixed amount of extra lead time (Y1) on top of the minimum lead time of 10 days. We choose 7 days as minimum lead time because DAP has worldwide customers for which it can take up to 7 days to ship orders and add 3 days to take into account supplier lead times of order specific purchases and production times
    Lead time to quote: 10 days + Y1

- **Anticipate potential supplier lead time:** Quote extra lead time based on supplier lead time of components. Multiply the most likely supplier lead time by a factor Y2.
  *Lead time to quote: 10 days + Y2*Most likely supplier lead time*

- **Purchasing Parameters:** For each component, the following two purchasing parameters will be set: "Critical purchasing level" and "purchasing quantity". When the forecasted inventory level of a component changes, the tool checks if it gets below the specified minimum level. If the forecasted level is below the specified minimum level, the tool advices to place a purchase order the size of the specified purchasing quantity. Using the tool, various purchasing policies can be applied. A policy consists of a combination of the order moment and the order quantity:

  <u>Order Moment (X):</u>
  - **Do not anticipate potential POs:** Place purchase order when inventory level gets below a minimum level (X1)
    Order moment: when Inventory Level < X1
  - **Anticipate potential POs:** Make forecast over worst case estimate of supplier lead time. Place purchase order when forecasted inventory level gets below a minimum level (X2)
    Order moment: when forecasted inventory level < X2

  <u>Order Quantity (Q):</u>
  - **Do not anticipate potential POs:** Always order a fixed quantity (Q1)
    Order quantity: MOQ+ Q1
  - **Anticipate potential POs:** Make forecast over worst case estimate of supplier lead time. Order a quantity (Q2) based on the total forecasted demand
    Order quantity: MOQ+ Forecasted demand during worst case supplier lead time + Q2

- **Output:** The tool generates output for the sales and purchasing department. For the sales department it generates advice on which lead time can reasonably be promised for new arriving opportunities. For the purchasing department it generates advice regarding when and how much to order.

To conclude, the combined input of the three departments will be transformed by the centralized inventory management tool and leads to two main parts of output: Purchasing advice regarding when and how much to order and due date quotation advice regarding which lead time can reasonably promised for new arriving opportunities. The purchasing advice should help the organization improving its delivery speed and the due date quotation advice should help the organization improving its delivery reliability.

In this section we worked out the conceptual design of the centralized inventory management tool. We worked out the broad outlines of function and processes. Sections 3.1 till 3.5 together give answer to Research Question 4: "What could be a suitable inventory management tool to improve the delivery reliability and delivery speed?". In the continuation of the research we try to explore if we could test what the expected effectiveness of the tool is, and how it can be used to improve the delivery speed and delivery reliability. We want to explore what the most promising due date quotation policies and purchasing policies are, that can be applied using the tool.

Chapter 4: Solution Test

In Chapter 3, we identified how a centralized inventory management tool should be shaped to improve the delivery reliability and delivery speed. We made a conceptual design for an IT system in which broad outlines of function and processes are described. The conceptual design describes which input of the three departments will be transformed by the tool. The transformed input should lead to output regarding "purchasing advice" and "due date advice". In this chapter we want to explore if we can test what the expected effectiveness of the inventory management tool could be and how the tool can be used. As mentioned in Chapter 3, using the centralized inventory management tool, various purchasing policies and due date quotation policies can be applied. In this chapter we want to test which policies are the most promising to achieve a delivery speed and delivery reliability of at least 95%.

First, we explore how we can test what the expected effectiveness of the tool could be and how the tool could be used in Section 4.1. Thereafter, we simulate the order delivery process, when the organization would have implemented the tool and the departments have full information availability. We conduct experiments to determine what seem to be the best purchasing policies and due date quotation policies in Section 4.2.

4.1) How can we test what the expected effectiveness of the tool could be and how the tool should be used?

In this section we want to explore how we can test what the effectiveness of the tool could be and how the tool should be used. First, in Section 4.1.1 we consult literature to get insight into evaluation methods that can be used in operations research to optimize a stochastic and dynamic problem. We determine that we want to build a discrete-event simulation model that can be used to simulate the order delivery process, when the tool would have been implemented. In Section 4.1.2, we consult additional literature to explore how we can use historical data to simulate the order delivery process based on real life properties. Thereafter, in Section 4.1.3 we investigate how we can simulate the order delivery process when the tool would have been implemented. In Section 4.1.4, we give a description of the simulation model that we build. Eventually, in Section 4.1.5 we work out the simulation experiments that can be conducted to test the expected effectiveness of the tool.

4.1.1) Literature: What type of model can be suitable to evaluate the expected effectiveness of the inventory management tool?

In this section, we consult literature to explore what can be suitable methods to evaluate how the inventory management tool should be used. We identify which methods are likely to work best for the situation at DAP Technology.

In operations research, we can identify various methods to optimize a stochastic and dynamic problem. Nahmias et al. (2005) mentions various alternatives that could be interesting for evaluating how the centralized inventory management tool should be shaped:

- Experimenting in reality: Create the tool and try to optimize gradually. This can be risky and expensive because of the organization's lack of knowledge whether implementing a tool can lead to significant improvements and how it can lead to improvements.
- Analytical model: The business processes are entirely described using mathematical equations. Optimization is faster, but the situation in reality is complex. Difficult probability distributions and dynamic effects are typically too complex to optimize analytically.

- Numerical model: An incremental time-stepping procedure is used, which will be iterated to learn about the development of the model over time. It can be time-consuming and complex to make an accurate description of the realistic problem.

Since we have to deal with many probability distributions and dynamic effects in the order delivery process, a numerical model seems to be the best option for evaluating how to set up the tool as well as possible. We can use numerical simulation to create an 'imitation model' of the order delivery process and conduct experiments with the model. Using a simulation model, one can learn about the behaviour and/or performance of dynamic (stochastic) systems. In operations research, simulation is a frequently used problem-solving technique to optimize a stochastic and dynamic problem. In situations that are too complex for an analytical analysis, simulation can be a powerful tool to get insight into which purchasing policies are most likely to lead to the best lead time performance (Ruiz-Torres et al., 2010), and to test the expected effectiveness of due date quotation policies (Keskinocak et al., 2013).

In this section, we identified that simulation can be a powerful tool to evaluate the various purchasing and due date quotation policies that can be applied using the tool. We want to build a discrete-event simulation model that can be used to simulate the order delivery process, when the tool would have been implemented. In the continuation of the research, we explore how this discrete-event simulation model can be built.

4.1.2) Literature: How can we use historical data to simulate the order delivery process based on real life properties?

In the previous section, we determined that we want to build a discrete-event simulation model that can be used to simulate the order delivery process, when the tool would have been implemented. In this section, we consult literature to explore which input information needs to be collected. We want to explore how we can use historical data to simulate the order delivery process based on real-life properties. Furthermore, we want to investigate what we can do when there only is a limited amount of historical data available.

To be able to simulate the order delivery process based on real-life properties, input data needs to be collected, which can sometimes be difficult to find. We need to dive into available historical data of the order delivery process. Many physical systems can be described by continuous probability density functions (Montgomery, 2010). Law (2015) mentions widely used methods of how to use historical data to simulate business processes. We will apply various described methods when modelling the order delivery process, which we will further explain in Section 4.1.3.

Due to the fact that we only have a limited amount of data available for some aspects of the order delivery process (supplier lead times, production times, arrival frequency of opportunities), we need to find a solution of how to model these parts. First of all, we have to investigate how we can model the arrival process of opportunities, despite of the limited amount of historical data. According to Law (2015), when there is no representative data available on the arrival mechanism of objects, it is common to assume that objects arrive in accordance with a Poisson process with constant rate equal to the predicted arrival rate of objects. In situations where it is not easy to predict the future arrival rate of opportunities, the size of λ (expected arrivals per day) can be varied over the experiments to explore various future scenarios. In Section 4.1.3, we will work out the application of the Poisson arrival process of opportunities more extensively.

Subsequently, we want to investigate how supplier lead times and production times can be modelled, despite of the limited amount of historical data. Vose (2008) mentions various ways to construct probability distributions based on a range of estimates, when there is only a limited amount of input data available. The following distributions can be used:

- Uniform distribution: the uniform distribution is the simplest way to sample a range of estimates. In this distribution, every value from the minimum estimate to the maximum estimate is equally likely. This distribution is especially useful in situations in which only a minimum and maximum estimate are available.
- Triangular distribution: If it is possible to get an additional estimate of the most likely value, in addition to the minimum and maximum estimate, this additional information can be used to create a triangular probability model, that is typically more realistic than the uniform distribution. This model creates a higher probability mass around the most likely value, and should provide a better estimate of the probabilities of reaching other values.
- The PERT Distribution: The PERT distribution also uses the most likely estimate. Unlike the triangular distribution, PERT constructs a smooth curve and can therefore resemble realistic probability distributions (Figure 16). PERT ensures a higher probability on values around the most likely estimate and a lower probability on values around the edges (minimum and maximum estimate). PERT is therefore especially useful in situations where one has great trust in the accuracy of the estimated most likely value.

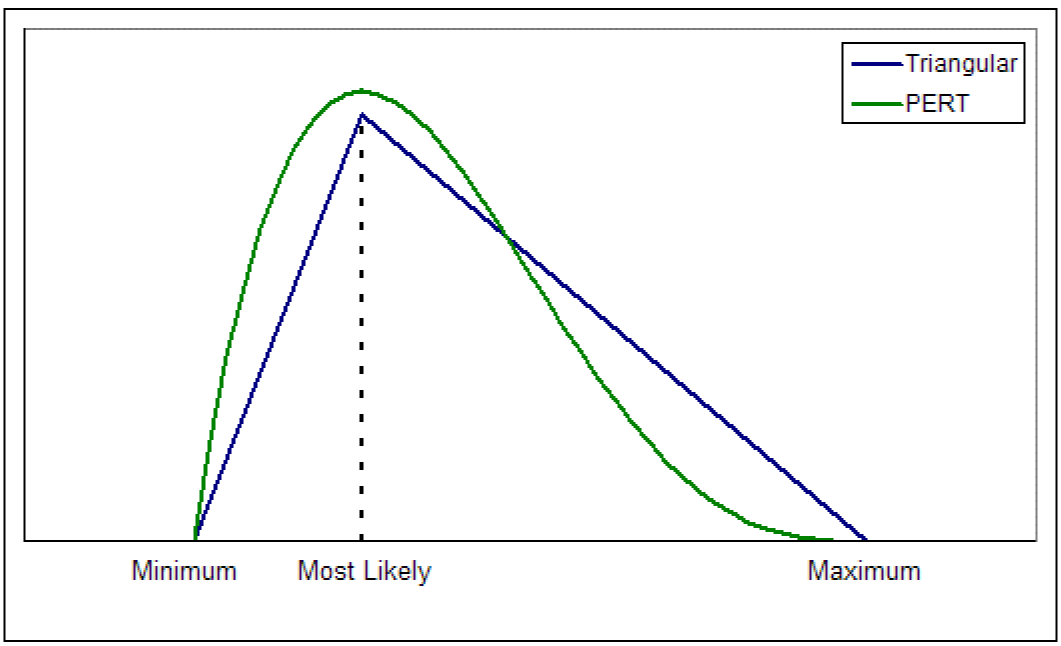

Figure 16: Triangular vs PERT

To decide which distribution we use to describe supplier lead times and production times, we take into account how much confidence we have in the estimates we can make. We want to use a distribution based on three estimates (minimum, most likely and maximum). Often, management judgements can be used for these estimates since the management team has the best overview about the company's business and possible shifts in customers' or suppliers' behaviour (Ghiani et al., 2013). However, because of the limited amount of input data, we hardly have any insights about the accuracy of the estimates. In such situations, Vose (2008) advices to use triangular distributions instead of PERT distributions. Salling (2007) also mentions that triangular distributions are suitable in simulation models for descibing a population for which only a very limited amount of sample data is available. In Section 4.1.3 we will work out the application of the triangular distribution for the supplier lead time and production time more extensively.

In this section, we explored how we can simulate the order delivery process based on real-life properties. When there is sufficient historical data available, processes often can be described by continuous probability density functions (Law, 2015). Due to the fact that we only have a limited amount of data available for some aspects of the order delivery process (supplier lead times, production times, arrival of opportunities), we explored how we can model these parts. We identified that it is common to assume a Poisson process for the arrival process of opportunities, when there is no representative data available (Law, 2015). Furthermore, we can use triangular distributions to model supplier lead times and production times (Vose, 2008). In Section 4.1.3 we further zoom in on literature that we apply in the simulation model.

4.1.3) How can we simulate the order delivery process, when the tool would have been implemented?

As mentioned in the literature review of Section 4.1.1, we want to build a discrete-event simulation model that can be used to simulate the order delivery process, when the tool would have been implemented. In this section we work out how we want to simulate the order delivery process based on real life properties.

The simulation model consists of several main parts, for which input information needs to be collected. The main parts per department (Sales, Purchasing and Order Processing) and the corresponding input information are described below:

Sales department

The modelled parts of the sales department are displayed in Figure 17. The flowchart describes how opportunities arrive in the model, how they behave and where they can flow.

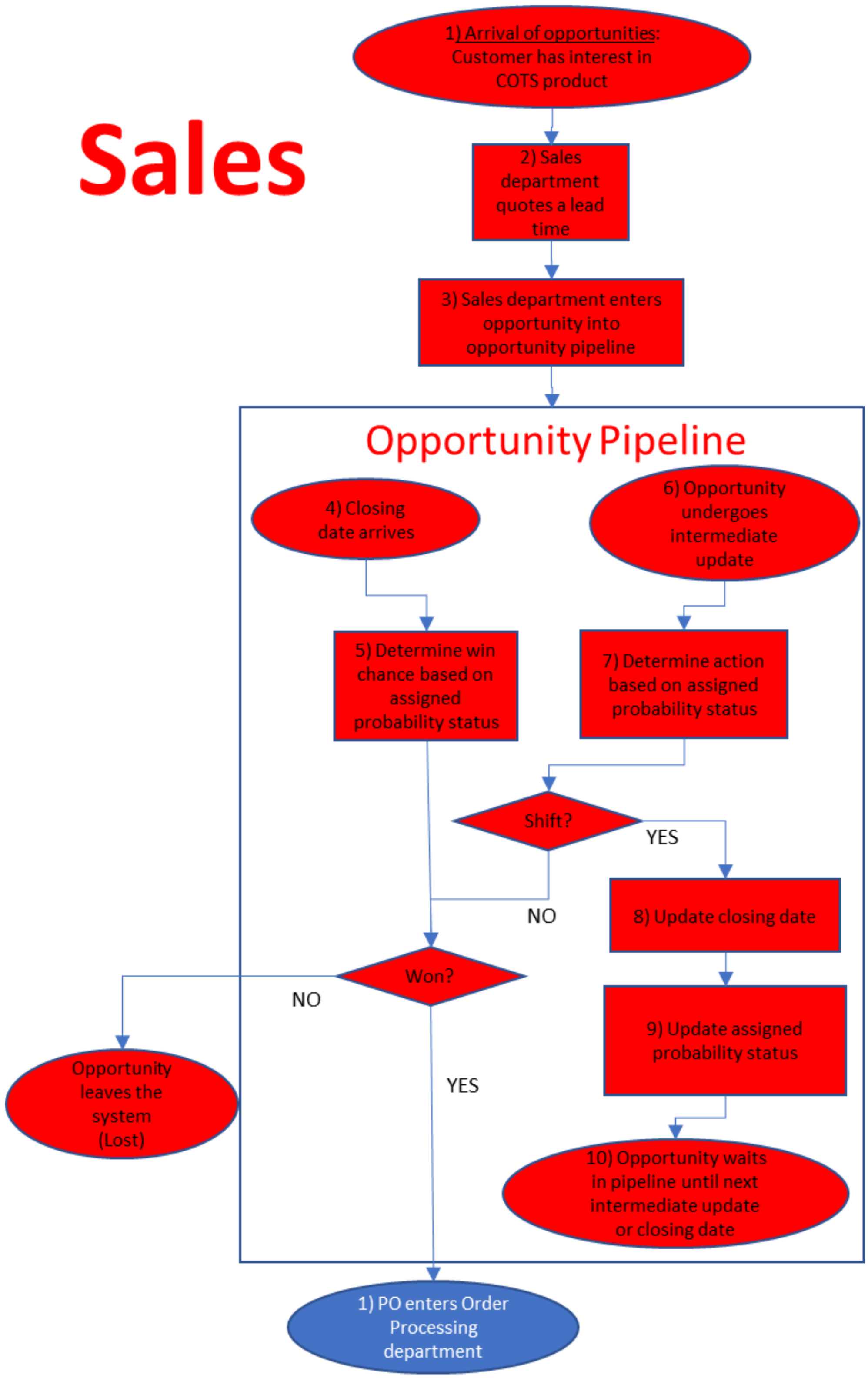

Figure 17: Simulation flowchart sales department

The numbered parts of the flowchart are worked out below:

Sales 1) Arrival of opportunities: customer has interest in one of DAP's COTS products
The process starts with the arrival of an opportunity. This means that a customer has interest in one of DAP's COTS products and is possibly going to place a PO for that product in the near future. For this step, the following two parts of input information need to be collected:

Input Sales 1A: Number of opportunity arrivals per month:
In Section 4.1.2 we saw that, according to Law (2015), we can assume that the arrival process of opportunities follows a Poisson process with λ expected arrivals per day. The size of λ can be varied over the experiments, to explore various future scenarios. To choose realistic values for λ, we dive deep into CRM system Goldmine. We manually collected Goldmine input data, using the "approximately monthly" generated pipeline overviews. These overviews form the basis of the data collection for a large part of the simulation model. We looked at opportunities from March 2017 until June 2019. Hence, we choose for the same time span as for the performance measurement in Chapter 2. In Appendix 2, an example of a part of a monthly generated Goldmine pipeline overview has been given. First, we count for each analyzed pipeline overview, what the total number of opportunities is. The total number of opportunities is given in Figure 18:

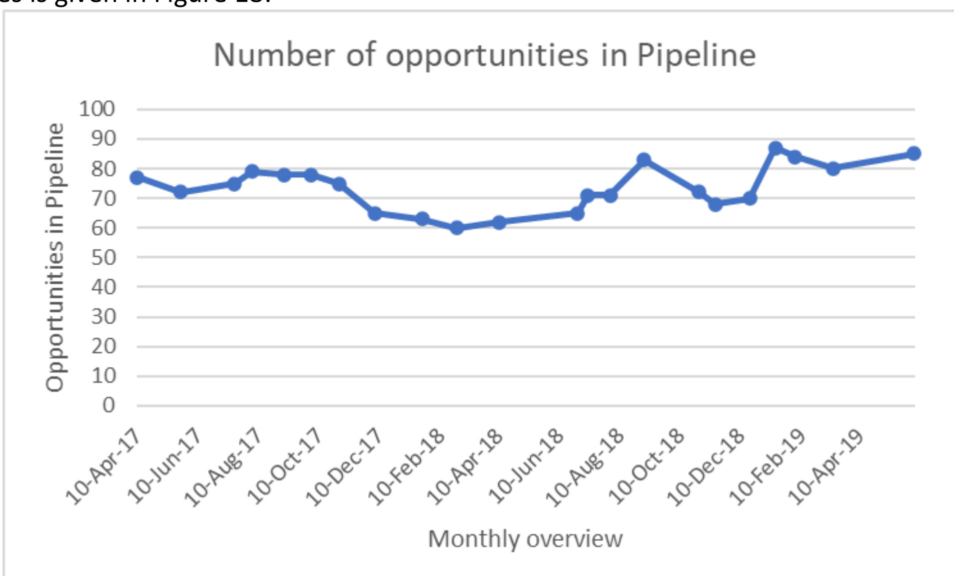

Figure 18: Total number of opportunities in pipeline

On average, there are 73 opportunities in the pipeline. We want to vary our λ to test future scenarios in which the average number of opportunities can be higher or lower than 73. We tested values for λ between 0.4 and 1.6. The corresponding average number of opportunities in the pipeline and expected number of orders per year for the different values of λ are shown in Figure 19:

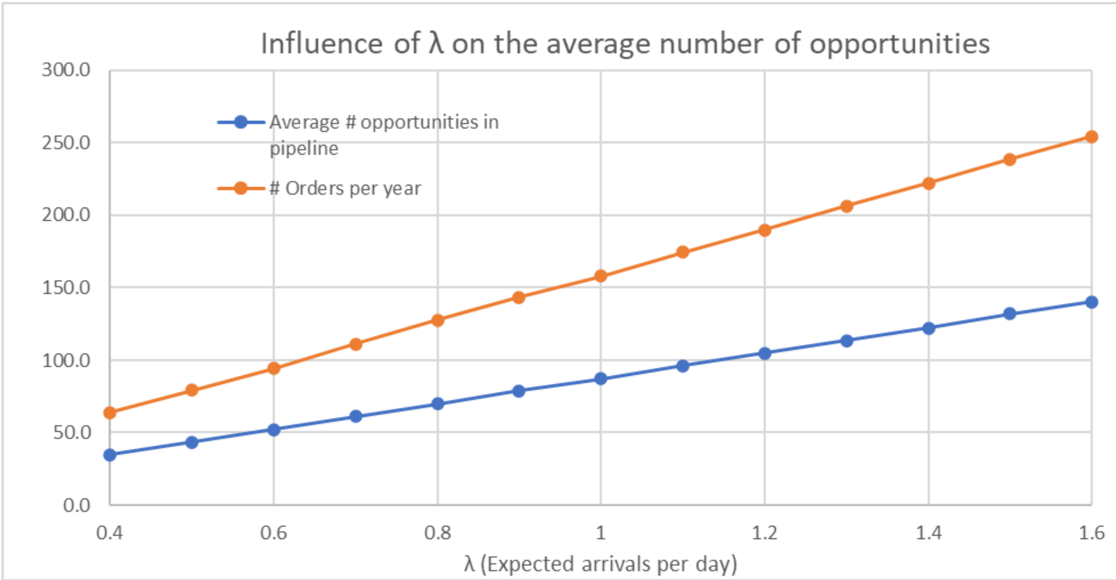

Figure 19: Influence of λ on the average number of opportunities

As mentioned above, we want to vary our λ to test future scenarios in which the average number of opportunities can be higher or lower than the current average of 73. To test various future scenarios, we take into account the following 3 values of λ in our experiments: 0.4, 1 and 1.6.

<u>Input Sales 1B: Relative frequency of COTS product arrivals:</u>
For the arrival process of opportunities, we also want to get insight into which COTS products should arrive often and which COTS product are hardly sold. We want to determine a relative frequency for COTS product arrivals. We use a combination of past sales analysis and estimations of the management team. To get a first insight we looked at sales frequencies since 2005. Thereafter, we try to include estimations for DAP's newest products that have not been sold so far by using estimations of the sales manager. This approach leads to an estimation of the future arrival frequency for each COTS product on a ten-point scale. A complete overview of the arrival frequency estimations is given in Appendix 3. A simplified example of the table is shown below (Table 11):

Table 11: Relative frequency of opportunity arrivals

Type	**Estimate of arrival score (0 = never; 10 = often)**
COTS product 1	3
COTS product 2	9
COTS product 3	5
COTS product 4	3
…	…
COTS product N	2

Since these are just rough estimations of the arrival frequency, the frequencies will be varied over various runs by adding a random factor between -1 and 1 to each arrival frequency. In our model, we use this input table for the relative frequency of COTS product arrivals.

A mentioned above, in this step an opportunity for a specific COTS product arrives in the system. Subsequently, the opportunity will flow to Step 2, in which the sales department quotes a lead time for the specific opportunity.

Sales 2) Sales department quotes lead time:
For each arriving opportunity, the sales department quotes a lead time. Since we simulate the order delivery process when the centralized inventory management tool would have been implemented, the sales department has the ability to check forecasted inventory levels for all required components. Various due date quotation policies can be applied. As mentioned in Section 3.4.2, a due date quotation policy consists of a "moment of quoting extra lead time" and a "quantity of extra lead time". The target is to quote a lead time that is as short as possible while 95% of the POs can still be delivered within the quoted lead time. In Section 4.1.5 we work out how we evaluate the due date quotation policies that can be applied using the inventory management tool.

Sales 3) Sales department enters opportunity into opportunity pipeline:
The sales department enters the opportunity into the opportunity pipeline and includes the following information:

- <u>Expected Closing date:</u> Estimation of the date on which the customer will place the PO
- <u>Probability status:</u> Assigned status representing the probability that the customer will actually place a PO on the expected closing date (described in problem 5 of the overview of problems in Chapter 2.3). A higher status means that the evaluation process at the customer organization has been further advanced and the probability that a PO is coming is higher.

For this step, the following two parts of input information need to be collected:

<u>Input Sales 3A: Expected closing date of opportunities:</u>
Each opportunity gets an assigned closing date. To get insight into how far in the future this closing date typically is, the Goldmine pipeline will be analyzed again. We look at situation where the opportunity appears for the first time in the Goldmine pipeline. The number of "Days Ahead" has been calculated, using the following formula:

Number of Days Ahead = Initial Expected Closing Date – Date of Entry

We analyze 242 new arriving opportunities. As mentioned in Section 4.1.2, the procedure as described in the book of Law (2015) can be followed to fit probability density functions when sufficient historical data is available. We follow the following procedure (Law, 2015): hypothesizing distributions, parameter estimation, checking fit with plots (QQ plot), and goodness-of-fit test (Chi test). The results are shown below.

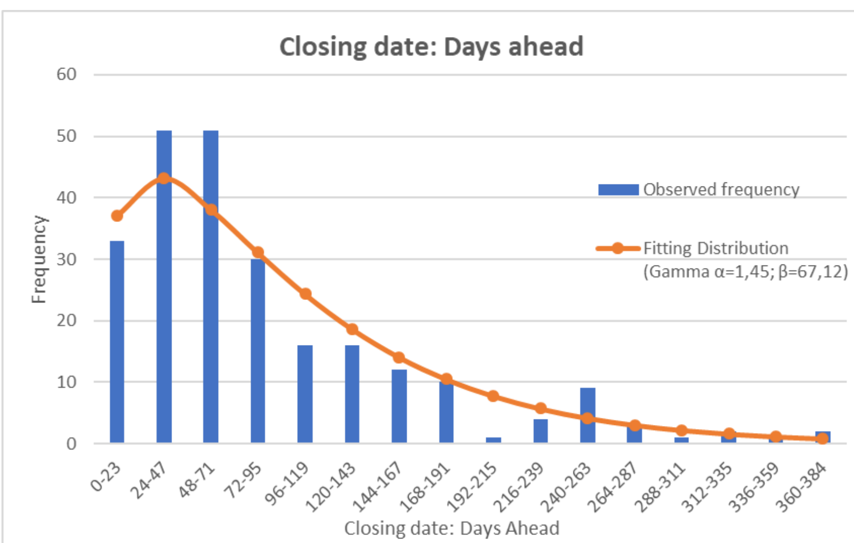

Figure 20: Probability density function Closing date "Days Ahead"

A theoretical Gamma distribution (α=1,45; β= 67,12) seems to be a good representation (Figure 20). The Gamma distribution is a widely used distribution to model continuous variables that are always positive. We check graphically if the data plausibly comes from the above-mentioned gamma distribution using a QQ-plot (Figure 21).

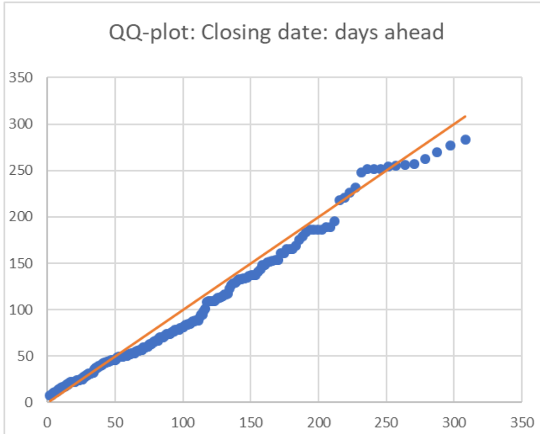

Figure 21: QQ-plot Closing date "Days Ahead"

The observed values seem to be close to a straight line, implying that the theoretical gamma distribution with α=1,45 and β= 67,12 is a good representation. Finally, we check the goodness of fit using a Chi -test (Table 12):

Table 12: Chi-Test Closing date "Days Ahead"

Chi: Goodness of fit			
Significance level	**Degrees of freedom**	**Critical value**	**Observed value**
0,95	**15**	**24,996**	**24,233**

The observed value is smaller than the critical value. Therefore, we can conclude with a significance level of 95% that the above-mentioned gamma distribution is a good representation. In our model, we use this distribution to assign an expected closing date to new arriving opportunities.

Input Sales 3B: Expected closing date of opportunities:

Each opportunity gets an assigned probability status. Again, we analyze the Goldmine opportunity pipeline and look at situations where the opportunity appears for the first time. The assigned probabilities on entry are given in Figure 22:

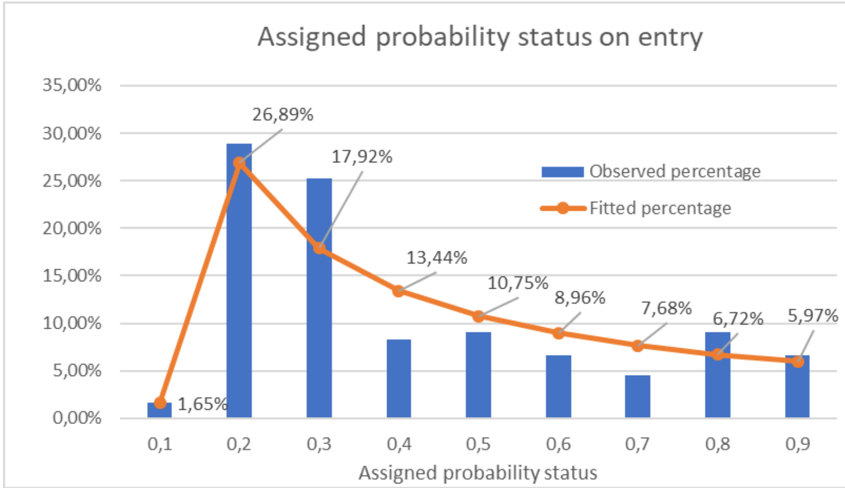

Figure 22: Assigned probability status on entry

We assume that the distribution of probability statuses on entry can be reasonably represented by the following formula:

$$P(probability\ status = X) = \frac{0.57}{X} \quad for\ X > 0{,}1$$
$$where\ P(probability\ status = 0.1) = 0.0165$$

In our model, we use the above-mentioned formula to assign a probability status to new arriving opportunities. We assume that the number of days ahead (Sales 3A) has no influence on the assigned probability status.

As mentioned above, in this step the opportunity is stored in the opportunity pipeline with the expected closing date and assigned probability status. The opportunity stays in the opportunity pipeline until the expected closing date arrives or until it undergoes an intermediate update.

Sales 4) Closing date arrives:
When the closing date of an opportunity arrives, the opportunity will leave the opportunity pipeline. The opportunity can lead to a PO (won), or otherwise the opportunity will be lost.

Sales 5) Determine win chance based on assigned probability status:
As mentioned in Step 4, the opportunity will leave the opportunity pipeline when its closing date arrives. The probability that an opportunity that is closed on (or around) its closing date results in a PO depends on the assigned probability status. To determine the probability that an opportunity results in a PO, we looked at the result of each opportunity (won/lost) in combination with the assigned probability at the moment of closing. The following results are obtained (Figure 23):

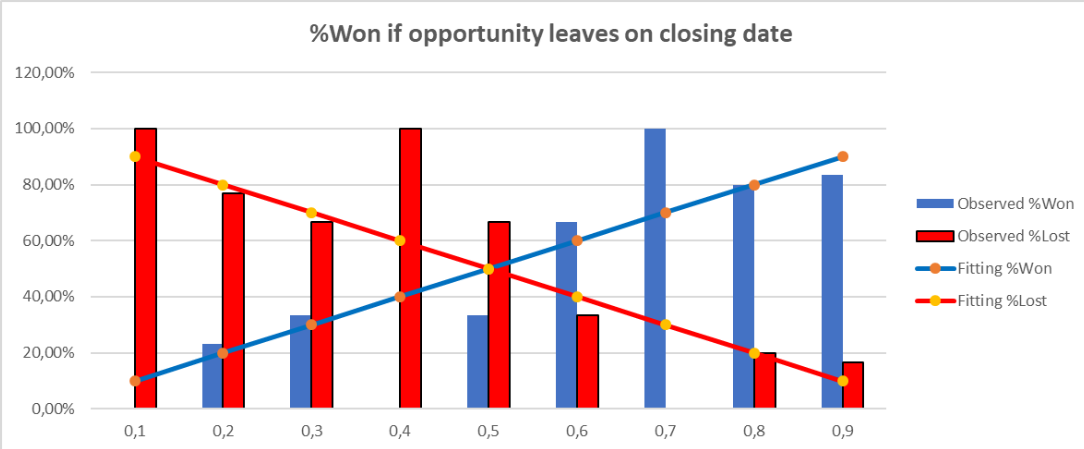

Figure 23: Percentage won if opportunity leaves on closing date

It seems plausible that the actual probability of winning an opportunity matches reasonably the assigned probability status at the moment of closing. Therefore, in our model, we use the assigned probability statuses to determine the chance that an opportunity becomes a PO when it leaves the pipeline on its expected closing date.

Sales 6) Opportunity undergoes intermediate update:

Opportunities stay in the opportunity pipeline until the closing date has arrived. However, the opportunity can be updated intermediately (several times). During an intermediate update, the following actions can happen:

- shift in the expected closing date and/or an update of the assigned probability status
- premature PO (won)
- premature system exit (lost).

To get insight into how often opportunities undergo intermediate changes, we again looked at the monthly overviews of the Goldmine opportunity pipeline. In situations where the opportunities were not closed on (or around) the expected closing date, we determine how long it typically takes before an opportunity undergoes a change in closing date and/or the assigned probability status. The results are given in the Figure 24:

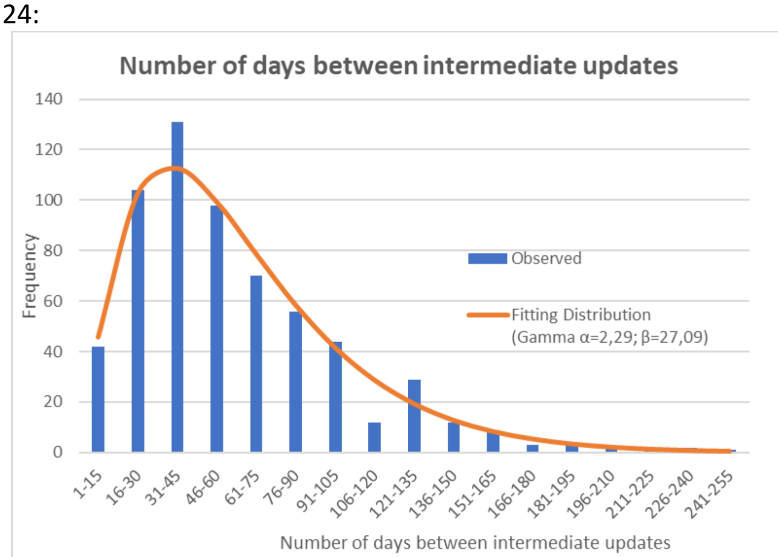

Figure 24: Probability density function “Number of days between intermediate updates”

A theoretical Gamma distribution (α=2,29; β= 27,09) seems to be a good representation. We check graphically if the data plausibly comes from the above-mentioned gamma distribution using a QQ-plot (Figure 25).

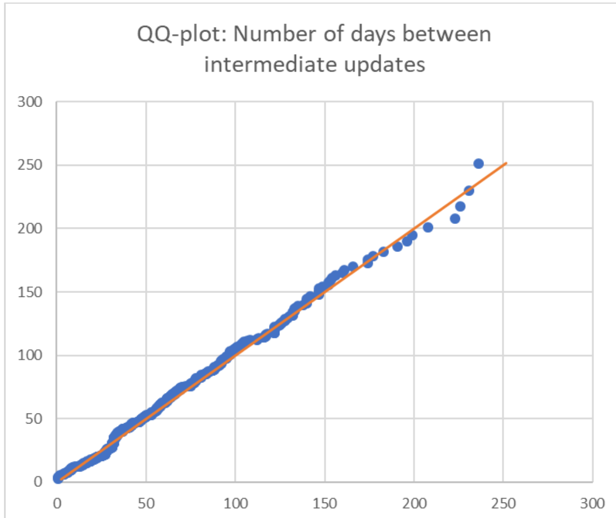

Figure 25: QQ-plot Number of days between intermediate updates

The observed values seem to be close to a straight line. Finally, we check the goodness of fit using a Chi - test (Table 13):

Table 13: Chi-Test Number of days between intermediate updates

Chi: Goodness of fit			
Significance level	**Degrees of freedom**	**Critical value**	**Observed value**
0,95	**16**	**26,2962276**	**22,45515082**

The observed value is smaller than the critical value. Therefore, we can conclude with a significance level of 95% that the above-mentioned gamma distribution is a good representation.

In our model, the opportunity gets a "moment of intermediate update" assigned according to the above-mentioned gamma distribution. When this moment is earlier than the assigned expected closing date, the opportunity will undergo an intermediate update. Otherwise, when the closing date is earlier, the opportunity leaves the system without (extra) intermediate updates. After each update, the opportunity gets a new "moment of intermediate update" assigned.

Sales 7) Determine action based on assigned probability status

As mentioned in Step 6, during an intermediate update there are three possible actions for the opportunity:

- Shift: The closing date and/or the assigned probability status will be update
- Premature Won: The opportunity leads to a PO before its closing date has arrived
- Premature Loss: The opportunity already leaves the system before its closing date has arrived

The probability of which action the opportunity takes, depends on the assigned probability status. We analyzed the intermediate updates and obtained the following results (Figure 26):

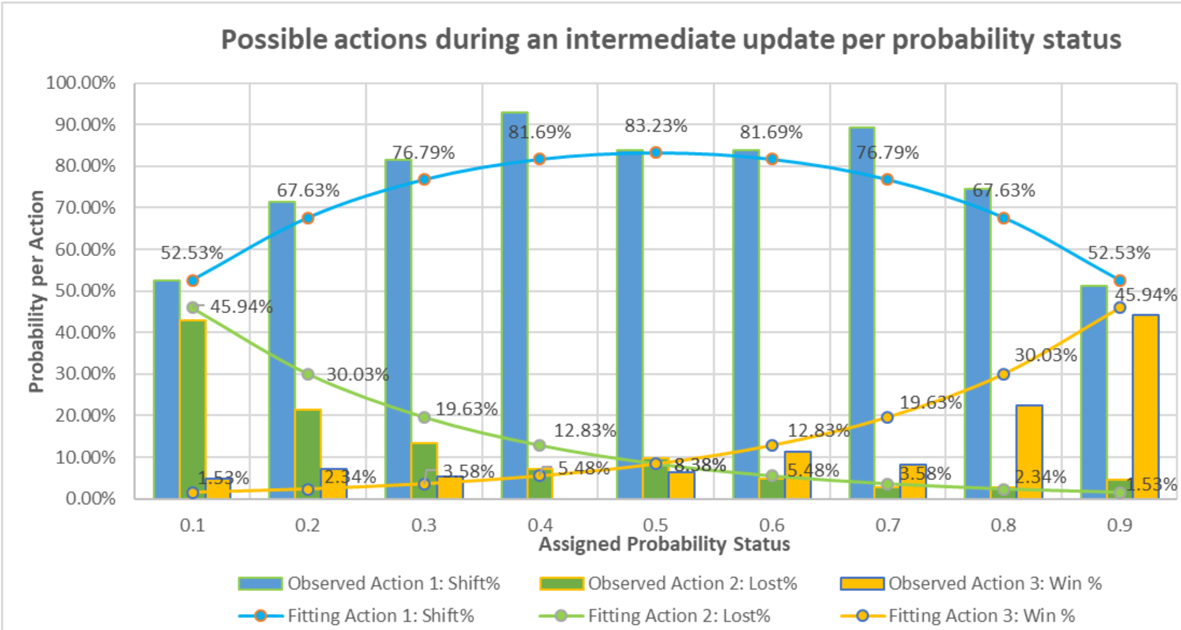

Figure 26: Possible actions during an intermediate update per probability status

The probability of which action the opportunity takes can be modelled using the following formulas:

$$P(Action = Won|Probability\ status = X) = 1{,}53^{10X}$$

$$P(Action = Lost|Probability\ status = X) = 1{,}53^{10(1-X)}$$

$$P(Action = Shift|Probability\ status = X) = 100 - 1{,}53^{10X} - 1{,}53^{10(1-X)}$$

The sum of the 3 different actions equals 100% for each probability status. Figure 26 tells us that opportunities with high or low probability statuses have a relatively high probability of being closed during an intermediate update, where high statuses will most of the times lead to a "Premature Won" and low statuses will most of the times lead to a "Premature Loss". For the intermediate statuses, the probability is higher that the expected closing date and/or the assigned probability status will shift.

Sales 8) Update closing date:

If the opportunity takes the "shift action" during an intermediate update, the expected closing date will be updated. We looked at what happens with the closing date if the opportunity undergoes intermediate changes. The results are given in Figure 27:

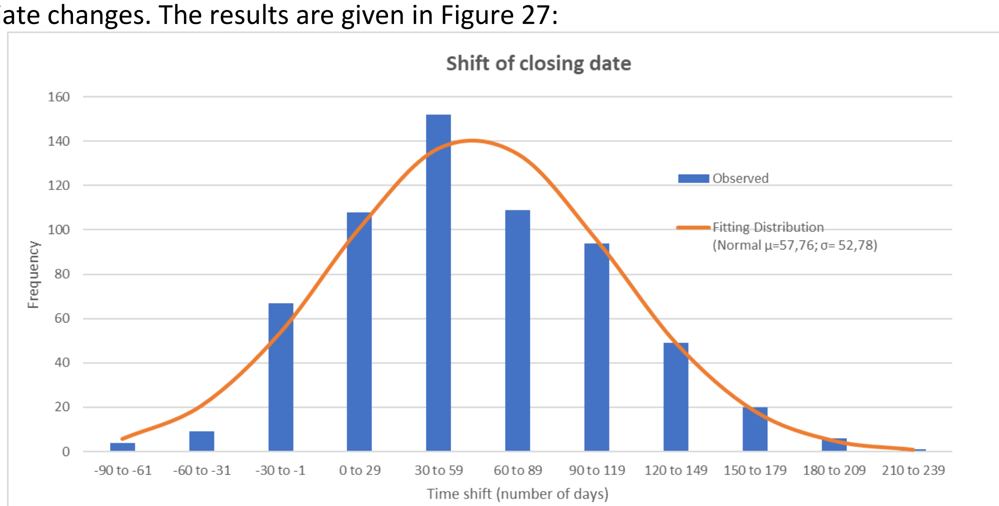

Figure 27: Probability density function "Shift of closing date"

A theoretical Normal distribution (μ=57,76; σ= 52,78) seems to be a good representation. We check graphically if the data plausibly comes from the above-mentioned normal distribution using a QQ-plot (Figure 28):

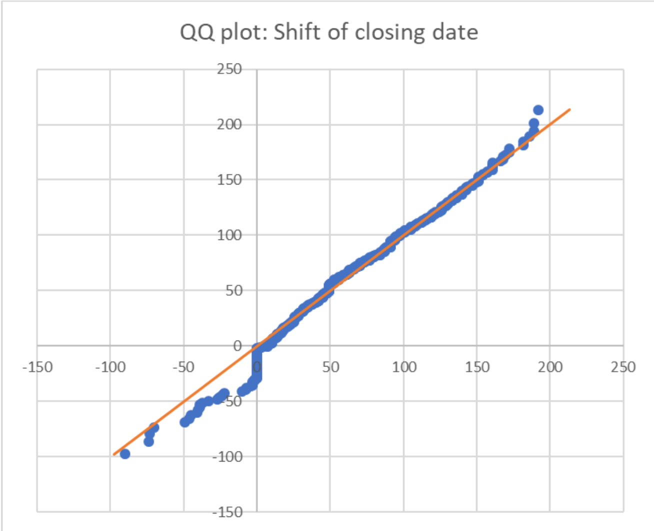

Figure 28: QQ-plot "Shift of closing date"

The observed values seem to be close to a straight line. Finally, we check the goodness of fit using a Chi - test (Table 14):

Table 14: Chi-Test "Shift of closing date"

Chi: Goodness of fit			
Significance level	**Degrees of freedom**	**Critical value**	**Observed value**
0,95	**10**	**18,30703805**	**17,83945275**

The observed value is smaller than the critical value. Therefore, we can conclude with a significance level of 95% that the above-mentioned normal distribution is a good representation. We use the normal distribution to determine how the expected closing date of an opportunity shifts during an intermediate update. From the probability distribution we can derive that, most of the times, the expected closing date shifts into the future, but it is also possible that the expected closing date becomes earlier.

Sales 9) Update assigned probability status:

Finally, we look at what happens with the assigned probability status if the opportunity undergoes intermediate changes. The results are displayed in Figure 29:

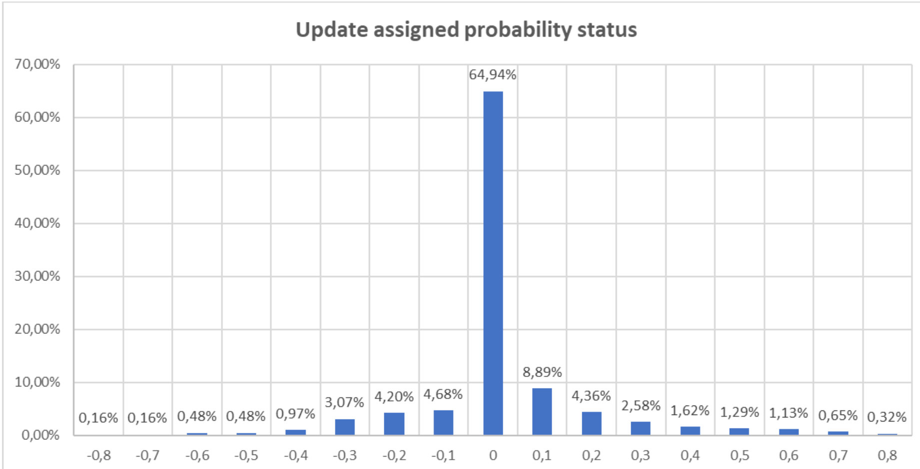

Figure 29: Update of assigned probability status

We use the results to determine how the assigned probability status of an opportunity gets updated. We see that, most of the times, the assigned probability does not get updated during an intermediate shift. If the probability status gets updated, it can both become higher and lower. In the model, we assume that the update of the probability status does not depend on the assigned probability status.

Sales 10) Opportunity stays in opportunity pipeline until closing date or next intermediate update
The opportunity is stored in the opportunity pipeline with the updated closing date and assigned probability status. When the new closing date or the new moment of intermediate update arrives, the opportunity will be closed or undergoes a new intermediate update.

In this section, we worked out the modelled parts of the sales department. We explained how opportunities arrive in the model, how they behave and where they can flow. In the next section we work out the modelled parts of the order processing and purchasing department.

Order processing & purchasing department

In this section we work out the main parts of the order processing and purchasing departments. The modelled parts are displayed in the flowchart of Figure 30. The flowchart shows how POs flow through the order processing department. Furthermore, it shows how the purchasing and order processing departments are interacted.

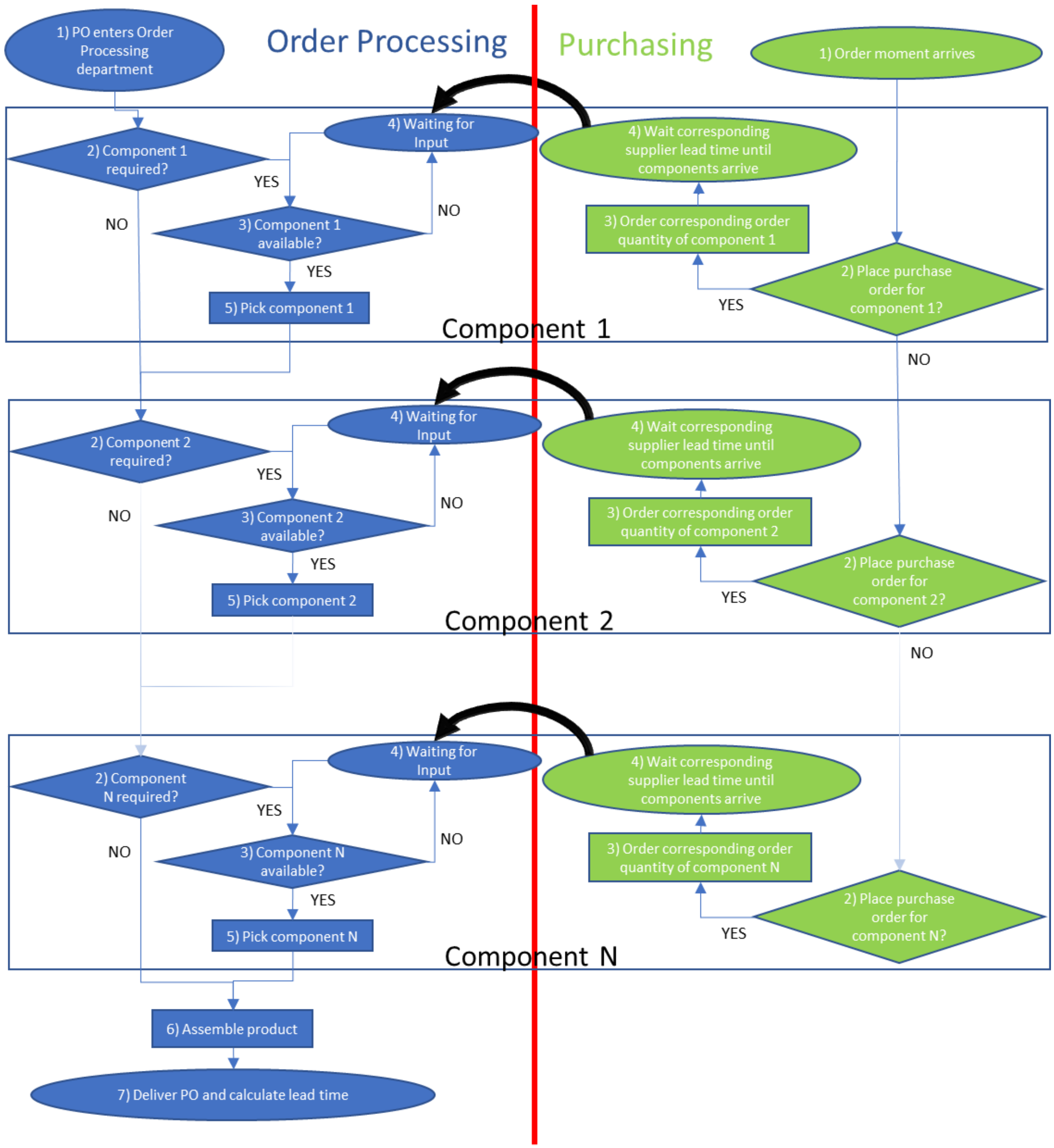

Figure 30: Simulation flowchart Order Processing & Purchasing

The numbered parts of the flowchart are worked out below. First, we work out the steps of the order processing department. Thereafter, we give a description of the steps of the purchasing department.

Order Processing 1) PO enters order processing department
A won opportunity flows from the sales department to the order processing department as a PO. The PO refers to a customer order for one of DAP's COTS products. In the order processing department, the required components will be picked and the COTS product will be assembled.

Order Processing 2) Component X required?
The required inventory components for a PO need to be picked. Therefore, the PO flows past all components to collect the required components. Which components to pick, is checked through a BOM input table that contains all COTS products and the required components per product. A simplified example of the BOM input table is given in Table 15:

Table 15: Simplified BOM input table

	COTS product 1	**COTS product 2**	**COTS product 3**	**COTS product 4**	**...**	**COTS product N**
Component 1				1		
Component 2	1	2				
Component 3	1					
Component 4		1				3
Component 5			1			
Component 6				1		
Component 7	2	2	3			
Component 8				1		
...						
Component n		1				

For each component the corresponding number in the table will be picked. After that, the COTS product can be assembled.

Order Processing 3) Component X available?
When component X is required for producing the PO, there will be checked if there are still enough components on stock to produce the PO.

Order Processing 4) Waiting for Input
When there is not enough inventory to produce the PO, the PO has to wait until a new batch of component X arrives.

Order Processing 5) Pick component X
When component X is/becomes available, the component can be picked. The picking time is negligible (0).

Order Processing 6) Assemble product
When all components are collected, the product can be assembled. As mentioned in Section 4.1.2, triangular distributions will be used for the production times. We make use of the following estimates for COTS products:

- *Best-case estimate of production time*
- *Most likely estimate of production time*
- *Worst-case estimate of production time*

Using the above-mentioned estimates, we make use of the following types of distributions (Figure 31):

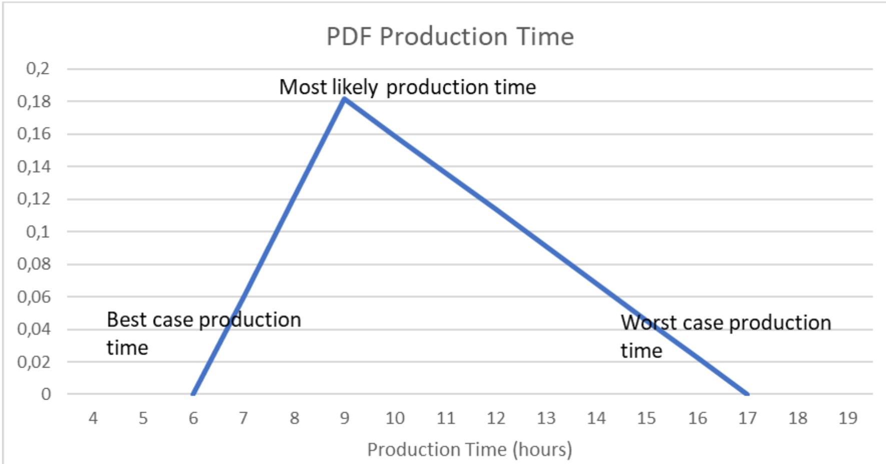

Figure 31: Probability density function "Production Time"

Order Processing 7) Deliver PO and calculate total lead time
When the PO is assembled, it can be shipped to the customer. We calculate the total lead time as follows: *Total Lead time = Moment of Shipping – Order date.* Since DAP is an internationally represented company with customers all over the world, the shipping time can go up to 7 days. The organization wants to be able to deliver all customers within 4 weeks (28 days). This means that the total lead time, as calculated above, should not be greater than 21 days to pass DAP's target.

In the above-mentioned steps, we worked out the modelled parts of the order processing department. In the next section we work out the steps of the purchasing department and explain how the departments are interacted.

Purchasing 1) Order moment arrives
When the order moment arrives for a specific component, this is a trigger for the purchasing department to place a purchase order. The order moment is determined by the reorder level of the component. Since we model the order delivery process when the centralized inventory management tool would have been implemented, the purchasing department has the ability to check forecasted inventory levels for all required components. Various strategies for the order moment can be applied. As mentioned in Section 3.3.2, a purchasing policy consists of a combination of an "order moment" and an "order quantity". The target is to place purchase orders in such a way that a 95% delivery speed performance can be obtained against the lowest possible inventory investments. In Section 4.1.5 we work out how we evaluate the various purchasing policies that can be applied using the inventory management tool.

Purchasing 2) Place purchase order for component X?
The purchasing department checks for all components if a purchase order needs to be placed according to the specified order moment.

Purchasing 3) Order the corresponding order quantity for component X
A purchase order will be placed the size of the specified order quantity. As mentioned in Step 1, the order quantity forms a purchasing policy together with the order moment. In Section 4.1.5 we work out how we evaluate the various purchasing policies that can be applied using the inventory management tool.

Purchasing 4) Wait supplier lead time until components arrive

When a purchase order has been placed, it takes some time before the ordered components arrive on stock. The amount of time depends on the supplier lead time of the specific component. As mentioned in Section 4.1.2, a triangular distribution will be used to model supplier lead times. We make use of the following estimates:

- *Best-case estimate of supplier lead time*
- *Most likely estimate of supplier lead time*
- *Worst-case estimate of supplier lead time*

Using these estimates, we make use of the following types of distributions (Figure 32):

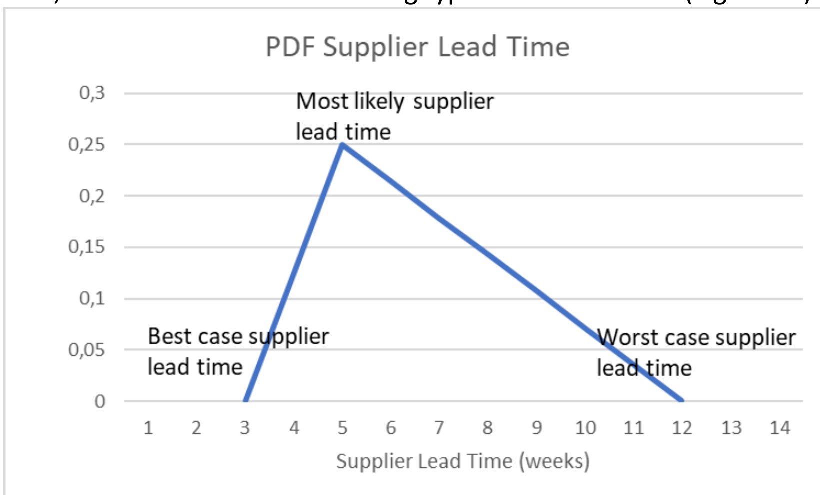

Figure 32: Probability density function "Supplier Lead Time"

Finally, when the supplier lead time expires, the ordered components arrive on stock and can be used by the order processing department. This can be a trigger for the order processing department to continue the picking process if POs are waiting for input.

In this section, we worked out how we can simulate the order delivery process, when the centralized inventory management tool would have been implemented. We collected input information to model the main parts of the sales, purchasing and order processing departments. In the next section we work out how we process the mentioned parts into a simulation model using Siemens Plant Simulation.

4.1.4) What does the simulation model look like?

In this section, we work out how we build a simulation model to simulate the order delivery process, when the centralized inventory management tool would have been implemented. We create our model using Siemens Plant simulation. We give a description of the used frames and explain their functionality. Furthermore, we explain which roles the sales, purchasing and order processing departments play in the simulation.

We simulate the model as a system that is operational 24/7, since we deal with an international environment and orders can always flow in. Due to international time differences and the increasing degree of a 24-hour economy, there is no system idle time in the evening or during the weekends. The organization itself is only operational on working days between 8 a.m. and 16 p.m. We deal with a nonterminating simulation, since we are interested in the performance of purchasing policies and due date quotation policies in the long run when the system is operating "normally".

Most of DAP's customers operate in the defense market. Experience show that the defense market adopts products and keeps them using for typically 10 to 15 years. In our model we assume that a generation of products will be sold at reasonable rate for 15 years. Therefore, we choose our run length to be 15 years (5475 days).

The root frame contains an overview of relevant aspects of the sales, order processing and purchasing departments that a PO flows through before it will be delivered to the customer. An overview of the root frame is given below (Figure 33):

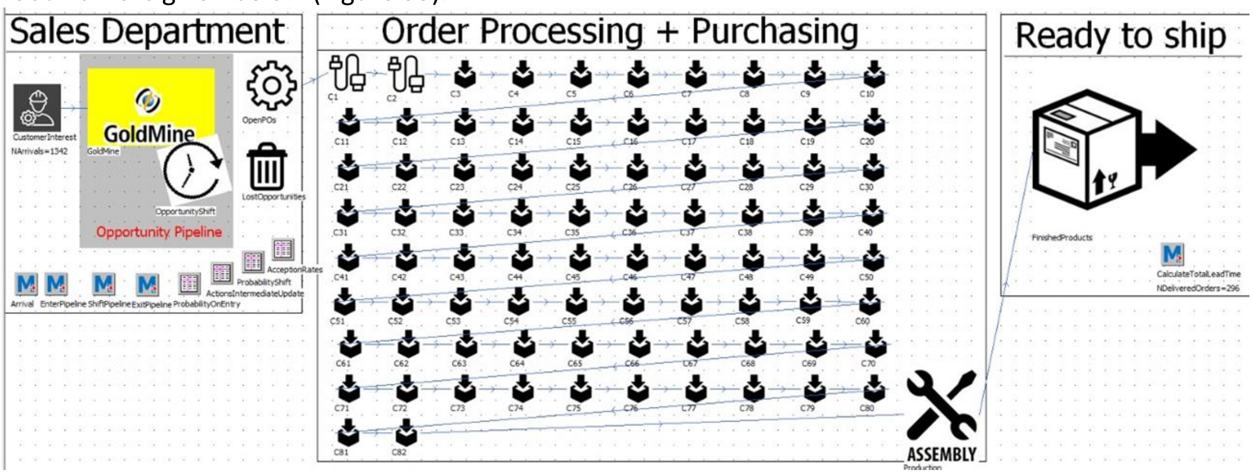

Figure 33: Root frame simulation model

When we look at the root frame, we see that the departments are modelled using various objects and frames. An explanation of the most important parts of the model are given below. First, we give a description of the sales department. Thereafter, the order processing and purchasing departments will be worked out.

Sales department

In this section, we give an explanation of the most important parts of the sales department. The main aspects of the sales department are modelled on the root frame as shown in Figure 34.

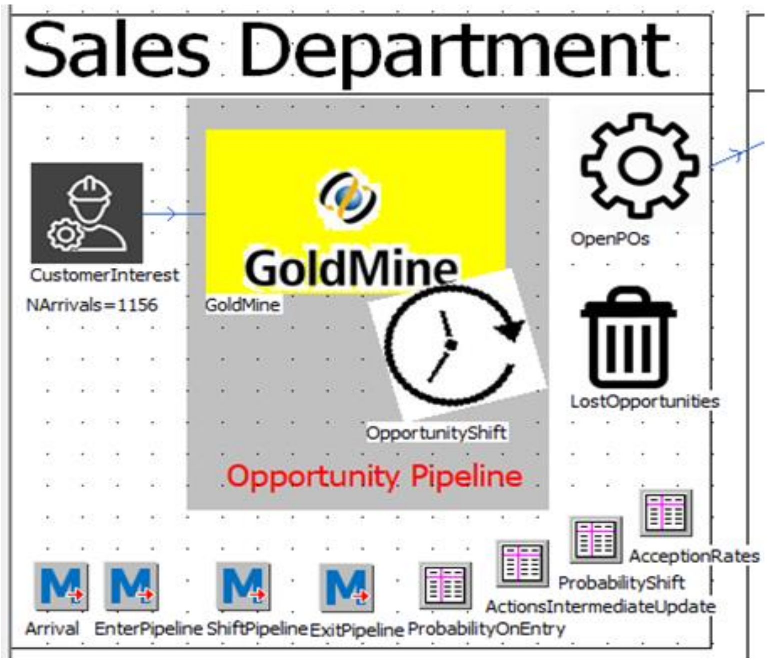

Figure 34: Sales department simulation model

Customer interest for a COTS product is stored as an opportunity in the Opportunity Pipeline. The opportunity can undergo various updates as described in Section 4.1.3. Eventually the opportunity will be won or lost. Won opportunities flow to "OpenPOs", enter the order processing department and need to be produced. Lost opportunities flow to "LostOpportunities" and leave the system.

Order processing & purchasing department

In this section, we give an explanation of the most important parts of the order processing and purchasing departments. The order processing department consist of an inventory frame for each component that we take into account. We only take into account inventory components, and we neglect order-specific components that are only purchased upon customer demand. Furthermore, we neglect components for which "Buying Price + (Fixed Ordering Cost/Typical lot size) < €5". We take into account 82 stock components. Each stock component has its own inventory frame. A PO flows through all inventory frames before it can be delivered (Figure 35):

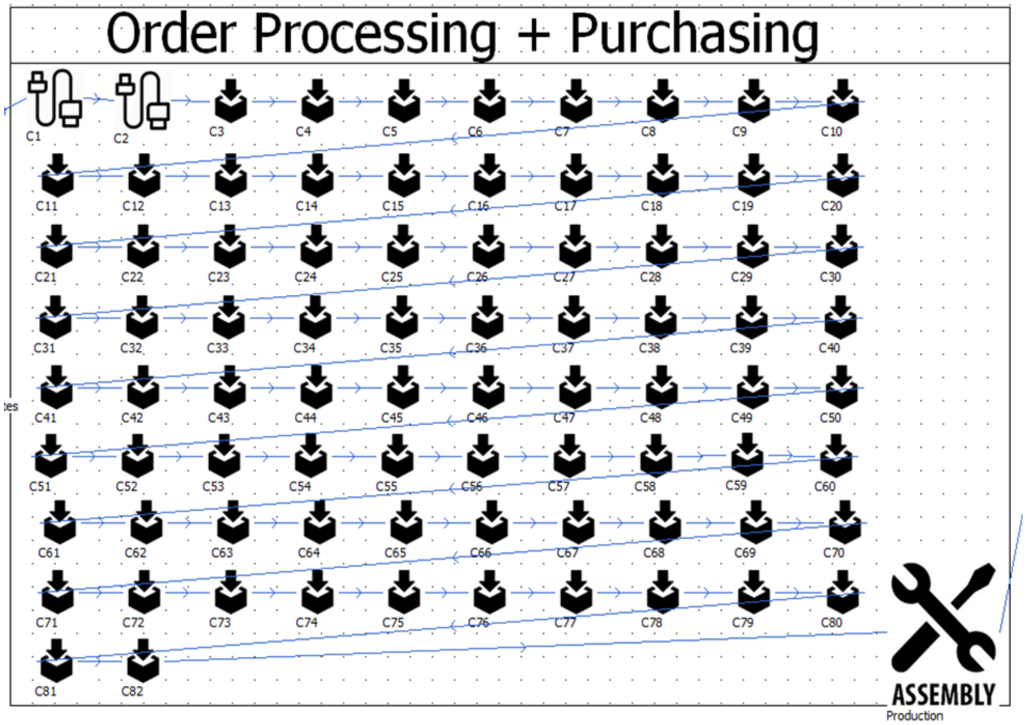

Figure 35: Order processing department simulation model

The PO flows through all inventory frames and picks the required components. We distinguish two different types of inventory frames. Frame C1 and C2 are inventory frames for the 6-pin and 9-pin firewire cable. The frames C1 and C2 differ slightly from the standard inventory frame. Namely, for the 6-pin and 9-pin firewire cables, DAP has two lengths on stock (5ft and 7ft). There are products for which only a 7ft cable can be picked. However, there are also products for which both the 5ft and 7ft cable will suffice. C3 till C90 are standard inventory frames. The components in these frames just need to be picked per unit. The FireWire cable inventory frame and the standard inventory frame are displayed below in Figure 36 and Figure 37:

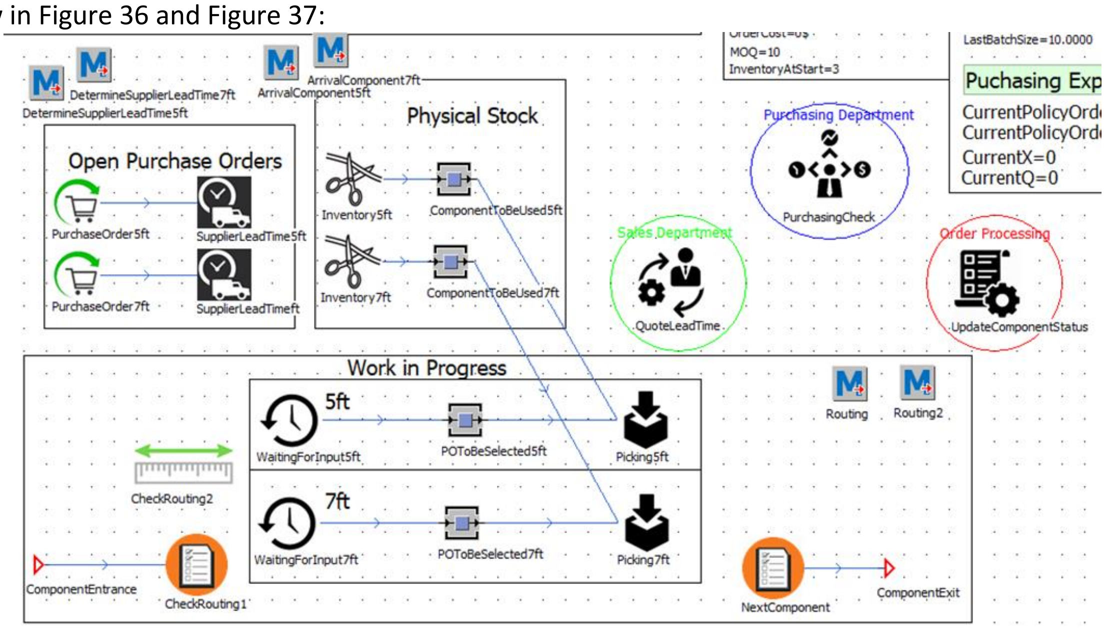

Figure 36: FireWire cable inventory frame (C1 + C2)

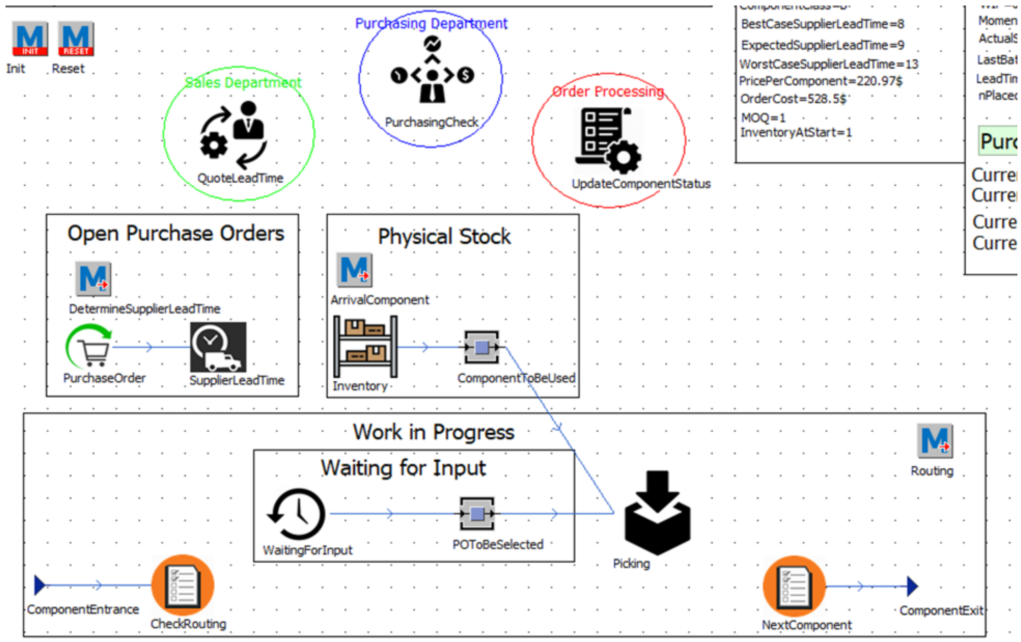

Figure 37: Standard inventory frame (C3 – C82)

As displayed in Figure 36 and Figure 37, the sales department and purchasing department can monitor the component status in all inventory frames. This represents the situation in which the centralized inventory tool would have been implemented. Namely, using the tool, inventory information is always up to date available for all departments. The sales department can use this information to quote lead times for new arriving opportunities. The purchasing department can place purchase orders when necessary. Every time there is a mutation in the inventory frame, the order processing department will update the status immediately.

When all components for a specific PO are picked, the order will be produced in the production frame (Figure 38). We assume that DAP has a production capacity of at most 2 employees. This means that at most 2 products can be produced at the same time. Production only takes place on working days between 8 a.m. and 16 p.m. When production is finished, the products will be shipped from the production facility in Nijmegen to the head office in Oldenzaal. We assume that it always takes one working day before products arrive in Oldenzaal.

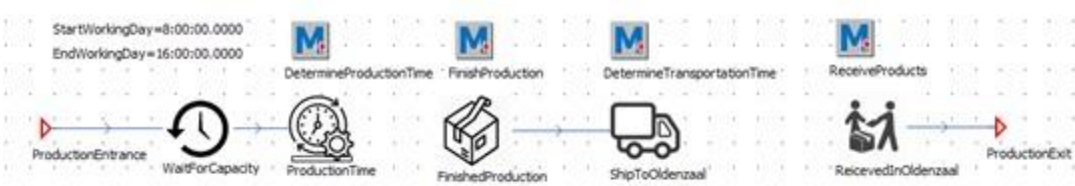

Figure 38: Production Frame

Eventually, the PO can be made ready for shipment. The total lead time will be calculated as follows:

Total Lead Time = Ship ready date – Order date

Based on this total lead time, the delivery speed and delivery reliability can be calculated. The targets for the delivery speed or delivery reliability are met when the PO is "Ship ready" within respectively 21 days or within the quoted lead time.

In this section, we worked out how we created our simulation model using Siemens Plant Simulation. The simulation model can be used to simulate the order delivery process when the tool would have been implemented. We explained the used frames and the roles of the sales, purchasing and order processing departments. We saw that the delivery speed depends on the applied purchasing policy and the delivery reliability depends on the applied due date quotation policy. In the next section we want to explore how we can use the simulation model to conduct experiments to test purchasing policies and due date quotation policies.

4.1.5) Which experiments can be conducted?

In this section, we want to explore how we can conduct simulation experiments to test purchasing policies and due date quotation policies. Our goal is to find purchasing policies that lead to a good delivery speed and due date quotation policies that lead to a good delivery reliability. First, we explore how purchasing policies can be evaluated in part A. Thereafter, we investigate how due date quotation policies can be evaluated in part B.

4.1.5 A) How can purchasing policies be evaluated?

Using the centralized inventory management tool, various purchasing policies can be applied. In this section we work out which experiments can be conducted to evaluate these purchasing policies. First, we explain how we categorize the inventory components. Thereafter, we work out the problem description, estimate a warm-up period and determine the number of replications per experiment. Finally, we give a description of the used optimization approach.

As mentioned in Section 4.1.4, we deal with 82 inventory components. Since it is not feasible in terms of time to run experiments for each component separately, we will discriminate between inventory items. As found in the literature review of Section 3.3.1, an ABC classification can be applied to be efficient in terms of time. We want to categorize components to explore which purchasing strategies could be applied for various component categories. We split up the components based on the expected total demand. The expected total demand influences both the order moment and order quantity. To make a classification, we assign the following score to each component:

$$DemandScore_j = \sum_{i=1}^{NumProducts} (EstimatedArrivalFrequency_i * Required_{ij})$$

$DemandScore_j$ = *Demand score that is assigned to component type j*

$NumProducts$ = *Number of COTS products that are taken into account*

$EstimatedArrivalFrequency_i$ = *Estimated relative frequency of opportunity arrivals of product i*

$Required_{ij}$ = *Number of components of type j that are required for producing product i*

The assigned demand score for each component is based on the estimated arrival frequency of the COTS products (Appendix 3). As mentioned in Section 4.1.3, the estimated arrival frequency is a score on a ten-point scale, where frequently asked products get a higher score assigned. For the demand score, we choose a critical level of 8, based on which we classify. We distinguish the following two inventory classes (Table 16):

Table 16: Classification of inventory items

	Class A: *Demand Score < 8*	**Class B:** *Demand Score ≥ 8*
Number of components per class	51	31

In each experiment, the same purchasing policy will be applied for components in a specific class.

To evaluate purchasing policies, we follow the procedure as shown in the book of Law (2015). First, we give a problem description. Subsequently, we estimate the required warm up period using Welch graphical procedure. After that, we determine the required number of replications per experiment. Finally, we give a description of the used optimization approach.

Problem description

Using the centralized inventory management tool, various purchasing policies can be applied. The performance of the purchasing policies can be evaluated based on various relevant costs. We split the standard price (VVP) in Minox into two components: Fixed ordering costs and buying price. We do not take into account the one-off tooling and assembly expenditures that have to be paid only the first time when DAP places an order for the component. These are sunk costs, and should therefore not be taken into account when taking operational decisions (Atrill et al., 2008). We use the following objective function to evaluate purchasing policies:

$$Minimize: \sum_{i=1}^{NumDays} \sum_{j=1}^{NumComponents} \sum_{k=1}^{InventoryLevel_{ij}} (BuyingPrice_j + (FixedOrderingCosts_j / LotSize_{jk}))$$

$NumDays = Length\ of\ the\ simulation\ run\ in\ days$

$NumComponents = Total\ number\ of\ components\ that\ are\ taken\ into\ account$

$InventoryLevel_{ij} = Number\ of\ components\ of\ type\ j\ that\ are\ in\ stock\ at\ the\ end\ of\ day\ i$

$BuyingPrice_j = Buying\ price\ of\ component\ type\ j$

$FixedOrderingCosts_j = Costs\ of\ placing\ a\ purchase\ order\ for\ component\ type\ j$

$LotSize_{jk} = Lot\ size\ of\ the\ purchase\ order\ in\ which\ component\ k\ of\ type\ j\ is\ ordered$

This means that, at the end of every simulated day, the value of all available stock will be summed. The objective function therefore takes into account that DAP doesn't want to hold too many components on stock because it requires large investments and involves risk of obsolescence. Components that lay on stock many days are counted many times in the objective function. However, DAP also needs to deal with order costs that can be significant. Therefore, ordering too often is also not preferable, because then the value of each component will be really high. A large fraction of the fixed ordering costs will then be assigned to that component. The objective function needs to be minimized taking the following restrictions into account:

$$\frac{Total\ number\ of\ orders\ delivered\ within\ targeted\ lead\ time}{Total\ number\ of\ delivered\ orders} \geq 0.95 \qquad (1)$$

$$LotSize_{jk} \geq MOQ_j \qquad for\ j = 1, 2, ..., NumComponents \qquad (2)$$

The first restriction takes into account that DAP wants to be able to deliver 95% of its COTS products within the targeted lead time of 4 weeks. The second one takes into account that the purchasing department cannot order less than the minimum order quantity specified by the supplier. For each purchasing policy we want to minimize the above-mentioned objective function while the two constraints will be met.

Estimate required warm up period

Since we start with an empty opportunity pipeline, it will take some time before the typical number of orders will come in. This means that performance measures of the first days are not representative to evaluate purchasing policies. We will delete some observations from the beginning of the run and use the remaining observations for further analysis. A suitable technique to deal with this startup problem is the graphical method of Welch (1983). We store the number of opportunities in the pipeline per day to estimate the required warm up period. As mentioned in Section 4.1.3, we will test 3 different values for λ (expected arrivals per day), causing that the number of opportunities in the pipeline per day will be different for each value of λ. We will choose a warm-up period for which the system has reached its steady state for all 3 values. We choose our warm-up period based on Figure 39:

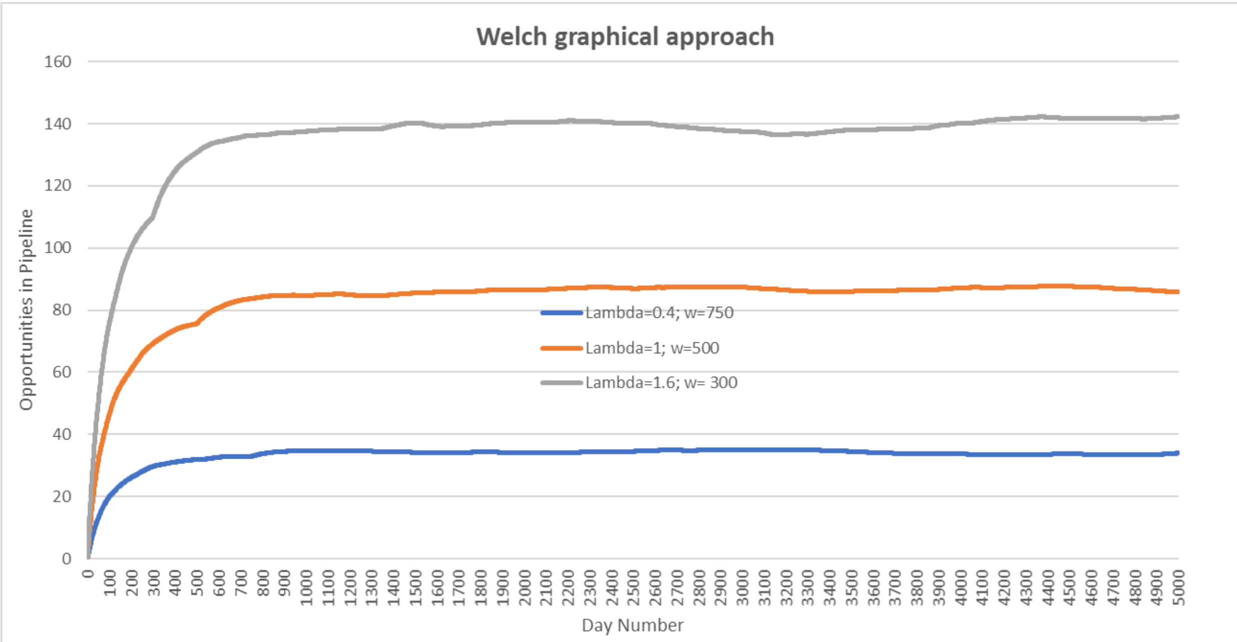

Figure 39: Welch graphical approach

For λ =0,4, λ =1 and λ =1,6, the graph seems to be reasonably smooth for a value of w (moving average) of respectively 750, 500 and 300. After approximately 700 days, all graphs have reached their steady state value. Therefore, we choose our warm up period to be 700 days for all values of λ. This means that, in our experiments we will not take into account performance measures of the first 700 days.

Determine number of replications

In this section we want to determine the number of required replications to obtain a good statistical performance. We apply the replication/deletion approach as mentioned by Law (2015). We want to obtain a 95 percent confidence interval for a certain precision of the delivery speed. As mentioned in Section 4.1.4, we choose our run length to be 15 years (5475 days). We make replications until the length of the confidence interval is at most two, such that we are 95% sure that the actual delivery speed of a configuration lies between 94% and 96%. By trial and error, we get the following results (Table 17):

Table 17: Nr of replications delivery speed

N (nr of replications)	**2**	**3**	**4**	**5**
Mean of each replication	94.97383	95.16682	95.10481	95.01794
Standard deviation	0.302654	0.396898	0.346985	0.357813
t-value	12.70620	4.302653	3.182446	2.776445
95% Confidence interval Lower Bound	92.25459	94.18087	94.55268	94.57366
95% Confidence interval Upper Bound	97.69307	96.15277	95.65694	95.46222
Length of confidence interval	5.43848	1.971897	1.104261	0.888567

By using 3 replications, the length of the confidence interval seems to be small enough (highlighted in yellow). Therefore, in our optimization approach, we continue experimenting until the delivery speed over 3 replications is above the limit of 95%.

Thereafter, we would like to obtain a 95 percent confidence interval (γ=0,05) for a certain precision of the objective value. We make replications until the length of the confidence interval is small enough. This means that the relative error needs to be smaller than γ/(γ+1) = 0,0476. By trial and error, we get the following results (Table 18):

Table 18: Nr of replications; Objective value Purchasing

N (nr of replications)	**2**	**3**	**4**	**5**
Mean of each replication	656566739,4	661830716,4	664757467,2	663477845,3
Standard deviation	21049131,95	17454550,74	15406850,46	13646077,86
t-value	12,70620474	4,30265273	3,182446305	2,776445105
95% Confidence interval Lower Bound	467447792,1	618471208,7	640241730,0	646534001,7
95% Confidence interval Upper Bound	845685686,6	705190224,2	689273204,3	680421688,9
Relative error	0,288042229	0,065514499	0,03687922	0,025537919

By using 4 replications, the relative error seems to be small enough (highlighted in yellow). Therefore, for each configuration, we store the average objective value over 4 replications. In the next section, we explain how we use the number of replications to sub-optimize the various purchasing policy alternatives that can be applied using the centralized inventory management tool.

Design optimization approach

In this section we want to evaluate purchasing policies that can be applied using the centralized inventory management tool. For each purchasing policy we want to minimize the objective function, mentioned in the problem description above, while the delivery speed is at least 95%. As mentioned in Section 3.3.2, a purchasing policy consists of an order moment (X) and an order quantity (Q) for each component. In our optimization approach, we want to sub-optimize the values of X and Q for each purchasing policy, such that a delivery speed of 95% will be achieved. The following flowchart describes the used optimization approach (Figure 40):

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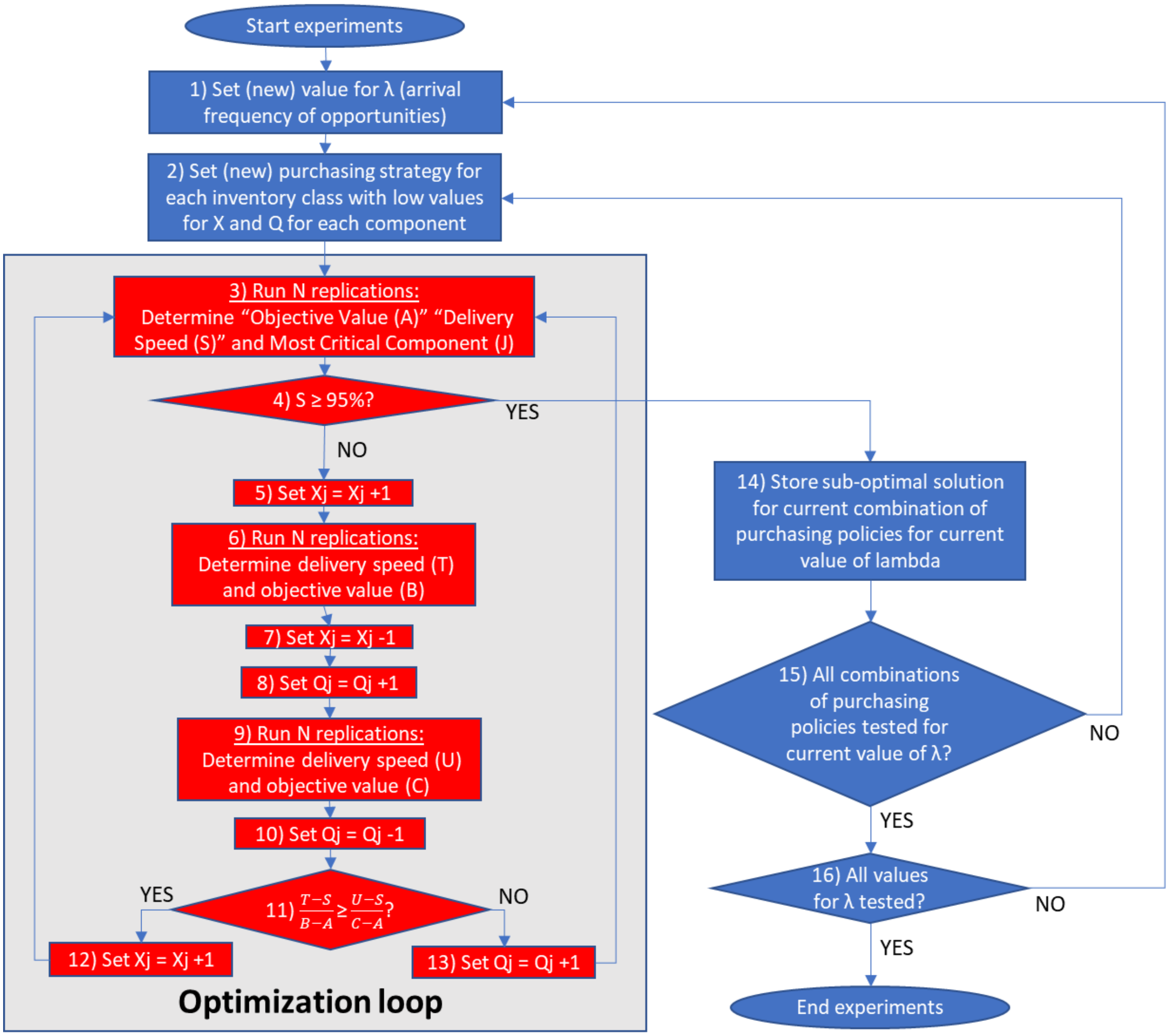

Figure 40: Experimental design purchasing policies

The numbered steps of the optimization approach are worked out below:

1) Set (new) value for λ (arrival frequency of opportunities): As mentioned in Section 4.1.3, we will run experiments for 3 different values for the expected number of opportunity arrivals per day (λ=0,4; λ=1; λ=1,6), to test various future scenarios.

2) Set (new) purchasing strategy for each inventory class with low values for X and Q for each component: For each inventory class, we pick one of the mentioned purchasing policies of Section 3.3.2 and start with low parameters for the order moment (X) and the order quantity (Q) for each component. In the optimization loop we will gradually increase the values for X and Q, until a sufficient delivery speed will be obtained.

3) <u>Run N replications</u>: Determine "Objective Value (A)" "Delivery Speed (S)" and Most Critical Component (J): We will run N replications with the current parameters for the order moment X and order quantity Q. N=1 in early stages to quickly explore interesting values. When the delivery speed approaches 95%, we take N=3 to construct a confidence interval for the delivery speed, as mentioned in the previous section. We calculate the objective value (mentioned in the problem description above), delivery speed and most critical component of the current configuration. The most critical component is the component that most often arrives last when POs are not delivered fast enough, and is therefore the bottleneck why the production cannot start earlier.

4) S ≥ 95%?: We check what the delivery speed performance is with the current parameters for the order moment X and order quantity Q. We continue our optimization loop until the delivery speed of the current configuration is at least equal to 95%.

5) Set $X_j := X_j + 1$: We increase the re order level of the most critical component. This means that a purchasing order will be placed earlier.

6) <u>Run N replications</u>: Determine delivery speed (T) and objective value (B): We run N replications with the increased value for the reorder level of the most critical component and determine the delivery speed and objective value of the updated configuration.

7) Set $X_j := X_j - 1$: We again decrease the re order level of the most critical component to the original value.

8) Set $Q_j := Q_j + 1$: We increase the order quantity of the most critical component. This means that we will order more when a purchase order will be placed.

9) <u>Run N replications:</u> Determine delivery speed (U) and objective value (C): We run N replications with the increased value for the order quantity of the most critical component and determine the delivery speed and objective value of the updated configuration.

10) Set $Q_j := Q_j - 1$: We again decrease the order quantity of the most critical component to the original value.

11) $\frac{T-S}{B-A} \geq \frac{U-S}{C-A}$? : We calculate which action (increasing re-order level or increasing order quantity) led to the highest increase in delivery speed per increase of the objective value.

12) Set $X_j := X_j + 1$: If increasing the re order level of the most critical component led to the highest increase in delivery speed per increase of the objective value, we will update the current configuration by increasing the reorder level of the most critical component.

13) Set $Q_j := Q_j + 1$: If increasing the order quantity of the most critical component led to the highest increase in delivery speed per increase of the objective value, we will update the current configuration by increasing the order quantity of the most critical component.

14) Store sub-optimal solution for current combination of purchasing policies for current value of λ: The following graphs show the development of both the delivery speed (Figure 41) and objective value during the optimization loops (Figure 42):

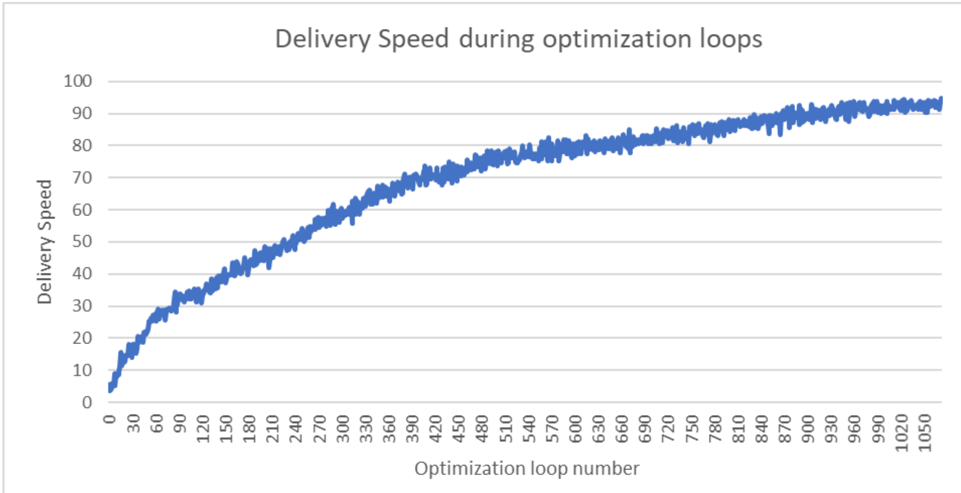

Figure 41: Development of delivery speed

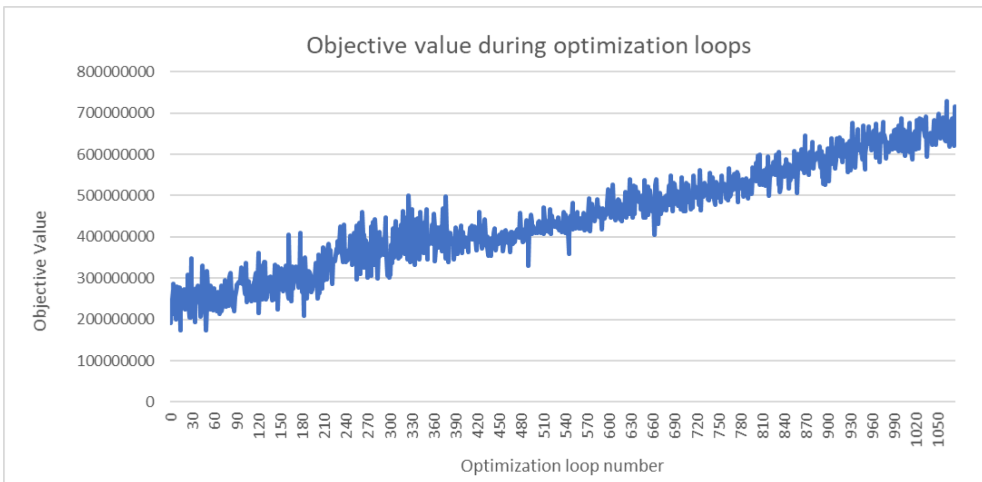

Figure 42: Development of objective value

When a delivery speed of 95% has been obtained, we store the current values for the order moment and order quantity as "sub-optimal" solution for the current value of λ and the current purchasing policy. As mentioned in the previous section, to construct a 95% confidence interval for the objective value, we run 4 replications with the sub-optimal configuration and store the average objective value.

15) All combinations of purchasing policies tested for current value of λ?: We continue experimenting until all combinations of purchasing policies have been tested.

16) All values for λ tested?: We continue experimenting until all three values for the expected number of opportunity arrivals have been tested.

In this section we worked out how purchasing policies can be evaluated. First, we gave a description of how we categorized the inventory components to be efficient in terms of time. Always the same purchasing policy will be applied for components in the same inventory class. Thereafter, we worked out the problem description, estimated a warm-up period using Welch graphical procedure (Figure 39) and determined the number of replications per experiment. Finally, we gave a description of the optimization approach that we use. Experiments can be conducted to sub optimize the various purchasing policy alternatives that can be applied using the tool. After sub optimizing the various alternatives, we can evaluate which purchasing policies are likely to be the most suitable to apply for DAP.

B) How can due date quotation policies be evaluated?

In this section, we work out how due date quotation policies can be evaluated. We follow the same structure as in part A of this section. First, we explain how we categorize the inventory components. Thereafter, we work out the problem description, estimate a warm-up period and determine the number of replications per experiment. Finally, we give a description of the used optimization approach.

To quote a lead time for a specific opportunity, the sales department has to make an estimation of the inventory status of all the required components at the moment that a customer places an order. As mentioned in part A, it is not feasible in terms of time to run experiments for each component separately. We want to categorize components to explore which due date quotation policies could be promising for various component categories. We will categorize the stock components using the same categorization as in Section 4.1.5A:

Class A: Demand Score < 8

Class B: Demand Score ≥ 8

To evaluate due date quotation policies, we again follow the procedure as shown in the book of Law (2015). First, a problem description will be given. Subsequently, we determine the required warm up period & required number of replications per experiment. Finally, we give a description of the used optimization approach.

Problem description

Using the centralized inventory management tool, various due date quotation policies can be applied. In Section 3.4.1, we identified that the performance of due date quotation policies can be evaluated based on various objectives. To be able to keep a leading position in the IEEE-1394 market, DAP's objective is to be able to inform customers regarding reliable lead times that are preferably as short as possible. Therefore, the due date quotation strategies will be evaluated using the following objective function:

$$Minimize: \frac{\sum_{i=1}^{NumOpportunityArrivals} Quoted\ Lead\ Time_i}{NumOpportunityArrivals}$$

In the model, the average quoted lead time will be minimized. When DAP is able to quote short lead times, it increases the probability of keeping customers satisfied and attracting new customers. However, the delivery reliability should be at least 95% to avoid customer disappointment. Therefore, the following restriction needs to be respected:

$$\frac{Number\ of\ orders\ delivered\ within\ quoted\ lead\ time}{Total\ number\ of\ delivered\ orders} \geq 0.95$$

For each due date quotation policy, we want to minimize the above-mentioned objective function while the delivery reliability is at least 95%.

Warm up period, run length and number of replications

Since the effectiveness of a due date quotation strategy is dependent on the number of opportunities in the pipeline, and we start with an empty opportunity pipeline, we again have to apply a warm up period for various values of the arrival frequency (λ). We again use a warming up length of 700 days as described in Section 5.1.4A. To determine the number of required replications to obtain a reasonably good statistical performance, we apply the replication/deletion approach (Law, 2015). We would like to obtain a 95 percent confidence interval for a certain precision of the delivery reliability. We make replications until the length of the confidence interval is at most two, such that we are 95% sure that the actual delivery reliability of a configuration lies between 94 and 96. By trial and error, we get the following results (Table 19):

Table 19: Nr of replications delivery reliability

N (nr of replications)	**2**	**3**	**4**	**5**
Mean of each replication	95.09866626	95.12953761	95.30164275	95.1694405
Standard deviation	0.506337627	0.362005548	0.453702617	0.491702884
t-value	12.70620474	4.30265273	3.182446305	2.776445105
95% Confidence interval Lower Bound	90.54940317	94.23026598	94.57970064	94.55891073
95% Confidence interval Upper Bound	99.64792935	96.02880924	96.02358486	95.77997027
Length of confidence interval	9.098526174	1.798543267	1.443884218	1.221059537

By using 3 replications, the length of the confidence interval seems to be small enough (highlighted in yellow). Therefore, in our optimization approach, we take a configuration as sub-optimal if the delivery reliability over 3 replications is above the limit of 95%.

Thereafter, we would like to obtain a 95 percent confidence interval (γ=0,05) for a certain precision of the objective value. We make replications until the length of the confidence interval is small enough. This means that the relative error needs to be smaller than $\gamma/(\gamma+1)$ = 0,0476. By trial and error, we get the following results (Table 20):

Table 20: Nr of replications; Objective value due date quotation

N (nr of replications)	**2**	**3**	**4**	**5**
Mean of each replication	1795986.227	1802124.151	1795490.46	1792279.938
Standard deviation	26109.44796	21304.31849	21877.06717	20260.59757
t-value	12.70620474	4.30265273	3.182446305	2.776445105
95% Confidence interval Lower Bound	1561402.144	1749201.29	1760679.165	1767123.084
95% Confidence interval Upper Bound	2030570.309	1855047.012	1830301.756	1817436.793
Relative error	0.130615747	0.029366934	0.019388182	0.014036231

By running 3 replications, the relative error seems to be small enough (highlighted in yellow). Therefore, for each sub-optimal configuration, we store the average objective value over 4 replications. In the next section, we explain how we use the number of replications to sub-optimize the various due date quotation policy alternatives that can be applied using the centralized inventory management tool.

Design optimization approach

In this section we want to evaluate due date quotation policies that can be applied using the centralized inventory management tool. The optimization approach is comparable with the mentioned approach in Section 4.1.5A. For each due date quotation policy, we want to minimize the objective function mentioned in the problem description above, while the delivery reliability is at least 95%. As mentioned in Section 3.4.2, a due date quotation policy consists of an “Moment of quoting extra lead time (K)” and a “Quantity of extra lead time (Y)” for each component. In our optimization approach, we want to sub-optimize the values of K and Y for each due date quotation policy, such that a delivery reliability of 95% will be achieved. The following flowchart describes the used optimization approach (Figure 43):

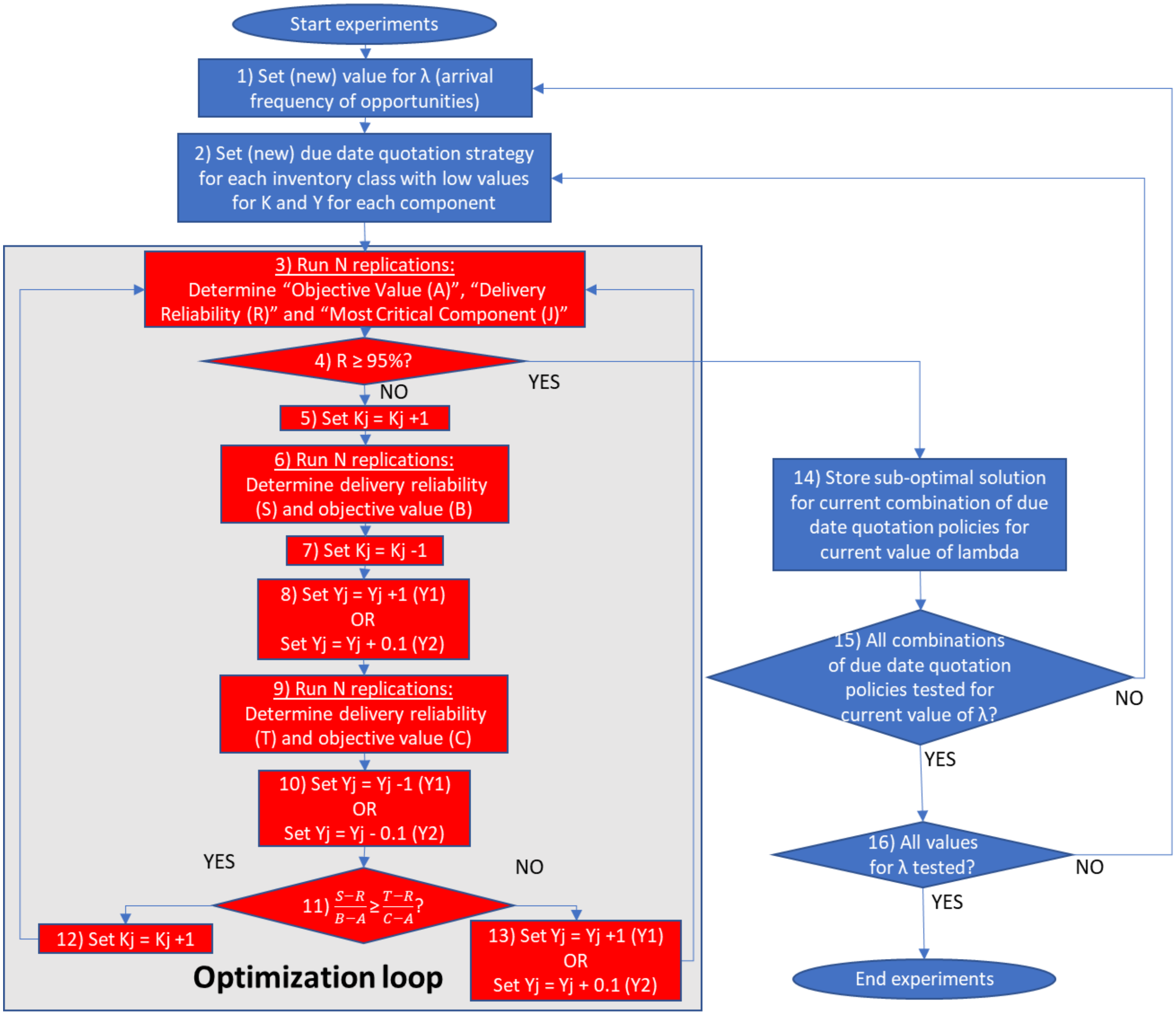

Figure 43: Experimental design due date quotation

The numbered steps of the optimization approach are worked out below:

1) Set (new) value for λ (arrival frequency of opportunities): We run experiments for 3 different values for the expected number of opportunity arrivals per day (λ=0,4; λ=1; λ=1,6), to test various future scenarios.

2) Set (new) due date quotation strategy for each inventory class with low values for K and Y for each component: For each inventory class, we pick one of the mentioned due date quotation policies of Section 3.4.2 and start with low parameters for the "Moment of quoting extra lead time (K)" and "Quantity of extra lead time (Y)". In the optimization loop we will gradually increase the values for K and Y, until a sufficient delivery reliability will be obtained.

3) Run N replications: Determine "Objective Value (A)" "Delivery Speed (R)" and Most Critical Component (J): We will run N replications with the current parameters for the "Moment of quoting extra lead time (K)" and "How much extra lead time to quote (Y)". N=1 in early stages to quickly explore interesting values. When R approaches 95%, we take N=3 to construct a confidence interval for the delivery reliability as mentioned in the previous section. We calculate the objective value (mentioned in the problem description above), delivery reliability and most critical component of the current configuration. Unlike the optimization approach in Section 4.1.5A, the most critical component is in this case the component that most often arrives last in situations where the quoted lead time cannot be met.

4) R ≥ 95%?: We check what the delivery reliability performance is with the current parameters for K and Y. We continue our optimization loop until the delivery reliability of the current configuration is at least equal to 95%.

5) Set $K_j := K_j + 1$: We increase the critical level of quoting extra lead time of the most critical component. This means that extra lead time will be quoted earlier.

6) Run N replications: Determine delivery reliability (S) and objective value (B): We run N replications with the increased value for critical level of quoting extra lead time of the most critical component and determine the delivery reliability and objective value of the updated configuration.

7) Set $K_j := K_j - 1$: We again decrease the critical level of quoting extra lead time of the most critical component to the original value.

8) Set $Y_j := Y_j + 1$ (Y1) OR $Y_j := Y_j + 0.1$ (Y2): We increase the quantity of extra lead time of the most critical component. This means that we will quote more extra lead time when the critical level of quoting extra lead time has passed. As mentioned in Section 3.4.2, two different strategies can be used for the quantity of extra lead time (Y1 and Y2). We increase by 1 day if we use a policy with Y1. If we use a policy with factor Y2, we increase with 0.1.

9) Run N replications: Determine delivery reliability (T) and objective value (C): We run N replications with the increased value for the quantity of extra lead time for the most critical component and determine the delivery reliability and objective value of the updated configuration.

10) Set $Y_j := Y_j - 1$ (Y1) OR $Y_j = Y_j - 0.1$ (Y2): We again decrease the quantity of extra lead time of the most critical component to the original value.

11) $\frac{S-R}{B-A} \geq \frac{T-R}{C-A}$? : We calculate which action (increasing "critical level of quoting extra lead time" or "increasing the quantity of extra lead time") led to the highest increase in delivery reliability per increase of the objective value.

12) Set $K_j := K_j + 1$: If increasing the critical level of quoting extra lead time of the most critical component led to the highest increase in delivery reliability per increase of the objective value, we will update the current configuration by increasing the critical level of quoting extra lead time of the most critical component.

13) Set $Y_j := Y_j + 1$ (Y1) OR $Y_j = Y_j + 0.1$ (Y2): If increasing the quantity of extra lead time of the most critical component led to the highest increase in delivery reliability per increase of the objective value, we will update the current configuration by increasing the amount of extra lead time to quote of the most critical component.

14) Store sub-optimal solution for current combination of due date quotation policies for current value of λ: When a delivery reliability of 95% has been obtained, we store the current values for the "critical level of quoting extra lead time" and "quantity of extra lead time" as "sub-optimal" solution for the current value of λ and the current due date quotation policy. We run 3 replications with the sub-optimal configuration and store the average objective value.

15) All combinations of due date quotation policies tested for current value of λ?: We continue experimenting until all combinations of due date quotation policies have been tested.

16) All values for λ tested?: We continue experimenting until all three values for the expected number of opportunity arrivals have been tested.

In this section we worked out how due date quotation policies can be evaluated. We use the same categorization of inventory components and warm up period as in Section 4.1.5A. Thereafter, we worked out the problem description and determined the number of replications per experiment. Finally, we gave a description of the optimization approach that we can use. Experiments can be conducted to sub optimize the various due date quotation policy alternatives that can be applied using the tool. After sub optimizing the various alternatives, we can evaluate which purchasing policies are likely to be the most suitable to apply for DAP.

Sections 4.1.1 till 4.1.5 give answer to the question: "How can we test what the expected effectiveness of the tool could be and how the tool should be used?". We identified that we can simulate the order delivery process, when the tool would have been implemented. Using the tool, various purchasing policies and due date quotation policies could be applied. Conducting simulation experiments, we can sub-optimize these policies. After sub-optimizing the purchasing policies, we can evaluate which policy achieves a delivery speed of at least 95% against the lowest inventory investments. Furthermore, after sub-optimizing the due date quotation policies, we can evaluate which policy achieves a delivery reliability of at least 95% against the lowest average quoted lead time. In Section 4.2 we work out the results of the conducted experiments and give answer to the question: "What is the best way to use the tool to achieve a delivery reliability and delivery speed of at least 95%?".

4.2) What is the best way to use the tool to achieve a delivery speed and delivery reliability of at least 95%?

In this section we describe the results of the conducted simulation experiments. As mentioned in Section 3.5.2, various purchasing policies and due date quotation policies could be applied using the centralized inventory management tool. In Section 4.2.1 we determine what the best purchasing policies are to achieve a delivery speed of at least 95%. Thereafter, in Section 4.2.2 we determine what the best due date quotation policies are to achieve a delivery reliability of at least 95%.

4.2.1) What are the best purchasing policies to achieve a delivery speed of at least 95%?

In this section we run experiments as described in Section 4.1.5A. We want to explore what the best purchasing policies are that can be applied using the tool.

As mentioned in Section 4.1.5 we first classify components into two categories:

- Category A: Components with a low expected demand (demand score < 8).
- Category B: Components with a high expected demand (demand score ≥ 8)

For each category, we choose an order moment strategy and an order quantity strategy as described in Section 3.3.2:

- **Order Moment A) Do not anticipate potential POs:** Place purchase order when inventory level gets below a minimum level (X1)

  Order moment: when Inventory Level < X1

- **Order Moment B) Anticipate potential POs:** Make forecast over worst case estimate of supplier lead time. Place purchase order when forecasted inventory level gets below a minimum level (X2)

  Order moment: when forecasted inventory level < X2

- **Order Quantity 1) Do not anticipate potential POs:** Order a fixed quantity (Q1)

  Order quantity: MOQ+ Q1

- **Order Quantity 2) Anticipate potential POs:** Make forecast over worst case estimate of supplier lead time. Order a quantity based on the total forecasted demand

  Order quantity: MOQ+ Forecasted demand during worst case supplier lead time + Q2

When we carry out the optimization loops as described in Section 4.1.5A, sub-optimal configurations for all combinations of purchasing policies and values of λ can be stored. For each value of λ, we run the experiments displayed in Table 21:

Table 21: Purchasing experiments

Experiment	Order moment strategy cat. A components	Order Quantity strategy cat. A components	Order moment strategy cat. B components	Order Quantity strategy cat. B components
1	A	1	A	1
2	A	1	A	2
3	A	1	B	1
4	A	1	B	2
5	A	2	A	1
6	A	2	A	2
7	A	2	B	1

8	A	2	B	2
9	B	1	A	1
10	B	1	A	2
11	B	1	B	1
12	B	1	B	2
13	B	2	A	1
14	B	2	A	2
15	B	2	B	1
16	B	2	B	2

The obtained sub-optimal configurations per experiment are given in Appendices 4 till 6. As mentioned in Section 4.1.5A, our goal is to minimize the following objective value:

$$Minimize: \sum_{i=1}^{NumDays} \sum_{j=1}^{NumComponents} \sum_{k=1}^{InventoryLevel_{ij}} (BuyingPrice_j + (FixedOrderingCosts_j / LotSize_{jk}))$$

$NumDays = Length\ of\ the\ simulation\ run\ in\ days$

$NumComponents = Total\ number\ of\ components\ that\ are\ taken\ into\ account$

$InventoryLevel_{ij} = Number\ of\ components\ of\ type\ j\ that\ are\ in\ stock\ at\ the\ end\ of\ day\ i$

$BuyingPrice_j = Buying\ price\ of\ component\ type\ j$

$FixedOrderingCosts_j = Costs\ of\ placing\ a\ purchase\ order\ for\ component\ type\ j$

$LotSize_{jk} = Lot\ size\ of\ the\ purchase\ order\ in\ which\ component\ k\ of\ type\ j\ is\ ordered$

The corresponding sub-optimal objective values for the 16 conducted experiments (Appendix 7) are displayed in Figure 44:

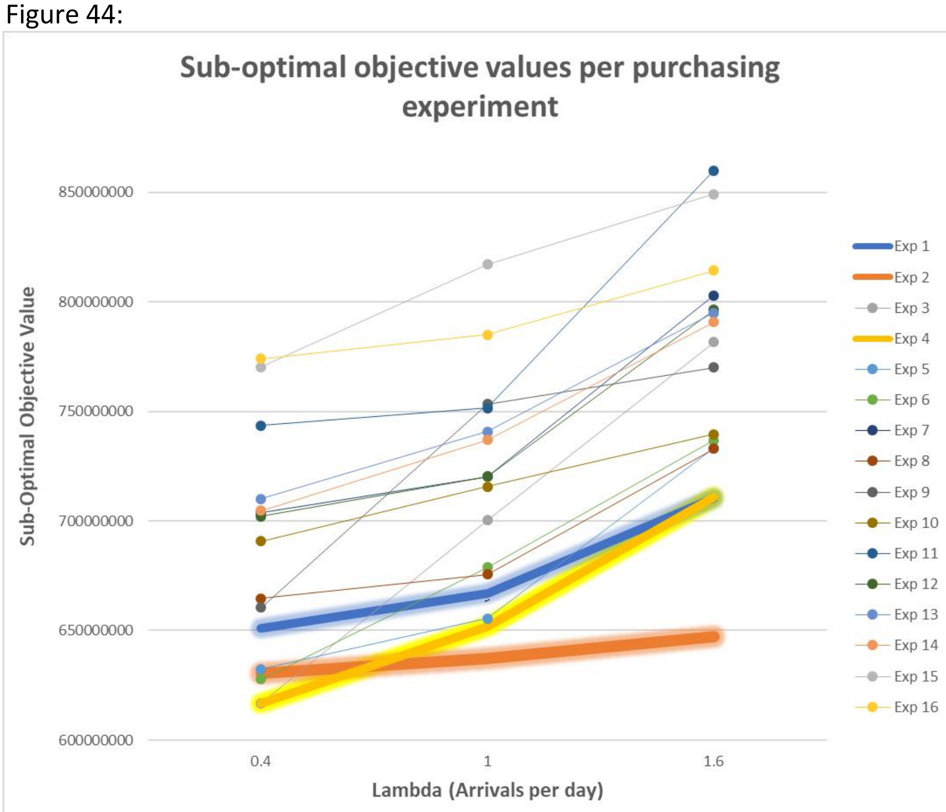

Figure 44: Sub-optimal objective values per purchasing experiment

In Figure 44, we see that the sub-optimal objective value of each experiment increases when the value for λ increases. Our goal is to find purchasing policies that have a low sub-optimal objective value for each value of λ. Therefore, we need to identify which experiment performs well for all tested values of λ. We see that some experiments are dominated by other experiments. That means that the objective value of that specific experiment is higher than the objective value of another experiment for each value of λ. The experiments 5 to 16, in which we try to anticipate potential POs with category A components all seem to be dominated. This means that, for the components with a low expected demand, DAP can better not purchase based on sales forecasts. When we delete all dominated experiments, we obtain the following best purchasing policies, which are highlighted in Figure 44 (Figure 45):

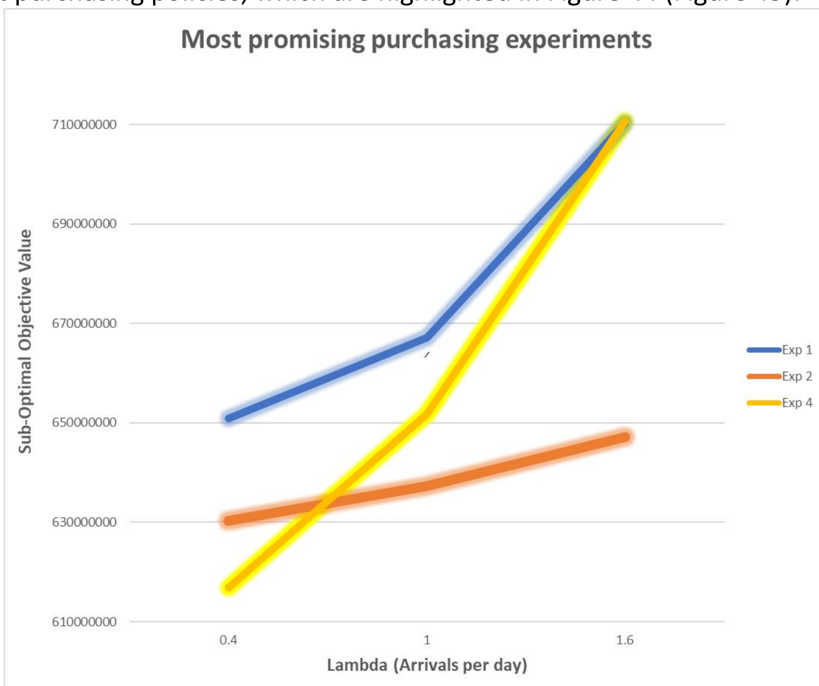

Figure 45: Most promising purchasing experiments

We identify experiment 1,2 and 4 as most promising purchasing policies. Experiment 1 is the easiest to apply for the purchasing department, because a fixed order moment and fixed order quantity are used for each component. No distinction has to be made between the different components. It results in a relatively low objective value for each tested value of λ.

As shown in the graph, there are possibilities to improve the obtained objective values of experiment 1. Experiment 2 investigates a policy where a fixed reorder point for each component is used, but the order quantity differs between the different inventory classes. For the components of category B, we order a quantity based on a forecast of the opportunity pipeline. This policy seems to be beneficial especially when the average number of opportunities in the pipeline increases. The fixed order moment ensures that purchase orders are placed on time, and the order quantity based on the pipeline forecast ensures that not too much components will be purchased. Especially when the number of opportunities in the pipeline is high, the organization can really make the difference by varying the order quantity of category B components, based on the opportunity pipeline.

Another possibility to improve the objective value of experiment 1 is by using the policy of experiment 4. Experiment 4 investigates a policy where a fixed order quantity and order moment are used for category A component, and we anticipate potential POs with both the order moment and order quantity for category B components. This policy seems to be beneficial especially when the average number of opportunities in the pipeline is low. In such situations, the policy ensures that purchase orders are placed on time, and not too much will be purchased. However, when the number of POs increases, the policy results in placing too many purchase orders for which the order costs can be high.

In this section we ran experiments to test what are the most promising purchasing policies that DAP could apply, using the centralized inventory management tool. The following policy (tested in experiment 2) seems to be the most robust for various future scenarios:

Category A components:	*Fixed re-order level; Fixed order quantity*
Category B components:	*Fixed re-order level; Variable order quantity based on opportunity pipeline*

In the next section we run experiments to test what are the most promising due date quotation policies that DAP could apply, using the tool.

4.2.2) What are the best due date quotation policies to achieve a delivery reliability of at least 95%?

In this section we run experiments as described in Section 4.1.5B. We want to explore what the best due date quotation policies are that can be applied using the tool.

For due date quotation, we still use the same categories for the inventory components as described in Section 4.1.5:

- Class A: Components with a low expected demand (demand score < 8).
- Class B: Components with a high expected demand (demand score ≥ 8)

For each category, we choose a "moment of extra lead time" strategy and a "quantity of extra lead time" strategy as described in Section 3.4.2:

- **Moment extra lead time A) Do not anticipate potential POs:** Quote extra lead time if the physical stock of a required component is below a fixed level (K1) at the moment of opportunity arrival.

  Extra lead time if: Physical Stock < K1

- **Moment extra lead time B) Anticipate potential POs:** Make inventory forecast over worst case estimate of supplier lead time. Quote extra lead time if forecasted inventory level gets below a fixed level (K2)

  Extra lead time if: Forecasted inventory level < K2

- **Quantity extra lead time 1) Do not anticipate supplier lead time:** Quote fixed amount of extra lead time (Y1) on top of the minimum lead time of 10 days. We choose 7 days as minimum lead time because DAP has worldwide customers for which it can take up to 7 days to ship orders and add 3 days to take into account supplier lead times of order specific purchases and production times

  Lead time to quote: 10 days + Y1

- **Quantity extra lead time 2) Anticipate potential supplier lead time:** Quote extra lead time based on supplier lead time of components. Multiply the most likely supplier lead time by a factor Y2.

  *Lead time to quote: 10 days + Y2*Most likely supplier lead time*

When we carry out the optimization loops as described in Section 4.1.5B, sub-optimal configurations for all combinations of due date quotation policies and values of λ can be stored. For each value of λ, we run the experiments displayed in Table 22:

Table 22: Due date quotation experiments

Experiment	"Moment extra lead time" strategy cat. A components	"Quantity extra lead time" strategy cat. A components	"Moment extra lead time" strategy cat. B components	"Quantity extra lead time" strategy cat. B components
1	A	1	A	1
2	A	1	A	2
3	A	1	B	1
4	A	1	B	2
5	A	2	A	1
6	A	2	A	2
7	A	2	B	1
8	A	2	B	2
9	B	1	A	1
10	B	1	A	2
11	B	1	B	1
12	B	1	B	2
13	B	2	A	1
14	B	2	A	2
15	B	2	B	1
16	B	2	B	2

The obtained sub-optimal configurations per experiment are given in Appendix 8 till 10. As mentioned in Section 4.1.5, we want to minimize the following objective value:

$$Minimize : \frac{\sum_{i=1}^{NumOpportunityArrivals} Quoted\ Lead\ Time_i}{NumOpportunityArrivals}$$

The corresponding sub-optimal objective values for the 16 conducted experiments (Appendix 11) are displayed in the following graph (Figure 46):

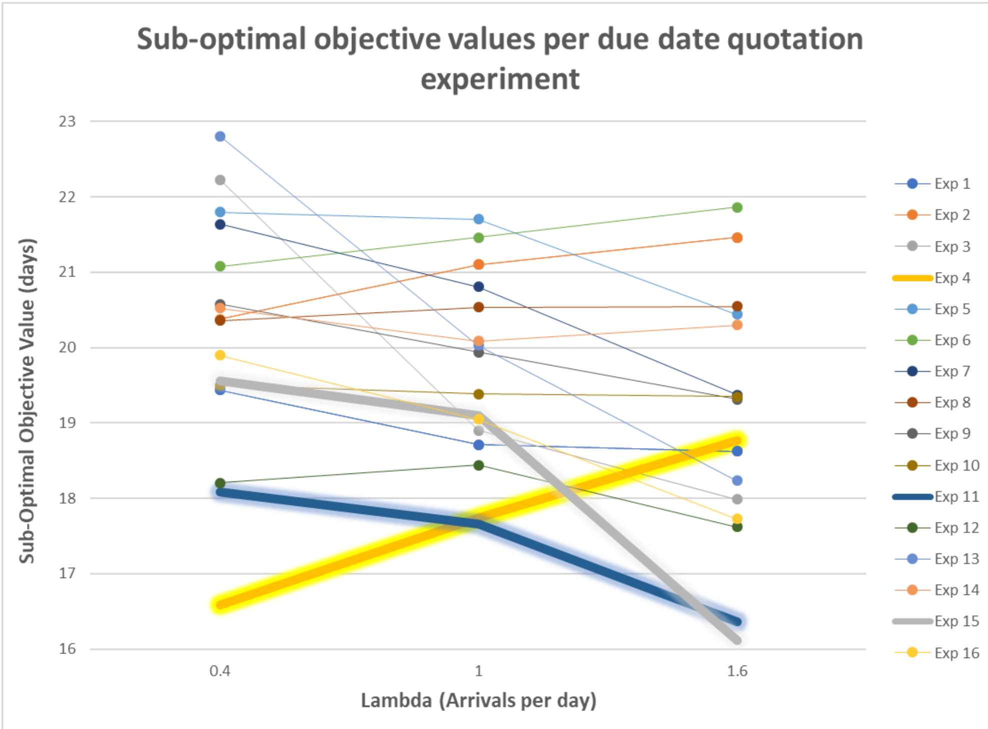

Figure 46: Sub-optimal objective values per due date quotation experiment

Looking at Figure 46, we see that the expected arrivals per day can have different influences on the performance of due date quotation policies. For some policies, the average quoted lead time increases when the expected number of arrivals per day (λ) increases. For other policies, the average quoted lead time decreases when the number of arrivals per day increases. Our goal is to find due date quotation policies that have a low sub-optimal objective value for each value of λ. Therefore, we need to identify which experiment performs well for all tested values of λ. Again, some experiments are dominated by other experiments. When we delete the dominated experiments, we obtain the following most promising due date quotation policies, which are highlighted in Figure 46 (Figure 47):

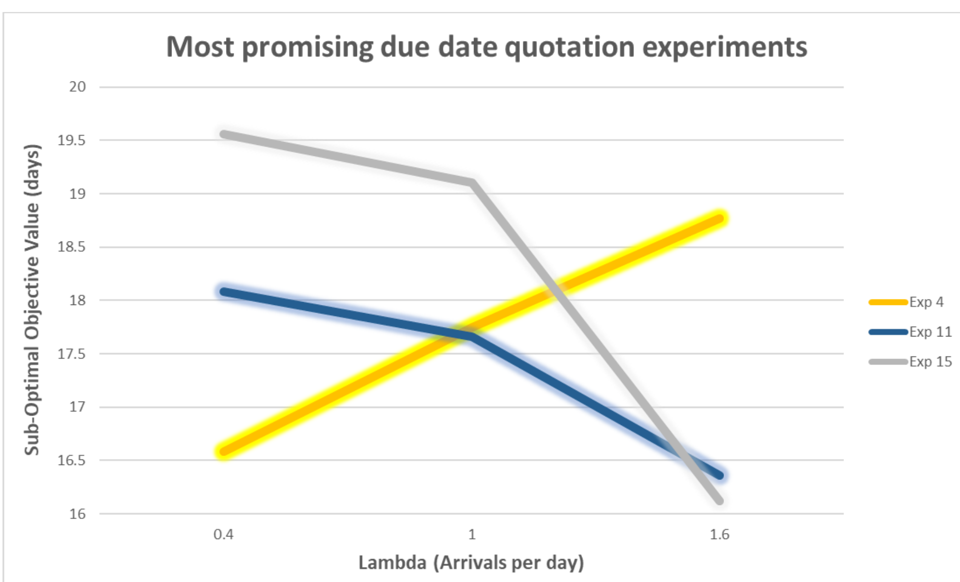

Figure 47: Most promising due date quotation experiments

We identify experiment 4, 11 and 15 as most promising due date quotation policies. First, we want to get insight into which strategy for determining the moment of extra lead time is the most suitable. We see that, for all most promising due date quotation policies, the moment of quoting extra lead time for category B components is based on a forecast of the opportunity pipeline. For category A components, the organization can choose both for a fixed moment of extra lead time and for a moment based on a forecast of the opportunity pipeline. In experiment 4, a fixed moment of extra lead time has been used for category A components. This is especially suitable for low values of λ. When the value of λ increases, we see that experiment 11 and 15 perform better. These experiments use a moment of extra lead time based on the opportunity pipeline forecast. This means that, especially for high values of λ, the moment of quoting extra lead time for category A components can be based on a forecast of the opportunity pipeline to obtain the best results. This seems logical, since the forecast of the opportunity pipeline gives a more realistic insight into the potential orders when the number of opportunities in the pipeline increases.

Furthermore, we want to get insight into which strategy for determining the quantity of extra lead time is the most suitable. We see that the best policy to determine the quantity of extra lead time really differs between the different values of λ. For low values of λ, a fixed quantity for quoting extra lead time can be used for category A components, and a quantity based on the expected supplier lead time can be used for category B components, as tested in experiment 4. For high values of λ, it can also be beneficial to quote a lead time based on the supplier lead time for category A components, as tested in experiment 15. However, in that case it is not good to use a quantity based on the supplier lead time for category B components. Namely, when the number of opportunities is high, the probability that there come in orders requiring common components before the specific order is placed increases. Because of this, it could be that the component that has been identified as 'most critical when quoting lead time' is not the component that is indeed the most critical when the order is placed. This means that one takes into account extra lead time that is not relevant at the moment that the order is placed. Since it is not easy to predict future scenarios, the most robust option is to apply the strategies as tested in experiment 11. In experiment 11, a fixed quantity of extra lead time is used for all inventory components.

In this section we ran experiments to test what are the most promising due date quotation policies that DAP could apply, using the centralized inventory management tool. We identified that the following policy (tested in experiment 11) seems to be the most robust for various future scenarios:

Category A + B components: *Moment of quoting extra lead time based on opportunity pipeline; Fixed quantity of extra lead time*

This means that, for this policy the organization does not have to distinguish between components. The same policy can be applied for all inventory components. Together with Section 4.2.1, this section gives answer to the question: "What is the best way to use the tool to achieve a delivery speed and delivery reliability of at least 95%?".

Chapter 5: Conclusions, Implementation Plan and Recommendations, Limitations

In this chapter we work out the conclusion, implementation plan and limitations of research. First in Section 5.1, we work out the conclusions of the research. In Section 5.2, the implementation plan and recommendations are listed. Eventually, the limitations of research are described in Section 5.3.

5.1 Conclusions

In this section, we work out the main conclusions of the research. The research focusses on improving the delivery speed and delivery reliability performance:

- **Delivery Reliability**: Percentage of total number of Production Orders (POs) that is delivered within the quoted lead time.
- **Delivery Speed:** Percentage of total number of POs that is delivered within 4 weeks, when the customer prefers to receive the products as soon as possible.

As mentioned in the introduction section (Chapter 1), the research goal is to identify what the current performance regarding delivery reliability and delivery speed is, and what the main reasons are why the organization is currently not able to improve this performance. After that, the objective of the research is to provide Dap Technology with a plan on how to improve the current order delivery process to achieve a delivery reliability and delivery speed of at least 95%. To this end, we answer the following main research question:

How can DAP Technology achieve delivery reliability and delivery speed of at least 95%?

In Chapter 2, we saw that the performance regarding delivery speed and delivery reliability is currently respectively 80.9% and 82.6%. We identified that the current information systems do not provide sufficient support for the sales, purchasing and order processing departments to achieve the desired performance. The departments are in need of the following aspects of inventory management, which cannot completely be fulfilled in the current way of working:

- **Order Processing**: To know what can be produced and shipped to the customer, it is important to monitor the available stock.
- **Sales**: To provide reliable lead times to potential customers, it is important to monitor the available stock and forecast upcoming customer demand.
- **Purchasing**: To make a well-founded decision regarding when and how much to purchase, it is important to monitor the available stock and forecast upcoming customer demand.

We identified the following reasons why the above-mentioned needs cannot completely be fulfilled in the current way of working:

- **Monitor available stock**: The three departments currently use information system Minox to monitor the available stock. The current way of managing inventory in Minox leads to overviews of inventory that are not reliable and not up-to-date. The purchasing department uses these unreliable overviews as input to decide when and how much to purchase. Moreover, the sales department uses these overviews as input to quote lead times for potential customers. Therefore, the sales department and purchasing department cannot directly use Minox and have to make poorly informed decisions, leading to underperformance.
- **Forecast upcoming customer demand**: The organization currently tracks upcoming customer demand by storing opportunities in Customer Relationship Management (CRM) system Goldmine. These opportunities are stored in the Goldmine Opportunity pipeline. Currently, there is no connection between potential customer demand in Goldmine and the inventory

status in Minox. Therefore, it is currently difficult to identify upcoming inventory shortages. Again, the sales department and the purchasing department cannot directly use the opportunity pipeline information as input, and have to make their decisions to a great extent based on feeling.

In order to achieve a better delivery reliability and delivery speed, the information systems should provide better support, such that Sales and Purchasing can better anticipate inventory shortages and improve the delivery performance. An additional inventory management tool is needed, in which crucial information of the three departments can be combined. To design a solution, in Chapter 3 we explored how a centralized inventory management tool should be shaped to improve the delivery reliability and delivery speed. We made a conceptual design for an IT system that can be used by all three departments to monitor available stock and forecast upcoming customer demand. Crucial information of the sales, purchasing and order processing departments should be combined. Information regarding upcoming customer demand, that is currently stored in the Goldmine Opportunity Pipeline, should be linked with information regarding the inventory status, that is currently stored in Minox. Moreover, information about supplier lead times should be added, which the organization currently does not register. This combined information can be used to make inventory forecasts to better anticipate inventory shortages.

In Chapter 4, we tested the expected effectiveness of the inventory management tool is and how it can be used. We built a simulation model that can be used to simulate the order delivery process, when the centralized inventory management tool would have been implemented and the departments therefore have full information availability. Using the tool, various purchasing policies and due date quotation policies can be applied. Conducting simulation experiments, we tested which purchasing policies are the most promising to achieve a delivery speed of at least 95%. Furthermore, we tested which due date quotation policies are the most promising to achieve a delivery reliability of at least 95%. Since it is not easy to predict future scenarios, we vary the opportunity arrival frequency over the experiments to find the most robust policies.

In Section 4.2.1 we explored which purchasing policies can be applied, using the input of the centralized tool. The goal is to find purchasing policies that result in a delivery speed of at least 95% with a low average value on stock. A purchasing policy consists of the following two factors: “Order Moment” and “Order Quantity”. We saw that the easiest way to obtain a delivery speed of 95% against a reasonably low average value on stock is by using a fixed re-order level and order quantity for all components. However, when the average number of opportunities increases or decreases considerably, there are other policies that can lead to a better performance. For these policies, we categorize the inventory components into two categories:

A) Components with a low expected demand (demand score < 8)
B) Components with a high expected demand (demand score ≥ 8)

We saw that it is almost impossible to determine purchasing needs of category A components based on forecasts of the opportunity pipeline. It seems to be better to always use a fixed re-order level and fixed order quantity for components in this category. For frequently asked components (category B), it can be beneficial to purchase based on the opportunity pipeline forecast. Since it is not easy to predict future scenarios, it is wise to choose for a policy that performs well under all tested scenarios for the opportunity arrival frequency. The following policy seems to be the most robust for various future scenarios:

Category A components:	*Fixed re-order level; Fixed order quantity*
Category B components:	*Fixed re-order level; Variable order quantity based on opportunity pipeline*

In Section 4.2.2, we explored which due date policies can be applied, using the input of the centralized tool. The goal is to find policies that minimize the average quoted lead time, while still obtaining a delivery reliability of at least 95%. A due date quotation policy consists of the following two factors for each component: “Moment of quoting extra lead time” and “Quantity of extra lead time”. We saw that the best option to determine the “moment of quoting extra lead time” is by looking at the component status based on the opportunity pipeline forecast. Especially when the number of opportunities in the pipeline increases, better results will be booked taking into account the pipeline forecast. For the “quantity of extra lead time”, the most robust option is to use a fixed quantity for all components. This results in a reasonably good performance for all tested future scenarios of the opportunity arrival frequency. The following policy seems to be the most robust for various future scenarios:

Category A+B components: *Moment of quoting extra lead time based on opportunity pipeline; Fixed quantity of extra lead time*

This means that the organization does not have to distinguish between components for this policy. The same policy can be applied for all inventory components.

To conclude, in this research we identified that the current information systems do not provide sufficient support for the sales, purchasing and order processing departments to achieve a delivery speed and delivery reliability of at least 95%. In the current situation, the sales and purchasing departments have to make their due date decisions and purchasing decisions to a great extent based on feeling. To improve, a centralized inventory management tool is needed to better align the sales, purchasing and order processing departments. Using the centralized tool, the delivery speed and delivery reliability are likely to improve because it enables the purchasing and sales departments to better anticipate inventory shortages. The simulation study shows that, using the tool, various purchasing policies and due date quotation policies can be applied to achieve the desired performance of 95%. This means that the current performance regarding delivery speed and delivery reliability of respectively 80.9% and 82.6% can be improved. Unfortunately, it is not possible to compare the average value on stock that is needed to achieve a delivery speed of 95% with the average value on stock that is needed in the current way of working. Namely, because of the limited number of POs, we calculate the average value on stock over 15 years to get a valuable insight into the performance of a purchasing policy. It is not possible to calculate this for the past 15 years of DAP. Moreover, we take into account newly developed products for which DAP does not hold inventory yet. Furthermore, it is not possible to compare the average quoted lead time that is needed to achieve a delivery reliability of 95% with the average quoted lead time in the current way of working. Many quoted lead times are registered, but often without the desired lead time of the customer. This means that the current quoted lead times do not give insight into how fast DAP was actually able to deliver the products. In the next section we provide the organization with a plan on which steps have to be taken to improve the delivery reliability and delivery speed.

5.2 Implementation Plan and Recommendations

In this research we identified that DAP is currently not able to achieve a delivery speed and delivery reliability of 95%. This section contains a plan on which steps have to be taken to improve the delivery speed and delivery reliability. The plan consists of steps to take on the short term and on the long term:

<u>Steps to take on the short term</u>

1) The organization should internally discuss if they are willing to invest in additional IT to improve the delivery speed and delivery reliability. Moreover, the organization needs to discuss what kind of additional IT they would like to implement. This research provides guidelines to

implement additional IT that improves the delivery reliability and delivery speed. The organization could investigate which software package meets the requirements and functionalities mentioned in this research. Moreover, since the organization employs several software engineers, DAP can choose to internally develop an inventory management tool.

2) The organization should start better registering and monitoring crucial data. The current way of working makes it difficult to analyze the order delivery process. Data is currently often difficult to obtain and sometimes scarce. Better registering and monitoring crucial data of the sales, purchasing and order processing departments will make it easier to analyze the order delivery process and find future bottlenecks:
   - The order processing department should register the delivery reliability and delivery speed for each delivered order. In the current situation it is not clearly registered what the order date, desired lead time, quoted lead time and actual delivery date of a PO are. This makes it difficult to monitor the performance regarding delivery speed and delivery reliability. It becomes easier when this information will be centrally registered.
   - The purchasing department should register and monitor supplier lead times for each received purchase order. In the current situation, the organization does not register supplier lead times. When they will be accurately registered, this can be valuable input information for the sales and purchasing departments.
   - The sales department should register and monitor the arrival behavior of opportunities. The organization currently stores opportunities in CRM system Goldmine. The way they are currently registered makes it difficult to analyze the arrival behavior. It can be useful to register shifts of the expected closing date and shifts of the probability status. Moreover, it should be registered when opportunities are won or lost. This can provide valuable input information for the sales and purchasing departments.
   - The order processing department should register and monitor the Bill of Materials (BOM) of all commercial off-the-shelf COTS products. BOMs contain the components from which a product is build. In the current situation, many BOMs are not yet documented or not well documented. BOMs should always be up to date and reliable such that all departments are aware of the exact product composition.
   - The purchasing department should register and monitor the price specifications and MOQ of inventory components. It is important that the purchasing department is aware of all purchasing restrictions when making a choice regarding when and how much to purchase. Currently, the organization only stores a standard price in information system Minox.

   If the organization starts better registering and monitoring the above-mentioned data, it already creates more openness in the order delivery process for all departments, and it can therefore reduce the chance of making mistakes in managing inventory.

3) The organization should look into the results of the simulation study and check what valuable insights for the current way of working can be derived from the study:

   <u>3A) Valuable insight for the purchasing department:</u>
   - In the simulation study, we classified components based on demand scores. Category A components have a low expected demand and category B components have a high expected demand. Especially the frequently asked category B components should be monitored more frequently by the purchasing department.
   - In our optimization approach we obtained sub optimal re order levels and order quantities for all inventory components. These results can be taken into account as input information to determine when purchase orders need to be placed and how much

need to be ordered. The results are not directly applicable, since the organization currently does not have up to date overviews of inventory and has no opportunity pipeline component forecast.

3B) Valuable insight for the sales department:

- As mentioned above, in the simulation study we classified components based on demand scores. When new opportunities arrive, the sales department should accurately monitor the inventory status of especially the frequently asked category B components. If the inventory status of one of the category B components is minimal, there is a significant chance that extra lead time needs to be quoted.
- In our optimization approach we obtained sub optimal "critical levels of quoting extra lead time" and "quantities of extra lead time" for all inventory components. These results can be taken into account as input information to determine when extra lead time needs to be quoted and how much extra lead time needs to be quoted. Again, the results are not directly applicable, since the organization currently does not have up to date overviews of inventory and has no opportunity pipeline component forecast.

Steps to take on the long term

1) If better data becomes available, various organizational aspects could be investigated more extensively. Further research could be conducted regarding the following aspects:
   - The arrival behavior of opportunities could be investigated more extensively. One could investigate if the arrival behavior differs between different types of customers or between different types of products.
   - Further analyze the performance of suppliers in order to get a better insight into expected lead times and supplier delivery reliability. Perhaps, a better lead time distribution can be fit, instead of the used triangular distributions.

2) Learn how to work with the simulation model and include more accurate input data. When the organization is willing to adopt a centralized inventory management tool, the simulation model can be used to maximize the expected effectiveness of the tool. When more accurate data becomes available, experiments can be run again to explore what could be interesting purchasing policies and due date quotation policies. For example, components can be classified using other criteria. In the simulation model, inventory components are classified into just two categories (high and low expected demand). It could be interesting to make a more comprehensive categorization and conduct experiments to test purchasing and due date quotation strategies for the new categories. One could for instance categorize components based on factors like supplier lead time and/or buying price.

3) When the organization is willing to adopt a centralized inventory management tool, it is important to anticipate the main risks associated with IT projects. In Section 3.2 we saw that it is crucial to anticipate technical risks, organizational risks and business risks to increase the chance of a successful IT investment. Furthermore, we identified that the organization should make sure that the IT strategy is fully aligned with business strategy. The following four components need to be balanced: Business strategy, IT strategy, Organizational Infrastructure & Processes, IS Infrastructure and Processes. The organization should take into account that all the above-mentioned aspects should be balanced in order to achieve a good business IT alignment.

In this section, we worked out the steps that have to be taken to improve the delivery speed and delivery reliability. First, we mentioned three steps that should be taken on the short term. Thereafter, we mentioned three steps to take on the long term.

5.3 Limitations

There are some limitations that the organization should be aware of, when interpreting the results of this research:

- The quality of used input data is sometimes limited. For example, we used triangular distributions for supplier lead times and production times, based on best guesses. When the quality of input data improves, better decisions can be made.
- The goal of the simulation study is to explore if there are possibilities for the organization to improve its current way of working by adopting a centralized inventory management tool. Since the organization does currently not work with a centralized inventory management tool, the obtained sub-optimal configurations are not directly applicable for the current way of working.
- In this research we only focused on the order delivery process, and did not take into account the R&D department. The purchasing needs of the R&D department have not been taken into account when evaluating purchasing policies. This means that the obtained sub-optimal re order levels and order quantities could be slightly higher for components that are frequently asked by the R&D department.
- In our simulation model, we assume that every ordered component is qualitatively good, and can be used in production. In practice, it can exceptionally happen that components need to be sent back to the supplier because of defects. This means that the obtained sub-optimal re order levels and order quantities could be slightly higher for components that sometimes contain defects.
- In our simulation model we assume that in every opportunity/PO only one COTS product is requested. In practice, multiple (different) products can be requested in an opportunity/PO. This assumption influences the ease of forecasting for the purchasing department. Generally, the pipeline will contain more product opportunities when multiple products can be requested, which makes it easier for the purchasing department to anticipate potential POs. However, when the purchasing department anticipates an opportunity with many products that gets lost, it can lead to excess inventory.

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Appendices

Appendix 1: List of Figures & Tables

Chapter 1	Figure 1	Scope of research
	Figure 2	Problem cluster
Chapter 2	Figure 3	Sales flowchart
	Table 1	Sales flowchart steps
	Figure 4	Purchasing flowchart
	Table 2	Purchasing flowchart steps
	Figure 5	PO structure
	Figure 6	Order processing flowchart
	Table 3	Order processing flowchart steps
	Figure 7	Collected data
	Table 4	Explanation collected data
	Figure 8	Total lead time distribution
	Table 5	Delivery speed performance
	Figure 9	Violation of desired lead time
	Table 6	Delivery reliability performance
	Figure 10	Violation of quoted lead time
	Figure 11	Overview of problems
	Figure 12	Updating Minox inventory levels
	Figure 13	Distribution of time between quotation and order date
	Table 7	Statuses Goldmine
Chapter 3	Figure 14	Tool Functionalities
	Table 8	Information to combine
	Figure 15	Strategic Alignment Model [Henderson et al., 1999]
	Table 9	Lot sizing methods [Baciarello et al., 2013]
	Table 10	Information needs and information sources
Chapter 4	Figure 16	Triangular vs PERT
	Figure 17	Simulation flowchart sales department
	Figure 18	Total number of opportunities in the pipeline
	Figure 19	Influence of λ on the average number of opportunities
	Table 11	Relative frequency of opportunity arrivals
	Figure 20	Probability density function Closing date “Days Ahead”
	Figure 21	QQ-plot Closing date “Days Ahead”
	Table 12	Chi-Test Closing date “Days Ahead”
	Figure 22	Assigned probability status on entry
	Figure 23	Percentage won if opportunity leaves on closing date
	Figure 24	Probability density function “Number of days between intermediate updates”
	Figure 25	QQ-plot Number of days between intermediate updates
	Table 13	Chi-Test Number of days between intermediate updates
	Figure 26	Possible actions during an intermediate update per probability status
	Figure 27	Probability density function “Shift of closing date”
	Figure 28	QQ-plot “Shift of closing date”
	Table 14	Chi-Test “Shift of closing date”
	Figure 29	Update of assigned probability status
	Figure 30	Simulation flowchart Order Processing & Purchasing
	Table 15	Simplified BOM input table
	Figure 31	Probability density function “Production Time”
	Figure 32	Probability density function “Supplier Lead Time”
	Figure 33	Root frame simulation model
	Figure 34	Sales department simulation model
	Figure 35	Order processing department simulation model
	Figure 36	FireWire cable inventory frame (C1 + C2)
	Figure 37	Standard inventory frame (C3 - C82)
	Figure 38	Production Frame
	Table 16	Classification of inventory items
	Figure 39	Welch graphical approach
	Table 17	Nr of replications delivery speed
	Table 18	Nr of replications; Objective value purchasing
	Figure 40	Experimental design purchasing policies
	Figure 41	Development of delivery speed
	Figure 42	Development of objective value
	Table 19	Nr of replications delivery reliability
	Table 20	Nr of replications; Objective value due date quotation
	Figure 43	Experimental design due date quotation
	Table 21	Purchasing experiments
	Figure 44	Sub-optimal objective values per purchasing experiment
	Figure 45	Most promising purchasing experiments
	Table 22	Due date quotation experiments
	Figure 46	Sub-optimal objective values per due date quotation experiment
	Figure 47	Most promising due date quotation experiments

Appendix 2: Goldmine pipeline overview

March 2017

Act. Mgr.	Close Date	Last f/u	Company/Contact Person	Product/Service	Quote Ref.	Code	Prob.	Stage	Potential	Forcasted
PAUL	03/10/17	08/01/16	[redacted]	[redacted]	[redacted]	[redacted]	20%		[redacted]	[redacted]
PAUL	03/10/17	09/09/16	[redacted]	[redacted]	[redacted]	[redacted]	40%		[redacted]	[redacted]
PAUL	03/13/17	10/07/16	[redacted]	[redacted]	[redacted]	[redacted]	40%		[redacted]	[redacted]
PAUL	03/14/17	09/08/16	[redacted]	[redacted]	[redacted]	[redacted]	50%		[redacted]	[redacted]
PAUL	03/17/17	09/08/16	[redacted]	[redacted]	[redacted]	[redacted]	20%		[redacted]	[redacted]
PAUL	03/17/17	10/17/16	[redacted]	[redacted]	[redacted]	[redacted]	9%		[redacted]	[redacted]
PAUL	03/17/17	10/17/16	[redacted]	[redacted]	[redacted]	[redacted]	9%		[redacted]	[redacted]
PAUL	03/17/17	10/17/16	[redacted]	[redacted]	[redacted]	[redacted]	9%		[redacted]	[redacted]
PAUL	03/17/17	10/14/16	[redacted]	[redacted]	[redacted]	[redacted]	20%		[redacted]	[redacted]
PAUL	03/17/17	12/06/16	[redacted]	[redacted]	[redacted]	[redacted]	50%		[redacted]	[redacted]
PAUL	03/17/17	11/02/16	[redacted]	[redacted]	[redacted]	[redacted]	70%		[redacted]	[redacted]
PAUL	03/20/17	12/06/16	[redacted]	[redacted]	[redacted]	[redacted]	30%		[redacted]	[redacted]
PAUL	03/24/17	12/06/16	[redacted]	[redacted]	[redacted]	[redacted]	50%		[redacted]	[redacted]
PAUL	03/24/17	11/01/16	[redacted]	[redacted]	[redacted]	[redacted]	30%		[redacted]	[redacted]

April 2017

Act. Mgr.	Close Date	Last f/u	Company/Contact Person	Product/Service	Quote Ref.	Code	Prob.	Stage	Potential	Forcasted
PAUL	04/01/17	09/08/16	[redacted]	[redacted]	[redacted]	[redacted]	20%		[redacted]	[redacted]
PAUL	04/07/17	12/06/16	[redacted]	[redacted]	[redacted]	[redacted]	30%		[redacted]	[redacted]
PAUL	04/11/17	09/08/16	[redacted]	[redacted]	[redacted]	[redacted]	30%		[redacted]	[redacted]
PAUL	04/21/17	07/06/16	[redacted]	[redacted]	[redacted]	[redacted]	20%		[redacted]	[redacted]
PAUL	04/21/17	11/08/16	[redacted]	[redacted]	[redacted]	[redacted]	20%		[redacted]	[redacted]
PAUL	04/21/17	07/04/16	[redacted]	[redacted]	[redacted]	[redacted]	60%		[redacted]	[redacted]
PAUL	04/21/17	12/06/16	[redacted]	[redacted]	[redacted]	[redacted]	60%		[redacted]	[redacted]

Appendix 3: Arrival frequency of COTS products

COTS product (Minox)	Expected Sales
10.007	0.1
10.003	0.1
10.004	0.01
10.006	5
10.0061	0.01
10.0062	5
10.0063	0.01
10.0064	0.7
10.0065	0.01
10.0183	0.01
10.0184	0.01
10.018	0.01
10.0181	2.5
10.0182	0.01
10.0187	0.01
10.0185	0.01
10.0186	0.01
10.0192	0.01
10.019	8
10.0191	0.01
10.008	2
10.0081	1.8
10.0082	0.01
10.009	2
10.0091	0.01
10.015	1
10.0083	1
10.01812	0.01
10.0189	0.01
10.01810	0.01
10.0188	2.8
10.01811	0.01
10.01815	0.01
10.01813	0.01
10.01814	0.01
10.01818	0.01
10.01816	0.5
10.01817	0.01
13.002	10
13.003	4
14.002	0.02
14.001	8
12.005	0.02
65.005	0.01
65.004	0.01
65.003	0.01
65.030	0.5
65.007	0.5
65.0301	2
65.0302	2.2
65.031	0.02
65.0311	0.02
650,312	2.2
65.0091	0.02
65.0092	2
65.0093	2
65.0094	2.2
21.005	8
21.009	3
21.006	8

Appendix 4.1: Sub-optimal configuration Purchasing λ=0.4 (Exp 1 - 8)

Nr	Minox	Class	X Exp1	Q Exp1	X Exp2	Q Exp2	X Exp3	Q Exp3	X Exp4	Q Exp4	X Exp5	Q Exp5	X Exp6	Q Exp6	X Exp7	Q Exp7	X Exp8	Q Exp8
1	65.042	B	11	12	13	6	5	11	5	5	11	11	13	6	5	11	6	5
2	65.025	B	23	31	22	8	7	30	9	8	22	31	22	8	7	30	8	8
3	999.21.006	B	3	3	3	2	1	2	2	1	3	2	4	1	1	3	2	2
4	999.21.005	B	3	3	3	4	1	2	1	3	3	5	4	1	2	2	2	1
5	999.21.009	A	2	2	2	1	2	1	2	3	2	1	2	0	2	1	2	0
6	999.20.020	A	2	1	2	1	2	1	2	1	2	2	2	0	2	0	2	1
7	999.20.019	A	1	1	1	1	2	0	1	3	0	7	1	4	2	1	2	0
8	999.20.018	A	1	1	1	0	1	0	1	0	1	2	1	2	0	3	1	1
9	999.20.015	A	1	5	2	4	1	6	2	4	1	5	2	1	3	2	2	4
10	999.20.014	A	1	1	2	0	1	1	1	2	2	1	1	2	2	0	1	1
11	999.20.0111	A	2	1	2	0	2	1	2	0	2	1	2	0	2	1	2	0
12	999.20.011	B	6	5	6	2	2	5	2	3	5	4	5	4	2	5	2	3
13	999.20.0121	A	1	1	1	2	2	0	1	2	1	3	1	2	2	1	2	0
14	999.20.012	A	1	1	3	1	3	0	2	2	1	7	3	1	2	3	3	0
15	999.20.009	A	1	2	0	4	0	2	1	1	1	0	1	2	1	0	1	1
16	999.20.008	A	1	1	0	2	0	1	0	1	1	0	0	2	1	1	0	1
17	999.20.006	A	1	1	2	0	2	0	2	0	2	1	2	1	1	4	1	1
18	999.20.005	A	1	1	1	0	1	1	1	1	0	4	1	0	1	1	1	0
19	999.20.004	A	2	3	2	2	2	3	2	2	3	1	2	4	3	2	2	2
20	999.20.003	A	3	4	2	3	2	3	2	3	2	2	2	3	2	3	3	1
21	999.20.002	A	1	1	1	1	0	1	1	0	1	0	0	1	1	0	1	0
22	999.20.0011	A	1	1	1	0	0	2	0	1	1	0	1	0	0	1	1	0
23	999.14.002	A	1	1	1	0	1	0	0	1	1	1	0	1	1	0	1	0
24	999.14.001	B	3	3	4	3	1	2	2	2	3	2	3	5	1	2	2	2
25	999.13.002	B	5	3	4	2	1	3	2	3	4	2	4	2	1	3	1	3
26	999.13.003	A	2	3	2	4	2	2	2	2	2	2	2	3	2	2	1	6
27	999.12.005	A	1	1	1	1	1	0	0	1	0	2	1	0	0	2	1	0
28	999.10.020	A	4	3	3	3	3	3	3	2	3	3	3	3	4	1	4	1
29	999.10.019	B	4	1	4	1	1	2	2	0	3	1	4	2	2	2	2	1
30	999.10.0191	A	1	0	1	0	0	2	0	1	1	1	1	0	1	1	0	1
31	999.10.018	B	7	11	7	2	2	10	3	4	6	10	6	2	2	10	3	2
32	999.10.015	A	1	1	1	2	1	0	1	2	2	0	1	2	1	1	1	0
33	999.10.013	A	2	1	1	2	2	1	1	2	2	2	1	3	2	1	2	1
34	999.10.012	A	1	1	1	0	0	2	1	0	1	0	1	1	1	0	1	0
35	999.10.008	A	2	3	2	2	2	4	2	2	2	4	2	4	2	3	2	5
36	999.10.007	A	1	1	0	1	1	0	1	0	1	0	1	1	0	1	1	0
37	999.10.006	B	4	8	4	2	1	8	2	3	3	7	4	2	1	9	2	3
38	999.10.004	A	1	1	0	1	1	0	1	0	1	1	0	1	1	0	0	1
39	999.10.003	A	1	1	1	1	1	0	1	1	0	1	1	0	0	1	1	0
40	65.04	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
41	65.029	B	4	8	3	100	1	7	1	100	3	7	3	100	0	7	0	100
42	65.026	B	17	16	18	8	9	15	12	6	16	16	17	9	9	15	12	4
43	65.0091	B	39	37	43	15	9	37	13	17	39	37	41	18	9	37	14	14
44	65.007	A	1	3	1	2	1	2	1	2	2	1	2	1	1	3	2	0
45	65.005	A	1	1	1	0	1	0	1	0	1	0	1	1	1	0	1	0
46	65.004	B	4	7	4	4	2	8	2	3	4	7	4	2	2	7	3	2
47	54.2051	B	9	7	8	4	3	6	4	5	8	6	8	4	3	10	3	6
48	54.201	B	2	0	1	51	0	0	0	50	2	0	1	50	0	0	0	50
49	54.023	B	2	3	3	0	1	2	1	0	1	7	2	3	1	2	1	1
50	54.02	A	1	0	0	0	0	0	0	0	0	50	0	50	0	50	0	50
51	54.017	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
52	54.016	A	1	1	1	1	1	0	1	0	1	0	1	0	1	0	1	0
53	54.011	A	1	1	0	1	0	0	0	0	1	0	1	0	1	0	0	0
54	54.0062	B	1	0	0	100	0	0	0	100	0	0	1	100	0	0	0	100
55	54.024	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
56	54.0201	B	1	1	0	100	0	0	0	100	0	0	0	100	0	0	0	100
57	54.021	B	1	0	0	100	0	0	0	100	0	0	0	100	0	0	0	100
58	54.022	B	1	0	1	30	1	0	0	30	0	2	1	30	0	0	0	30
59	54.005	A	1	0	0	1	0	0	1	0	0	2	1	0	0	1	0	0
60	54.004	A	1	1	1	1	1	0	0	0	1	0	0	0	1	0	0	1
61	54.003	A	1	1	1	0	1	2	1	2	1	0	1	1	1	2	1	0
62	54.002	A	1	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0
63	54.001	A	1	1	0	1	0	2	1	0	0	1	0	1	1	0	1	1
64	124.54.001	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
65	54.023	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
66	53.004	A	1	1	1	2	1	0	0	3	1	0	1	1	1	0	1	0
67	53.003	A	4	3	4	2	4	2	4	2	4	1	4	1	5	1	4	1
68	53.002	A	3	2	3	1	2	1	3	1	3	2	3	2	3	1	2	2
69	53.001	B	5	4	5	2	2	3	3	0	4	3	5	0	2	3	3	0
70	51.004	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	51.003	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	45.2	B	1	2	1	1	0	5	1	1	1	4	1	1	1	1	1	3
73	41.068	B	0	1	0	2	0	0	0	2	0	0	0	2	0	0	0	2
74	41.062	B	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1
75	41.056	B	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1
76	41.045	A	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	1
77	30.007	B	2	4	2	2	0	4	1	0	2	4	2	1	1	3	1	1
78	30.005	A	1	1	0	3	1	0	1	1	1	2	1	0	1	0	1	0
79	30.004	B	1	1	1	0	1	0	1	2	1	0	1	3	1	0	1	0
80	41.051	B	46	45	45	100	19	44	19	100	45	44	45	100	19	44	19	100
81	123.41.001	B	15	17	14	100	7	17	7	100	14	17	14	100	7	16	7	100
82	123.41.002	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100

Appendix 4.2: Sub-optimal configuration Purchasing λ=0.4 (Exp 9 – 16)

Nr	Minox	Class	X Exp9	Q Exp9	X Exp10	Q Exp10	X Exp11	Q Exp11	X Exp12	Q Exp12	X Exp13	Q Exp13	X Exp14	Q Exp14	X Exp15	Q Exp15	X Exp16	Q Exp16
1	65.042	B	10	11	10	11	5	11	5	6	11	11	11	5	5	11	6	5
2	65.025	B	22	30	22	30	7	30	8	8	22	30	22	8	7	30	8	9
3	999.21.006	B	3	2	3	4	2	2	2	1	3	4	4	3	1	3	2	2
4	999.21.005	B	3	2	3	4	1	2	2	2	3	3	4	1	1	2	1	2
5	999.21.009	A	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1
6	999.20.020	A	1	1	1	3	1	0	1	0	1	3	1	0	1	0	1	1
7	999.20.019	A	1	0	1	1	1	0	1	2	1	0	0	3	1	1	1	1
8	999.20.018	A	1	0	0	2	0	1	1	0	0	1	1	0	0	1	1	1
9	999.20.015	A	1	4	1	6	1	5	1	4	1	1	1	5	1	1	1	2
10	999.20.014	A	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1
11	999.20.0111	A	1	0	0	2	1	0	1	0	1	0	1	1	1	0	1	1
12	999.20.011	B	5	4	6	4	1	6	3	3	6	4	6	2	2	6	2	3
13	999.20.0121	A	0	1	0	2	0	1	1	1	0	2	1	1	0	1	1	1
14	999.20.012	A	1	1	1	1	1	0	1	0	2	0	2	1	2	1	1	1
15	999.20.009	A	0	1	0	2	1	2	1	1	1	1	0	2	1	0	1	1
16	999.20.008	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
17	999.20.006	A	0	4	1	3	1	2	1	0	1	1	1	1	1	1	1	2
18	999.20.005	A	1	0	1	1	0	2	1	1	1	0	0	2	1	0	1	1
19	999.20.004	A	1	2	1	5	1	4	1	2	1	1	1	1	1	3	1	2
20	999.20.003	A	1	5	1	5	1	4	1	4	1	1	1	1	1	2	1	2
21	999.20.002	A	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1
22	999.20.0011	A	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1
23	999.14.002	A	0	0	0	0	1	0	0	1	0	0	1	0	1	0	1	1
24	999.14.001	B	3	2	3	3	2	2	1	3	3	2	3	4	1	2	1	3
25	999.13.002	B	4	2	4	2	2	3	1	3	4	2	4	2	1	4	1	3
26	999.13.003	A	1	2	1	2	1	4	1	2	1	4	1	3	1	2	1	3
27	999.12.005	A	0	0	0	1	1	1	1	0	0	1	1	0	0	1	1	1
28	999.10.020	A	1	2	1	2	1	5	1	2	1	2	1	3	1	4	1	2
29	999.10.019	B	4	0	4	1	2	0	2	0	4	0	4	1	2	0	2	1
30	999.10.0191	A	1	0	1	0	0	1	0	0	0	1	0	1	1	0	1	0
31	999.10.018	B	6	10	6	10	2	10	3	2	6	10	6	2	2	10	3	3
32	999.10.015	A	1	0	0	2	0	2	1	1	1	0	1	0	1	1	1	1
33	999.10.013	A	1	3	1	0	1	0	1	3	1	2	1	3	1	1	1	2
34	999.10.012	A	0	1	1	0	1	0	1	0	1	1	1	0	1	0	1	1
35	999.10.008	A	1	2	1	2	1	6	1	3	1	3	1	4	1	4	1	3
36	999.10.007	A	0	1	0	0	0	1	0	0	0	0	0	0	0	2	1	1
37	999.10.006	B	3	7	3	7	1	10	1	4	3	7	3	4	1	8	1	3
38	999.10.004	A	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	1
39	999.10.003	A	0	0	0	1	1	0	1	0	0	0	0	1	0	1	1	1
40	65.04	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
41	65.029	B	3	7	3	7	0	7	0	100	3	7	3	100	0	8	1	100
42	65.026	B	16	15	16	16	9	15	12	5	16	15	19	4	9	16	10	5
43	65.0091	B	38	36	38	38	8	36	9	18	38	37	42	16	8	36	9	14
44	65.007	A	1	3	1	3	1	5	1	2	1	0	1	0	1	1	1	0
45	65.005	A	1	0	1	0	1	0	1	0	1	0	1	0	0	2	1	1
46	65.004	B	4	6	3	7	1	7	2	2	4	6	4	2	1	6	2	3
47	54.2051	B	8	6	8	6	3	8	3	4	8	6	8	4	3	6	3	5
48	54.201	B	1	0	1	0	0	0	0	50	2	0	1	50	0	0	1	50
49	54.023	B	2	3	2	2	1	2	1	1	2	3	2	0	1	2	1	1
50	54.02	A	0	0	0	0	0	0	0	0	0	50	0	50	0	50	1	50
51	54.017	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	1	100
52	54.016	A	1	1	1	0	1	0	1	0	1	0	1	2	1	0	1	1
53	54.011	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
54	54.0062	B	0	0	0	0	0	0	0	100	0	0	0	100	0	0	0	100
55	54.024	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	1	100
56	54.0201	B	0	0	0	0	0	0	0	100	0	0	0	100	0	0	0	100
57	54.021	B	0	0	0	0	0	0	0	100	0	0	0	100	0	0	0	100
58	54.022	B	0	0	1	0	0	0	0	30	0	1	0	31	0	0	1	30
59	54.005	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
60	54.004	A	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1
61	54.003	A	1	0	1	1	1	0	1	0	1	0	1	1	1	1	1	1
62	54.002	A	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
63	54.001	A	0	0	0	1	1	0	1	0	0	0	1	0	0	1	1	1
64	124.54.001	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	1	100
65	54.023	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	1	100
66	53.004	A	1	0	1	0	0	3	1	2	0	1	1	0	0	2	1	0
67	53.003	A	1	3	2	2	2	3	2	2	2	3	2	1	2	2	2	2
68	53.002	A	1	1	1	2	1	1	1	1	1	4	2	1	2	2	1	2
69	53.001	B	4	3	4	3	2	3	3	0	4	3	5	0	2	3	3	1
70	51.004	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
71	51.003	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	45.2	B	1	1	1	1	1	2	0	4	1	1	1	1	1	1	1	2
73	41.068	B	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	3
74	41.062	B	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	2
75	41.056	B	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	2
76	41.045	A	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	2
77	30.007	B	2	4	2	3	0	3	1	0	1	5	2	0	1	4	1	1
78	30.005	A	0	0	0	1	0	1	0	1	0	1	1	0	1	0	0	1
79	30.004	B	1	0	1	0	1	0	0	2	1	0	1	0	1	0	1	1
80	41.051	B	45	44	45	44	19	44	19	100	45	44	45	100	19	44	20	100
81	123.41.001	B	14	16	14	16	7	16	7	100	14	16	14	100	7	16	8	100
82	123.41.002	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	1	100

Appendix 5.1: Sub-optimal configuration Purchasing λ=1 (Exp 1 - 8)

Nr	Minox	Class	X Exp1	Q Exp1	X Exp2	Q Exp2	X Exp3	Q Exp3	X Exp4	Q Exp4	X Exp5	Q Exp5	X Exp6	Q Exp6	X Exp7	Q Exp7	X Exp8	Q Exp8
1	65.042	B	17	18	17	9	7	17	7	9	16	18	17	11	7	17	7	8
2	65.025	B	34	47	35	15	11	46	14	15	34	46	35	15	11	46	11	14
3	999.21.006	B	5	5	6	3	2	5	2	4	5	5	6	3	2	4	2	3
4	999.21.005	B	5	5	6	2	2	5	2	6	5	5	6	3	1	7	2	3
5	999.21.009	A	3	3	3	2	3	3	3	2	3	2	4	1	3	1	3	2
6	999.20.020	A	3	2	3	2	3	2	3	3	3	2	3	2	3	3	4	1
7	999.20.019	A	1	2	2	1	2	1	2	1	2	2	2	0	1	4	1	3
8	999.20.018	A	1	1	1	0	1	0	1	1	1	2	1	1	1	0	1	1
9	999.20.015	A	2	7	2	7	3	6	2	9	3	4	2	8	2	8	3	4
10	999.20.014	A	2	2	2	1	2	1	2	1	2	0	2	1	2	1	2	1
11	999.20.0111	A	1	1	2	2	2	1	2	1	2	0	2	1	2	0	2	1
12	999.20.011	B	9	8	8	6	3	7	2	8	9	7	9	5	3	7	3	5
13	999.20.0121	A	1	1	2	2	2	0	2	1	1	2	1	2	1	2	0	4
14	999.20.012	A	2	1	3	3	3	3	4	2	3	4	3	3	4	0	4	2
15	999.20.009	A	1	3	1	4	1	4	1	3	1	2	1	3	2	1	1	0
16	999.20.008	A	1	1	1	1	0	1	1	0	0	2	1	1	1	1	1	0
17	999.20.006	A	2	2	2	2	2	1	2	3	2	3	2	2	1	4	2	2
18	999.20.005	A	1	2	0	4	1	2	1	1	1	3	1	1	1	1	1	0
19	999.20.004	A	3	5	3	5	4	5	3	5	3	6	4	3	4	3	4	2
20	999.20.003	A	4	6	3	5	4	5	3	5	4	2	4	2	4	2	3	5
21	999.20.002	A	1	1	0	2	0	1	1	1	0	1	0	3	1	0	0	1
22	999.20.0011	A	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
23	999.14.002	A	1	1	1	1	1	2	1	1	0	2	1	0	1	1	1	0
24	999.14.001	B	5	5	5	6	2	4	2	6	5	4	5	6	2	4	1	7
25	999.13.002	B	7	5	6	5	2	4	2	6	6	4	6	5	3	4	2	5
26	999.13.003	A	3	5	3	5	3	5	3	5	3	4	3	4	2	5	3	6
27	999.12.005	A	1	1	1	2	1	0	1	0	1	1	1	1	1	1	1	1
28	999.10.020	A	6	4	6	3	6	4	6	3	6	4	6	3	5	4	5	4
29	999.10.019	B	6	2	6	1	2	2	3	1	6	1	7	1	2	1	3	1
30	999.10.0191	A	1	0	1	0	1	1	1	1	1	2	1	1	0	2	0	2
31	999.10.018	B	10	16	10	7	3	15	3	8	9	15	10	6	2	15	4	6
32	999.10.015	A	1	2	2	1	1	1	1	5	1	3	2	0	2	0	2	2
33	999.10.013	A	3	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2
34	999.10.012	A	1	2	1	2	1	1	1	2	2	1	2	1	1	2	1	0
35	999.10.008	A	3	4	3	3	3	3	3	4	3	5	3	4	3	4	4	4
36	999.10.007	A	1	1	1	1	1	0	1	2	1	0	0	2	0	2	0	1
37	999.10.006	B	6	12	6	5	1	11	2	5	6	11	6	7	1	11	2	5
38	999.10.004	A	1	1	1	0	1	0	1	0	1	0	1	0	1	0	1	0
39	999.10.003	A	1	1	1	2	1	1	0	2	0	3	1	1	1	0	0	1
40	65.04	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
41	65.029	B	6	10	5	101	0	9	0	99	7	10	5	101	0	9	0	100
42	65.026	B	26	24	28	12	18	23	18	8	26	24	28	9	18	23	18	8
43	65.0091	B	58	56	62	30	13	55	13	25	58	58	61	30	13	55	13	25
44	65.007	A	2	4	2	3	2	3	2	3	3	0	2	1	2	0	2	0
45	65.005	A	1	1	1	0	1	1	1	1	1	1	1	0	1	0	0	2
46	65.004	B	6	10	5	8	2	9	2	5	6	9	5	8	2	9	2	5
47	54.2051	B	13	11	13	10	6	10	6	9	12	12	14	9	5	11	5	9
48	54.201	B	3	0	3	51	0	0	0	49	3	0	3	50	0	0	0	50
49	54.023	B	3	5	3	2	1	5	1	2	3	5	3	2	1	5	1	2
50	54.02	A	1	0	0	0	0	0	0	0	0	50	0	50	0	50	0	50
51	54.017	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
52	54.016	A	1	2	1	1	1	1	1	2	1	0	1	0	1	0	1	0
53	54.011	A	1	1	0	0	0	0	1	0	0	1	1	0	0	0	1	0
54	54.0062	B	2	0	1	106	0	0	0	99	3	1	2	101	0	0	0	100
55	54.024	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
56	54.0201	B	1	1	0	100	0	0	0	99	0	0	0	100	0	0	0	100
57	54.021	B	1	0	0	100	0	0	0	99	0	0	0	100	0	0	0	100
58	54.022	B	2	0	1	30	0	0	0	29	1	0	1	30	0	0	0	29
59	54.005	A	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1
60	54.004	A	1	1	0	2	0	1	0	1	1	0	1	1	0	0	1	0
61	54.003	A	2	1	2	0	1	1	1	1	1	2	2	1	2	0	2	0
62	54.002	A	1	0	1	0	1	1	1	0	0	2	1	1	0	1	0	1
63	54.001	A	1	1	1	1	1	0	1	1	0	2	1	0	1	0	0	1
64	124.54.001	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
65	54.023	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
66	53.004	A	2	1	1	1	2	0	1	1	2	1	2	0	2	0	2	1
67	53.003	A	6	4	7	4	6	5	6	3	7	2	7	2	7	2	6	4
68	53.002	A	4	3	4	5	4	2	4	2	4	2	4	2	4	2	4	3
69	53.001	B	7	6	9	1	4	5	5	0	7	7	8	2	4	5	5	0
70	51.004	B	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
71	51.003	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	45.2	B	1	3	1	2	0	4	1	2	1	2	1	6	1	3	1	2
73	41.068	B	0	2	0	4	0	1	0	4	0	1	0	4	0	1	0	4
74	41.062	B	0	2	0	2	0	1	0	2	0	1	0	2	0	1	0	2
75	41.056	B	0	1	0	2	0	0	0	2	0	0	0	2	0	0	0	2
76	41.045	A	0	1	0	0	0	0	0	0	0	2	0	2	0	2	0	2
77	30.007	B	3	6	2	2	0	5	0	1	2	5	3	1	0	5	0	1
78	30.005	A	1	1	1	1	0	4	0	3	0	3	1	2	1	1	1	1
79	30.004	B	2	2	1	1	0	1	0	1	1	3	1	1	0	1	0	1
80	41.051	B	69	67	69	133	39	66	39	129	69	66	69	130	39	66	39	129
81	123.41.001	B	23	26	24	106	14	25	14	104	22	25	25	105	14	25	14	104
82	123.41.002	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100

Appendix 5.2: Sub-optimal configuration Purchasing λ=1 (Exp 9 – 16)

Nr	Minox	Class	X Exp9	Q Exp9	X Exp10	Q Exp10	X Exp11	Q Exp11	X Exp12	Q Exp12	X Exp13	Q Exp13	X Exp14	Q Exp14	X Exp15	Q Exp15	X Exp16	Q Exp16
1	65.042	B	16	17	18	8	7	17	7	9	16	17	17	9	7	17	8	9
2	65.025	B	33	46	34	15	11	46	13	14	34	46	34	17	11	46	12	15
3	999.21.006	B	5	4	5	4	2	4	2	4	5	7	6	2	2	5	2	3
4	999.21.005	B	5	5	5	3	2	4	2	6	5	4	5	3	2	4	2	3
5	999.21.009	A	1	3	1	2	1	2	1	2	1	3	1	2	2	1	1	2
6	999.20.020	A	1	3	1	1	1	1	1	2	2	1	2	1	1	2	1	2
7	999.20.019	A	1	2	1	1	1	2	1	1	1	0	1	2	1	1	1	1
8	999.20.018	A	0	2	1	0	0	2	1	1	0	2	0	2	0	2	1	1
9	999.20.015	A	1	6	1	6	1	7	1	6	1	3	1	5	1	3	1	4
10	999.20.014	A	0	4	1	2	1	1	1	1	1	2	1	1	1	1	1	1
11	999.20.0111	A	1	0	0	2	1	0	1	0	1	1	1	0	1	1	1	1
12	999.20.011	B	8	8	8	7	3	7	4	5	9	7	8	7	3	9	3	6
13	999.20.0121	A	1	0	1	0	1	1	0	2	0	2	1	1	1	1	1	1
14	999.20.012	A	1	3	1	1	1	1	1	4	1	3	2	0	1	3	1	1
15	999.20.009	A	1	2	0	2	0	2	1	3	1	0	1	1	1	2	1	1
16	999.20.008	A	0	0	0	1	0	0	0	0	1	0	0	0	1	0	1	1
17	999.20.006	A	1	1	1	2	0	5	1	1	1	2	1	2	1	2	1	3
18	999.20.005	A	1	1	1	1	0	2	0	3	0	2	1	0	1	1	1	1
19	999.20.004	A	1	6	1	4	1	4	1	4	1	4	1	10	2	3	1	3
20	999.20.003	A	1	6	1	5	1	5	1	6	2	2	2	2	1	4	1	3
21	999.20.002	A	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1
22	999.20.0011	A	1	0	1	0	0	0	0	1	1	0	1	0	1	0	1	1
23	999.14.002	A	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	1
24	999.14.001	B	5	4	4	9	2	4	2	5	5	4	5	5	2	4	2	6
25	999.13.002	B	6	4	6	5	2	4	2	5	6	4	6	5	3	4	2	6
26	999.13.003	A	1	6	1	4	1	4	1	4	1	6	1	4	1	4	1	5
27	999.12.005	A	0	2	1	1	1	0	1	0	0	1	0	1	1	0	1	1
28	999.10.020	A	2	3	2	3	2	3	2	4	2	4	2	4	2	3	2	4
29	999.10.019	B	5	2	5	4	2	2	3	2	5	4	6	2	3	1	3	2
30	999.10.0191	A	0	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0
31	999.10.018	B	9	15	10	7	3	15	4	6	9	15	10	6	2	15	3	6
32	999.10.015	A	1	1	1	1	1	1	1	1	1	2	1	0	1	0	1	1
33	999.10.013	A	1	5	1	2	1	1	1	3	1	2	1	2	1	5	1	3
34	999.10.012	A	1	1	0	2	0	2	1	1	1	0	1	1	1	2	1	1
35	999.10.008	A	1	4	1	3	1	3	1	4	1	6	1	4	1	6	1	5
36	999.10.007	A	1	0	1	0	1	0	0	1	1	0	0	1	0	1	1	1
37	999.10.006	B	6	11	6	5	1	11	2	7	5	11	6	7	1	11	2	5
38	999.10.004	A	0	1	1	0	1	0	0	1	0	1	0	1	0	1	1	1
39	999.10.003	A	0	2	1	0	0	1	0	1	0	1	1	0	1	1	1	1
40	65.04	A	0	0	0	0	0	0	0	0	0	100	0	100	0	99	0	100
41	65.029	B	5	9	6	100	0	9	0	100	6	10	6	100	0	9	1	100
42	65.026	B	25	23	27	11	18	23	18	8	25	23	27	12	18	23	19	9
43	65.0091	B	58	57	58	27	13	55	13	25	59	57	62	26	13	55	14	26
44	65.007	A	1	10	1	3	1	3	1	3	1	0	1	1	1	0	1	0
45	65.005	A	1	0	0	1	0	1	1	1	1	0	1	1	1	1	1	1
46	65.004	B	6	9	6	6	2	9	2	5	6	9	6	5	2	9	3	6
47	54.2051	B	13	11	14	8	5	10	6	9	13	10	12	12	4	14	5	9
48	54.201	B	3	0	3	53	0	0	0	50	3	0	3	50	0	0	1	50
49	54.023	B	2	5	3	2	1	4	1	1	3	6	3	2	1	4	1	2
50	54.02	A	0	0	0	0	0	0	0	0	0	50	0	50	0	49	1	50
51	54.017	A	0	0	0	0	0	0	0	0	0	100	0	100	0	99	1	100
52	54.016	A	1	2	1	1	1	1	0	2	0	3	1	0	1	0	1	1
53	54.011	A	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0
54	54.0062	B	1	2	2	102	0	0	0	100	3	0	2	101	0	0	0	100
55	54.024	A	0	0	0	0	0	0	0	0	0	100	0	100	0	99	1	100
56	54.0201	B	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0	100
57	54.021	B	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0	100
58	54.022	B	1	0	1	30	1	0	0	30	2	0	1	30	1	0	1	30
59	54.005	A	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
60	54.004	A	1	0	1	0	0	0	1	0	1	0	0	1	1	0	1	1
61	54.003	A	1	0	1	0	0	4	1	0	1	0	1	0	1	1	1	1
62	54.002	A	0	1	1	0	0	1	0	0	0	0	0	0	0	1	1	0
63	54.001	A	0	1	0	1	0	1	1	0	1	0	1	0	0	2	1	1
64	124.54.001	A	0	0	0	0	0	0	0	0	0	100	0	100	0	99	1	100
65	54.023	A	0	0	0	0	0	0	0	0	0	100	0	100	0	99	1	100
66	53.004	A	1	0	1	0	1	0	1	0	1	0	1	0	1	0	2	0
67	53.003	A	2	7	3	3	3	3	3	3	4	3	3	5	3	4	3	3
68	53.002	A	1	4	2	4	2	3	2	2	2	2	2	2	2	5	2	3
69	53.001	B	7	5	9	1	4	5	4	2	7	7	9	0	4	5	5	1
70	51.004	B	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	2
71	51.003	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	45.2	B	1	2	1	4	0	3	1	3	1	4	1	2	1	2	1	3
73	41.068	B	0	1	0	4	0	1	0	4	0	1	0	4	0	1	0	5
74	41.062	B	0	1	0	2	0	1	0	2	0	1	0	2	0	1	0	3
75	41.056	B	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	3
76	41.045	A	0	0	0	0	0	0	0	0	0	2	0	2	0	2	0	3
77	30.007	B	2	5	2	1	0	5	0	1	2	5	3	1	0	5	0	2
78	30.005	A	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	2
79	30.004	B	1	2	1	1	0	1	0	1	1	1	1	1	0	1	0	2
80	41.051	B	68	66	68	130	39	66	39	130	68	66	69	129	39	66	40	130
81	123.41.001	B	24	25	25	105	14	25	14	104	24	28	24	106	14	25	15	105
82	123.41.002	A	0	0	0	0	0	0	0	0	0	100	0	100	0	99	1	100

Appendix 6.1: Sub-optimal configuration Purchasing λ=1.6 (Exp 1 - 8)

Nr	Minox	Class	X Exp1	Q Exp1	X Exp2	Q Exp2	X Exp3	Q Exp3	X Exp4	Q Exp4	X Exp5	Q Exp5	X Exp6	Q Exp6	X Exp7	Q Exp7	X Exp8	Q Exp8
1	65.042	B	22	23	23	9	8	22	9	10	21	22	23	9	8	22	8	9
2	65.025	B	44	61	49	18	12	60	16	18	45	63	47	20	12	60	15	17
3	999.21.006	B	7	7	7	7	3	6	3	2	6	10	7	5	2	6	3	3
4	999.21.005	B	7	7	7	5	2	6	3	3	7	7	7	4	2	6	3	3
5	999.21.009	A	4	4	3	3	3	3	3	3	4	2	4	3	4	2	4	3
6	999.20.020	A	4	3	4	3	4	3	4	2	5	1	5	1	4	2	4	2
7	999.20.019	A	1	4	2	3	2	4	2	3	3	1	3	0	3	1	2	4
8	999.20.018	A	1	1	1	1	1	1	1	2	1	3	2	1	2	1	1	2
9	999.20.015	A	3	9	3	8	3	8	3	8	4	3	3	6	4	5	3	5
10	999.20.014	A	3	3	2	2	2	2	2	2	3	2	3	0	3	1	3	1
11	999.20.0111	A	1	2	2	2	1	4	2	4	1	4	3	0	1	2	3	0
12	999.20.011	B	12	10	11	9	3	10	4	9	11	10	12	7	3	12	4	8
13	999.20.0121	A	1	2	1	2	2	1	2	2	3	1	2	2	2	1	2	0
14	999.20.012	A	3	1	4	2	5	1	4	2	4	3	4	3	5	1	5	3
15	999.20.009	A	1	4	1	4	0	8	0	7	2	0	2	1	0	7	2	3
16	999.20.008	A	1	1	1	0	0	1	1	0	1	0	1	1	1	0	1	1
17	999.20.006	A	3	3	2	2	2	2	2	3	2	3	2	4	3	2	2	3
18	999.20.005	A	1	3	1	3	1	3	1	4	1	3	2	0	1	3	1	3
19	999.20.004	A	4	7	4	6	4	7	4	6	5	5	4	6	5	4	5	5
20	999.20.003	A	5	8	4	7	4	8	4	8	5	4	5	6	6	3	5	6
21	999.20.002	A	1	1	1	0	0	2	1	0	1	1	0	2	0	2	1	0
22	999.20.0011	A	1	1	1	1	1	1	1	1	1	1	1	0	0	3	1	0
23	999.14.002	A	1	1	0	2	1	0	2	0	1	0	1	1	1	0	1	1
24	999.14.001	B	7	7	7	6	2	6	3	7	7	6	6	8	2	7	1	11
25	999.13.002	B	9	7	8	6	3	6	2	8	9	6	8	7	3	7	3	8
26	999.13.003	A	4	7	3	6	4	6	3	8	4	5	4	5	4	5	4	6
27	999.12.005	A	1	1	0	2	2	0	1	2	1	2	1	2	0	3	0	2
28	999.10.020	A	9	5	8	4	8	4	8	4	8	4	9	3	8	3	8	3
29	999.10.019	B	8	3	8	1	2	5	4	2	8	2	8	2	2	5	4	1
30	999.10.0191	A	1	0	1	1	1	1	0	3	0	2	1	1	0	2	0	2
31	999.10.018	B	13	21	13	7	3	20	6	6	12	20	14	6	3	20	5	8
32	999.10.015	A	1	3	1	2	1	2	2	2	2	0	2	0	2	0	2	1
33	999.10.013	A	4	3	3	2	3	2	3	2	3	2	3	2	3	2	3	2
34	999.10.012	A	1	3	2	2	1	3	1	2	2	3	1	3	2	0	1	4
35	999.10.008	A	4	5	4	7	4	5	4	4	4	9	5	5	4	5	4	5
36	999.10.007	A	1	1	1	2	1	0	1	0	0	3	1	1	0	2	1	1
37	999.10.006	B	8	16	8	6	2	16	3	8	7	16	8	8	2	17	2	8
38	999.10.004	A	1	1	0	2	1	0	1	0	1	1	1	0	0	2	1	1
39	999.10.003	A	1	1	1	0	2	0	0	3	1	2	1	1	0	2	1	0
40	65.04	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
41	65.029	B	8	13	9	100	0	12	0	100	8	14	8	102	0	12	0	101
42	65.026	B	34	31	35	12	20	30	20	9	33	31	37	11	20	30	20	9
43	65.0091	B	76	73	76	29	14	72	14	28	77	75	75	32	15	72	14	28
44	65.007	A	3	5	2	4	2	4	2	4	2	4	3	0	3	0	3	0
45	65.005	A	1	1	1	1	1	1	1	1	1	0	1	0	1	2	1	0
46	65.004	B	8	13	7	6	2	12	2	7	7	12	8	6	2	12	2	7
47	54.2051	B	17	14	18	12	6	16	6	17	18	15	18	17	7	14	8	12
48	54.201	B	4	0	5	53	0	0	0	51	4	2	5	51	0	0	0	50
49	54.023	B	4	7	4	1	1	10	1	3	3	6	4	2	1	7	2	1
50	54.02	A	1	0	0	0	0	0	0	0	0	50	0	50	0	50	0	50
51	54.017	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
52	54.016	A	1	3	1	2	1	3	1	2	1	0	1	2	1	0	1	3
53	54.011	A	1	1	0	1	0	1	0	1	0	1	0	2	0	2	1	1
54	54.0062	B	3	0	3	104	0	0	0	100	4	1	3	100	0	0	0	100
55	54.024	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
56	54.0201	B	1	1	0	100	0	0	0	100	1	0	0	100	0	0	0	100
57	54.021	B	1	0	0	100	0	0	0	100	1	4	0	100	0	0	0	100
58	54.022	B	3	0	2	30	1	0	0	31	2	0	2	30	0	0	0	30
59	54.005	A	1	0	1	0	0	1	0	1	1	0	1	0	1	0	1	0
60	54.004	A	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	0
61	54.003	A	3	1	2	0	2	0	2	0	2	0	2	0	2	0	2	0
62	54.002	A	1	0	0	1	1	0	1	0	1	0	1	0	0	1	0	2
63	54.001	A	1	1	1	0	1	0	1	0	1	1	1	2	1	1	1	0
64	124.54.001	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
65	54.023	A	1	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
66	53.004	A	3	1	2	0	2	0	2	1	2	0	3	0	2	0	2	0
67	53.003	A	8	5	8	6	8	8	9	4	10	2	9	4	8	7	9	4
68	53.002	A	5	4	5	4	6	4	5	4	6	4	6	4	5	4	6	3
69	53.001	B	9	8	11	2	5	7	6	3	10	10	12	1	5	7	7	1
70	51.004	B	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	1
71	51.003	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	45.2	B	1	4	1	9	0	3	0	3	1	3	1	2	0	3	0	2
73	41.068	B	0	3	0	5	0	2	0	5	0	2	0	5	0	2	0	5
74	41.062	B	0	3	0	2	0	2	0	2	0	2	0	2	0	2	0	2
75	41.056	B	0	1	0	2	0	0	0	2	0	0	0	2	0	0	0	2
76	41.045	A	0	1	0	0	0	0	0	0	0	2	0	2	0	2	0	2
77	30.007	B	4	8	3	1	0	7	0	1	3	7	3	1	0	7	0	1
78	30.005	A	1	1	1	0	1	1	1	2	0	4	0	3	1	2	1	1
79	30.004	B	3	3	2	1	0	2	0	1	2	2	2	1	0	2	0	1
80	41.051	B	94	92	100	150	48	93	53	149	100	94	100	160	50	93	52	151
81	123.41.001	B	30	35	33	122	16	34	17	117	35	42	35	125	17	34	17	116
82	123.41.002	A	1	0	1	0	0	0	1	3	0	102	0	100	0	102	0	100

Appendix 6.2: Sub-optimal configuration Purchasing λ=1.6 (Exp 9 – 16)

Nr	Minox	Class	X Exp9	Q Exp9	X Exp10	Q Exp10	X Exp11	Q Exp11	X Exp12	Q Exp12	X Exp13	Q Exp13	X Exp14	Q Exp14	X Exp15	Q Exp15	X Exp16	Q Exp16
1	65.042	B	21	22	21	9	9	22	9	9	22	22	22	11	8	22	9	10
2	65.025	B	46	60	47	19	13	60	13	18	47	61	47	19	12	60	13	17
3	999.21.006	B	7	6	7	7	3	6	3	7	7	7	7	4	2	6	3	3
4	999.21.005	B	6	7	6	6	3	7	3	5	6	7	7	4	2	6	3	4
5	999.21.009	A	1	4	1	3	1	4	1	3	1	2	2	1	2	1	1	2
6	999.20.020	A	1	3	1	3	1	3	1	3	1	2	1	2	2	2	1	2
7	999.20.019	A	1	3	1	3	1	3	1	3	1	1	1	0	1	1	1	1
8	999.20.018	A	0	2	0	2	1	2	1	1	0	3	1	0	0	2	1	1
9	999.20.015	A	1	8	1	8	1	8	1	8	1	5	1	3	1	3	1	4
10	999.20.014	A	1	2	1	2	1	2	1	2	1	1	1	0	1	1	1	1
11	999.20.0111	A	1	1	1	2	1	1	1	2	1	2	0	3	1	1	1	1
12	999.20.011	B	11	9	11	9	3	9	3	9	11	12	12	7	3	9	3	8
13	999.20.0121	A	1	1	1	2	1	1	1	2	1	1	1	1	1	0	1	1
14	999.20.012	A	1	1	1	2	2	1	2	2	1	1	2	1	2	0	2	1
15	999.20.009	A	0	3	0	4	1	3	1	4	0	7	0	3	0	3	1	1
16	999.20.008	A	0	0	0	1	1	0	1	0	1	0	1	0	0	0	1	1
17	999.20.006	A	1	2	1	2	1	2	1	2	1	2	1	2	1	3	1	3
18	999.20.005	A	0	2	0	3	1	2	1	3	0	3	1	1	1	0	1	1
19	999.20.004	A	1	6	1	6	2	6	2	6	2	4	2	2	2	2	2	3
20	999.20.003	A	1	8	1	7	1	8	1	7	2	3	2	4	1	5	1	4
21	999.20.002	A	0	0	0	0	1	0	1	0	0	2	0	1	1	0	1	1
22	999.20.0011	A	0	0	0	1	1	0	1	1	0	3	1	0	1	0	1	1
23	999.14.002	A	0	2	0	2	1	2	1	2	0	1	0	1	0	1	1	1
24	999.14.001	B	6	6	7	6	2	6	2	6	7	7	7	6	3	6	2	7
25	999.13.002	B	8	6	8	7	2	6	2	6	8	7	8	6	2	10	2	7
26	999.13.003	A	1	6	1	6	1	6	1	6	1	6	1	6	1	5	1	6
27	999.12.005	A	1	0	1	2	1	0	1	2	1	3	0	1	0	1	1	1
28	999.10.020	A	2	5	2	5	2	5	2	4	3	4	3	6	2	5	2	4
29	999.10.019	B	7	3	9	1	3	3	3	1	7	5	8	3	3	2	3	2
30	999.10.0191	A	1	0	1	1	1	0	1	1	1	2	0	1	0	1	1	0
31	999.10.018	B	12	20	13	8	4	20	4	7	12	20	14	9	3	20	4	7
32	999.10.015	A	1	2	1	2	1	2	1	2	1	0	1	0	1	0	1	1
33	999.10.013	A	1	4	1	2	1	4	1	2	1	2	1	2	1	2	1	3
34	999.10.012	A	0	3	1	2	1	3	1	2	1	0	1	0	1	0	1	1
35	999.10.008	A	1	7	1	7	1	7	1	7	1	5	1	5	1	10	1	6
36	999.10.007	A	1	0	1	2	1	0	1	2	1	2	1	0	0	1	1	1
37	999.10.006	B	7	15	8	6	2	15	2	6	7	17	8	7	2	16	2	7
38	999.10.004	A	0	1	0	2	1	1	1	2	0	2	0	1	0	1	1	1
39	999.10.003	A	0	1	0	1	1	1	1	0	0	2	1	1	0	1	1	1
40	65.04	A	0	0	0	0	0	0	0	0	0	100	0	100	0	100	0	100
41	65.029	B	7	14	8	100	1	14	1	100	8	12	8	101	0	12	1	100
42	65.026	B	33	30	36	12	21	30	21	12	34	30	36	11	20	30	21	10
43	65.0091	B	77	72	77	30	15	72	15	29	77	72	78	30	14	72	15	29
44	65.007	A	1	4	1	4	1	4	1	4	1	0	1	0	1	0	1	0
45	65.005	A	0	1	1	1	1	1	1	1	0	3	1	0	0	1	1	1
46	65.004	B	7	12	7	6	3	12	3	6	7	12	8	6	2	12	3	7
47	54.2051	B	18	15	20	12	6	15	6	12	18	16	18	13	6	13	6	10
48	54.201	B	5	2	5	53	1	2	1	53	5	0	4	52	0	0	1	50
49	54.023	B	3	6	4	3	1	6	1	1	3	7	4	2	1	6	1	2
50	54.02	A	0	0	0	0	1	0	1	0	0	50	0	50	0	50	1	50
51	54.017	A	0	0	0	0	1	0	1	0	0	100	0	100	0	100	1	100
52	54.016	A	0	2	0	2	1	2	1	2	1	1	1	2	1	1	1	1
53	54.011	A	0	0	0	1	1	0	1	1	0	2	0	1	0	0	1	0
54	54.0062	B	4	2	4	104	0	2	0	104	4	0	3	100	0	0	0	100
55	54.024	A	0	0	0	0	1	0	1	0	0	100	0	100	0	100	1	100
56	54.0201	B	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0	100
57	54.021	B	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0	100
58	54.022	B	2	0	2	30	1	0	1	30	2	0	2	30	1	0	1	30
59	54.005	A	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0
60	54.004	A	1	0	1	1	1	0	1	1	1	1	0	0	0	0	1	1
61	54.003	A	1	0	1	0	1	0	1	0	1	0	1	0	1	2	1	1
62	54.002	A	0	0	0	1	1	0	1	1	0	1	0	1	0	0	1	0
63	54.001	A	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1
64	124.54.001	A	0	0	0	0	1	0	1	0	0	100	0	100	0	100	1	100
65	54.023	A	0	0	0	0	1	0	1	0	0	100	0	100	0	100	1	100
66	53.004	A	1	0	1	0	2	0	2	0	1	0	1	0	1	0	2	0
67	53.003	A	4	6	4	6	4	6	4	6	4	7	5	4	4	4	4	3
68	53.002	A	3	5	3	4	2	5	2	4	3	4	2	6	2	6	2	4
69	53.001	B	8	15	10	4	6	15	6	2	10	7	10	5	5	7	6	1
70	51.004	B	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	2
71	51.003	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	45.2	B	1	4	1	9	1	4	1	9	1	3	1	2	0	3	1	3
73	41.068	B	0	2	0	5	0	2	0	5	0	2	0	5	0	2	0	6
74	41.062	B	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	3
75	41.056	B	0	0	0	2	0	0	0	2	0	0	0	2	0	0	0	3
76	41.045	A	0	0	0	0	0	0	0	0	0	2	0	2	0	2	0	3
77	30.007	B	3	7	3	1	0	7	0	1	3	7	3	1	0	7	0	2
78	30.005	A	0	0	0	0	0	0	0	0	0	2	0	1	0	1	0	2
79	30.004	B	2	2	2	1	0	2	0	1	2	2	2	1	0	2	0	2
80	41.051	B	98	98	99	152	49	98	49	150	100	98	100	148	49	91	49	146
81	123.41.001	B	34	36	35	122	17	36	17	122	34	36	34	123	17	34	17	116
82	123.41.002	A	0	0	0	0	1	0	1	0	0	100	0	100	0	100	1	100

Appendix 7: Sub-optimal objective values Purchasing

	Lambda		
	0,4	1	1,6
Exp 1	650922029,4	667110856,4	710326525
Exp 2	630314314,5	637324118,3	647235573
Exp 3	616918322,5	700381192,6	781557458,4
Exp 4	616885435,2	651769854,9	710720037,8
Exp 5	632283452,3	655451876,4	733186163,4
Exp 6	627699660	678684648,6	736720643,5
Exp 7	703631847,6	720213227,1	802960875,5
Exp 8	664577398,9	675642034	733009720,2
Exp 9	660359908	753193899,8	770062145,8
Exp 10	690766469,2	715580510,4	739589441,7
Exp 11	743537846	751582523,1	859829274,4
Exp 12	702072824,5	720304123,9	796236263
Exp 13	710150975,7	740687267,1	794931319,3
Exp 14	704696204,7	736918581,7	790708754,7
Exp 15	770298613,4	816970533,4	849148557,6
Exp 16	773939518,6	785029339,4	814307135,4

Appendix 8.1: Sub-optimal configuration Due date Quotation λ=0.4 (Exp 1 - 8)

Nr	Minox	Class	K Exp1	Y Exp1	K Exp2	Y Exp2	K Exp3	Y Exp3	K Exp4	Y Exp4	K Exp5	Y Exp5	K Exp6	Y Exp6	K Exp7	Y Exp7	K Exp8	Y Exp8
1	65.042	B	13	13	13	0.2	7	13	7	0.2	13	13	13	0.3	7	13	9	0.3
2	65.025	B	15	13	15	0.3	11	13	10	0.3	15	13	15	0.3	10	13	15	0.3
3	999.21.006	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.3
4	999.21.005	B	9	15	9	0.2	4	15	4	0.2	9	15	9	0.2	4	17	4	0.2
5	999.21.009	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
6	999.20.020	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
7	999.20.019	A	7	16	9	18	8	16	6	17	7	0.2	8	0.2	7	0.3	7	0.3
8	999.20.018	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
9	999.20.015	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
10	999.20.014	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
11	999.20.0111	A	8	15	8	15	8	15	8	15	8	0.2	8	0.2	8	0.2	8	0.2
12	999.20.011	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
13	999.20.0121	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	8	0.2
14	999.20.012	A	7	15	7	16	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
15	999.20.009	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
16	999.20.008	A	7	15	7	15	8	16	7	15	7	0.3	7	0.2	7	0.2	7	0.2
17	999.20.006	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
18	999.20.005	A	7	15	7	15	7	15	7	15	8	0.2	7	0.2	7	0.2	7	0.3
19	999.20.004	A	7	15	7	15	7	15	7	15	7	0.3	7	0.3	7	0.3	7	0.3
20	999.20.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
21	999.20.002	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
22	999.20.0011	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
23	999.14.002	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
24	999.14.001	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	4	0.3
25	999.13.002	B	11	15	11	0.2	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
26	999.13.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	8	0.2
27	999.12.005	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
28	999.10.020	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
29	999.10.019	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
30	999.10.0191	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
31	999.10.018	B	9	15	9	0.3	7	15	7	0.3	9	15	9	0.3	7	15	7	0.3
32	999.10.015	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
33	999.10.013	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	8	0.2	7	0.2
34	999.10.012	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
35	999.10.008	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
36	999.10.007	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
37	999.10.006	B	11	15	11	0.2	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
38	999.10.004	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
39	999.10.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
40	65.04	A	7	9	7	9	7	9	7	9	7	0.2	7	0.2	7	0.2	7	0.2
41	65.029	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
42	65.026	B	13	13	13	0.2	7	13	7	0.2	13	14	13	0.2	7	13	8	0.2
43	65.0091	B	16	6	17	0.4	11	6	9	0.4	17	7	16	0.4	10	7	9	0.4
44	65.007	A	9	9	9	9	9	9	9	9	9	0.2	9	0.2	9	0.2	9	0.2
45	65.005	A	7	9	7	9	7	9	7	9	7	0.2	7	0.2	7	0.2	7	0.2
46	65.004	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
47	54.2051	B	13	15	13	0.2	7	15	7	0.2	13	15	13	0.2	7	15	7	0.2
48	54.201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
49	54.023	B	9	11	9	0.2	3	11	4	0.2	9	11	9	0.2	3	11	3	0.2
50	54.02	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
51	54.017	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
52	54.016	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
53	54.011	A	7	11	7	11	8	12	7	11	7	0.2	7	0.2	7	0.2	7	0.2
54	54.0062	B	11	13	11	0.2	5	13	5	0.2	11	13	11	0.2	5	13	5	0.2
55	54.024	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
56	54.0201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
57	54.021	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
58	54.022	B	9	11	9	0.2	5	12	3	0.2	9	11	9	0.2	3	11	3	0.2
59	54.005	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
60	54.004	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	8	0.2	7	0.2
61	54.003	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
62	54.002	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
63	54.001	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
64	124.54.001	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
65	54.023	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
66	53.004	A	7	19	7	19	7	19	7	19	7	0.2	7	0.2	7	0.2	7	0.2
67	53.003	A	7	19	7	19	7	20	7	19	7	0.2	7	0.2	7	0.2	7	0.2
68	53.002	A	7	19	7	19	7	19	7	19	7	0.2	7	0.2	7	0.2	7	0.2
69	53.001	B	11	19	11	0.2	5	19	5	0.2	11	19	11	0.2	5	19	5	0.2
70	51.004	B	11	7	11	0.3	5	7	5	0.3	11	7	11	0.3	5	7	5	0.3
71	51.003	A	5	7	5	7	5	7	5	7	5	0.3	5	0.3	5	0.3	5	0.3
72	45.2	B	9	7	9	0.3	5	8	3	0.3	9	7	9	0.3	3	7	3	0.3
73	41.068	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
74	41.062	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
75	41.056	B	9	7	9	0.5	3	7	3	0.5	9	7	9	0.5	3	7	3	0.5
76	41.045	A	9	7	9	7	9	7	9	7	9	0.5	9	0.5	9	0.5	9	0.5
77	30.007	B	11	7	11	0.5	5	7	5	0.5	11	7	11	0.5	5	7	5	0.5
78	30.005	A	7	7	7	7	7	7	7	7	7	0.5	7	0.5	7	0.5	7	0.5
79	30.004	B	11	7	11	0.5	6	7	6	0.5	11	7	11	0.5	6	7	6	0.5
80	41.051	B	15	26	15	0.3	9	25	9	0.2	15	25	15	0.2	9	25	9	0.2
81	123.41.001	B	13	25	13	0.2	7	25	7	0.2	13	25	13	0.2	7	25	7	0.2
82	123.41.002	A	7	25	7	25	7	25	7	25	7	0.2	7	0.2	7	0.2	7	0.2

Appendix 8.2: Sub-optimal configuration Due date Quotation λ=0.4 (Exp 9 – 16)

Nr	Minox	Class	K Exp9	Y Exp9	K Exp10	Y Exp10	K Exp11	Y Exp11	K Exp12	Y Exp12	K Exp13	Y Exp13	K Exp14	Y Exp14	K Exp15	Y Exp15	K Exp16	Y Exp16
1	65.042	B	15	13	13	0.2	7	14	7	0.2	14	13	13	0.2	8	13	7	0.2
2	65.025	B	16	17	16	0.3	10	13	11	0.3	15	13	15	0.3	10	13	10	0.3
3	999.21.006	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
4	999.21.005	B	9	15	9	0.2	4	15	4	0.2	9	15	9	0.2	4	15	4	0.2
5	999.21.009	A	1	15	1	15	2	15	1	15	2	0.2	1	0.2	1	0.2	1	0.2
6	999.20.020	A	1	15	2	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
7	999.20.019	A	1	17	1	16	1	16	1	16	1	0.2	2	0.2	1	0.2	1	0.2
8	999.20.018	A	1	15	1	15	2	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
9	999.20.015	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
10	999.20.014	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
11	999.20.0111	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
12	999.20.011	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
13	999.20.0121	A	4	15	1	15	2	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
14	999.20.012	A	1	15	1	15	2	16	1	15	1	0.2	1	0.2	1	0.2	1	0.2
15	999.20.009	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
16	999.20.008	A	3	16	1	15	7	16	1	16	1	0.2	1	0.2	2	0.2	1	0.2
17	999.20.006	A	1	15	1	15	4	17	1	15	1	0.2	1	0.2	1	0.2	1	0.2
18	999.20.005	A	1	15	1	15	1	16	1	15	1	0.2	1	0.2	1	0.2	1	0.2
19	999.20.004	A	0	15	0	15	0	15	0	15	0	0.3	0	0.3	0	0.3	0	0.3
20	999.20.003	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
21	999.20.002	A	1	15	1	15	2	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
22	999.20.0011	A	2	15	1	15	1	18	1	15	1	0.2	1	0.2	1	0.2	1	0.2
23	999.14.002	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
24	999.14.001	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
25	999.13.002	B	11	15	11	0.2	6	15	5	0.2	11	15	11	0.2	5	15	5	0.2
26	999.13.003	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
27	999.12.005	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
28	999.10.020	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
29	999.10.019	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
30	999.10.0191	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
31	999.10.018	B	9	15	9	0.3	7	15	7	0.3	9	16	9	0.3	8	16	7	0.3
32	999.10.015	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
33	999.10.013	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
34	999.10.012	A	2	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
35	999.10.008	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
36	999.10.007	A	1	15	1	15	1	15	1	15	1	0.3	1	0.2	1	0.2	1	0.2
37	999.10.006	B	11	15	11	0.2	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
38	999.10.004	A	2	16	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
39	999.10.003	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
40	65.04	A	1	9	1	9	1	9	1	9	1	0.2	1	0.2	1	0.2	1	0.2
41	65.029	B	14	9	13	0.2	8	9	7	0.2	14	9	13	0.2	7	9	7	0.2
42	65.026	B	16	19	13	0.2	9	13	7	0.2	13	13	13	0.2	8	13	7	0.2
43	65.0091	B	21	10	17	0.5	9	7	10	0.5	21	6	18	0.6	10	6	9	0.4
44	65.007	A	3	9	3	9	3	9	3	9	3	0.2	3	0.2	3	0.2	3	0.2
45	65.005	A	1	9	1	9	2	11	1	9	1	0.2	1	0.2	1	0.2	1	0.2
46	65.004	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
47	54.2051	B	13	16	13	0.2	9	20	7	0.2	13	15	13	0.2	7	15	7	0.2
48	54.201	B	11	12	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
49	54.023	B	9	11	9	0.2	3	11	4	0.2	9	11	9	0.2	3	11	3	0.2
50	54.02	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
51	54.017	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
52	54.016	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
53	54.011	A	1	11	1	11	2	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
54	54.0062	B	11	13	11	0.2	5	13	5	0.2	11	13	11	0.2	5	13	5	0.2
55	54.024	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
56	54.0201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
57	54.021	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
58	54.022	B	9	12	9	0.2	3	11	3	0.2	9	11	9	0.2	3	11	3	0.2
59	54.005	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
60	54.004	A	1	11	1	11	2	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
61	54.003	A	1	11	1	11	1	14	1	11	1	0.2	1	0.2	1	0.2	1	0.2
62	54.002	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
63	54.001	A	3	12	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
64	124.54.001	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
65	54.023	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
66	53.004	A	1	19	1	19	1	19	1	19	1	0.2	1	0.2	1	0.2	1	0.2
67	53.003	A	1	23	1	19	1	19	1	19	1	0.2	1	0.2	1	0.2	1	0.2
68	53.002	A	1	19	1	20	1	19	1	19	1	0.2	1	0.2	1	0.2	1	0.2
69	53.001	B	11	19	11	0.2	5	19	5	0.2	11	19	11	0.2	5	19	5	0.2
70	51.004	B	11	7	11	0.3	5	7	5	0.3	11	7	11	0.3	5	7	5	0.3
71	51.003	A	-1	7	-1	7	-1	7	-1	7	-1	0.3	-1	0.3	-1	0.3	-1	0.3
72	45.2	B	9	7	9	0.3	9	10	3	0.3	9	7	9	0.3	3	7	3	0.3
73	41.068	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
74	41.062	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
75	41.056	B	9	7	9	0.5	3	7	3	0.5	9	7	9	0.5	3	7	3	0.5
76	41.045	A	3	7	3	7	3	7	3	7	3	0.5	3	0.5	3	0.5	3	0.5
77	30.007	B	11	8	11	0.5	5	7	5	0.5	11	7	11	0.5	5	7	5	0.5
78	30.005	A	7	10	3	8	5	11	4	9	2	0.5	2	0.5	2	0.5	2	0.5
79	30.004	B	12	7	11	0.5	9	9	6	0.5	11	8	11	0.5	6	7	6	0.5
80	41.051	B	15	25	15	0.2	9	26	9	0.2	15	25	15	0.2	9	25	9	0.2
81	123.41.001	B	13	25	14	0.2	7	25	7	0.2	13	25	13	0.2	7	25	7	0.2
82	123.41.002	A	1	25	1	25	1	25	1	25	1	0.2	1	0.2	1	0.2	1	0.2

Appendix 9.1: Sub-optimal configuration Due date Quotation λ=1 (Exp 1 - 8)

Nr	Minox	Class	K Exp1	Y Exp1	K Exp2	Y Exp2	K Exp3	Y Exp3	K Exp4	Y Exp4	K Exp5	Y Exp5	K Exp6	Y Exp6	K Exp7	Y Exp7	K Exp8	Y Exp8
1	65.042	B	13	13	13	0.2	7	13	7	0.2	13	13	13	0.3	7	13	9	0.3
2	65.025	B	15	13	15	0.3	11	13	10	0.3	15	13	15	0.3	10	13	15	0.3
3	999.21.006	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.3
4	999.21.005	B	9	15	9	0.2	4	15	4	0.2	9	15	9	0.2	4	17	4	0.2
5	999.21.009	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
6	999.20.020	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
7	999.20.019	A	7	16	9	18	8	16	6	17	7	0.2	8	0.2	7	0.3	7	0.3
8	999.20.018	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
9	999.20.015	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
10	999.20.014	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
11	999.20.0111	A	8	15	8	15	8	15	8	15	8	0.2	8	0.2	8	0.2	8	0.2
12	999.20.011	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
13	999.20.0121	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	8	0.2
14	999.20.012	A	7	15	7	16	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
15	999.20.009	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
16	999.20.008	A	7	15	7	15	8	16	7	15	7	0.3	7	0.2	7	0.2	7	0.2
17	999.20.006	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
18	999.20.005	A	7	15	7	15	7	15	7	15	8	0.2	7	0.2	7	0.2	7	0.3
19	999.20.004	A	7	15	7	15	7	15	7	15	7	0.3	7	0.3	7	0.3	7	0.3
20	999.20.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
21	999.20.002	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
22	999.20.0011	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
23	999.14.002	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
24	999.14.001	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	4	0.3
25	999.13.002	B	11	15	11	0.2	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
26	999.13.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	8	0.2
27	999.12.005	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
28	999.10.020	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
29	999.10.019	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
30	999.10.0191	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
31	999.10.018	B	9	15	9	0.3	7	15	7	0.3	9	15	9	0.3	7	15	7	0.3
32	999.10.015	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
33	999.10.013	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	8	0.2	7	0.2
34	999.10.012	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
35	999.10.008	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
36	999.10.007	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
37	999.10.006	B	11	15	11	0.2	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
38	999.10.004	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
39	999.10.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
40	65.04	A	7	9	7	9	7	9	7	9	7	0.2	7	0.2	7	0.2	7	0.2
41	65.029	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
42	65.026	B	13	13	13	0.2	7	13	7	0.2	13	13	13	0.2	7	13	8	0.2
43	65.0091	B	16	6	17	0.4	9	6	9	0.4	17	6	16	0.4	9	7	9	0.4
44	65.007	A	9	9	9	9	9	9	9	9	9	0.2	9	0.2	9	0.2	9	0.2
45	65.005	A	7	9	7	9	7	9	7	9	7	0.2	7	0.2	7	0.2	7	0.2
46	65.004	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
47	54.2051	B	13	15	13	0.2	7	15	7	0.2	13	15	13	0.2	7	15	7	0.2
48	54.201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
49	54.023	B	9	11	9	0.2	3	11	4	0.2	9	11	9	0.2	3	11	3	0.2
50	54.02	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
51	54.017	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
52	54.016	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
53	54.011	A	7	11	7	11	8	12	7	11	7	0.2	7	0.2	7	0.2	7	0.2
54	54.0062	B	11	13	11	0.2	5	13	5	0.2	11	13	11	0.2	5	13	5	0.2
55	54.024	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
56	54.0201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
57	54.021	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
58	54.022	B	9	11	9	0.2	5	12	3	0.2	9	11	9	0.2	3	11	3	0.2
59	54.005	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
60	54.004	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	8	0.2	7	0.2
61	54.003	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
62	54.002	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
63	54.001	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
64	124.54.001	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
65	54.023	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
66	53.004	A	7	19	7	19	7	19	7	19	7	0.2	7	0.2	7	0.2	7	0.2
67	53.003	A	7	19	7	19	7	20	7	19	7	0.2	7	0.2	7	0.2	7	0.2
68	53.002	A	7	19	7	19	7	19	7	19	7	0.2	7	0.2	7	0.2	7	0.2
69	53.001	B	11	19	11	0.2	5	19	5	0.2	11	19	11	0.2	5	19	5	0.2
70	51.004	B	11	7	11	0.3	5	7	5	0.3	11	7	11	0.3	5	7	5	0.3
71	51.003	A	5	7	5	7	5	7	5	7	5	0.3	5	0.3	5	0.3	5	0.3
72	45.2	B	9	7	9	0.3	5	8	3	0.3	9	7	9	0.3	3	7	3	0.3
73	41.068	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
74	41.062	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
75	41.056	B	9	7	9	0.5	3	7	3	0.5	9	7	9	0.5	3	7	3	0.5
76	41.045	A	9	7	9	7	9	7	9	7	9	0.5	9	0.5	9	0.5	9	0.5
77	30.007	B	11	7	11	0.5	5	7	5	0.5	11	7	11	0.5	5	7	5	0.5
78	30.005	A	7	7	7	7	7	7	7	7	7	0.5	7	0.5	7	0.5	7	0.5
79	30.004	B	11	7	11	0.5	6	7	6	0.5	11	7	11	0.5	6	7	6	0.5
80	41.051	B	15	25	15	0.2	9	25	9	0.2	15	25	15	0.2	9	25	9	0.2
81	123.41.001	B	13	25	13	0.2	7	25	7	0.2	13	25	13	0.2	7	25	7	0.2
82	123.41.002	A	7	25	7	25	7	25	7	25	7	0.2	7	0.2	7	0.2	7	0.2

Appendix 9.2: Sub-optimal configuration Due date Quotation λ=1 (Exp 9 – 16)

Nr	Minox	Class	K Exp9	Y Exp9	K Exp10	Y Exp10	K Exp11	Y Exp11	K Exp12	Y Exp12	K Exp13	Y Exp13	K Exp14	Y Exp14	K Exp15	Y Exp15	K Exp16	Y Exp16
1	65.042	B	14	13	13	0.2	7	13	7	0.2	13	13	13	0.2	7	13	7	0.2
2	65.025	B	16	17	16	0.3	10	13	11	0.3	15	13	15	0.3	10	13	10	0.3
3	999.21.006	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
4	999.21.005	B	9	15	9	0.2	4	15	4	0.2	9	15	9	0.2	4	15	4	0.2
5	999.21.009	A	1	15	1	15	2	15	1	15	2	0.2	1	0.2	1	0.2	1	0.2
6	999.20.020	A	1	15	2	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
7	999.20.019	A	1	17	1	16	1	16	1	16	1	0.2	1	0.2	1	0.2	1	0.2
8	999.20.018	A	1	15	1	15	2	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
9	999.20.015	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
10	999.20.014	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
11	999.20.0111	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
12	999.20.011	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
13	999.20.0121	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
14	999.20.012	A	1	15	1	15	2	16	1	15	1	0.2	1	0.2	1	0.2	1	0.2
15	999.20.009	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
16	999.20.008	A	3	16	1	15	7	16	1	15	1	0.2	1	0.2	1	0.2	1	0.2
17	999.20.006	A	1	15	1	15	4	17	1	15	1	0.2	1	0.2	1	0.2	1	0.2
18	999.20.005	A	1	15	1	15	1	16	1	15	1	0.2	1	0.2	1	0.2	1	0.2
19	999.20.004	A	0	15	0	15	0	15	0	15	0	0.3	0	0.3	0	0.3	0	0.3
20	999.20.003	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
21	999.20.002	A	1	15	1	15	2	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
22	999.20.0011	A	1	15	1	15	1	18	1	15	1	0.2	1	0.2	1	0.2	1	0.2
23	999.14.002	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
24	999.14.001	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
25	999.13.002	B	11	15	11	0.2	6	15	5	0.2	11	15	11	0.2	5	15	5	0.2
26	999.13.003	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
27	999.12.005	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
28	999.10.020	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
29	999.10.019	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
30	999.10.0191	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
31	999.10.018	B	9	15	9	0.3	7	15	7	0.3	9	15	9	0.3	8	16	7	0.3
32	999.10.015	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
33	999.10.013	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
34	999.10.012	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
35	999.10.008	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
36	999.10.007	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
37	999.10.006	B	11	15	11	0.2	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
38	999.10.004	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
39	999.10.003	A	1	15	1	15	1	15	1	15	1	0.2	1	0.2	1	0.2	1	0.2
40	65.04	A	1	9	1	9	1	9	1	9	1	0.2	1	0.2	1	0.2	1	0.2
41	65.029	B	14	9	13	0.2	8	9	7	0.2	14	9	13	0.2	7	9	7	0.2
42	65.026	B	14	16	13	0.2	7	13	7	0.2	13	13	13	0.2	7	13	7	0.2
43	65.0091	B	19	7	17	0.5	9	7	9	0.4	19	6	18	0.5	10	6	9	0.4
44	65.007	A	3	9	3	9	3	9	3	9	3	0.2	3	0.2	3	0.2	3	0.2
45	65.005	A	1	9	1	9	2	11	1	9	1	0.2	1	0.2	1	0.2	1	0.2
46	65.004	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
47	54.2051	B	13	16	13	0.2	9	20	7	0.2	13	15	13	0.2	7	15	7	0.2
48	54.201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
49	54.023	B	9	11	9	0.2	3	11	4	0.2	9	11	9	0.2	3	11	3	0.2
50	54.02	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
51	54.017	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
52	54.016	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
53	54.011	A	1	11	1	11	2	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
54	54.0062	B	11	13	11	0.2	5	13	5	0.2	11	13	11	0.2	5	13	5	0.2
55	54.024	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
56	54.0201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
57	54.021	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
58	54.022	B	9	11	9	0.2	3	11	3	0.2	9	11	9	0.2	3	11	3	0.2
59	54.005	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
60	54.004	A	1	11	1	11	2	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
61	54.003	A	1	11	1	11	1	14	1	11	1	0.2	1	0.2	1	0.2	1	0.2
62	54.002	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
63	54.001	A	2	12	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
64	124.54.001	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
65	54.023	A	1	11	1	11	1	11	1	11	1	0.2	1	0.2	1	0.2	1	0.2
66	53.004	A	1	19	1	19	1	19	1	19	1	0.2	1	0.2	1	0.2	1	0.2
67	53.003	A	1	21	1	19	1	19	1	19	1	0.2	1	0.2	1	0.2	1	0.2
68	53.002	A	1	19	1	19	1	19	1	19	1	0.2	1	0.2	1	0.2	1	0.2
69	53.001	B	11	19	11	0.2	5	19	5	0.2	11	19	11	0.2	5	19	5	0.2
70	51.004	B	11	7	11	0.3	5	7	5	0.3	11	7	11	0.3	5	7	5	0.3
71	51.003	A	-1	7	-1	7	-1	7	-1	7	-1	0.3	-1	0.3	-1	0.3	-1	0.3
72	45.2	B	9	7	9	0.3	9	10	3	0.3	9	7	9	0.3	3	7	3	0.3
73	41.068	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
74	41.062	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
75	41.056	B	9	7	9	0.5	3	7	3	0.5	9	7	9	0.5	3	7	3	0.5
76	41.045	A	3	7	3	7	3	7	3	7	3	0.5	3	0.5	3	0.5	3	0.5
77	30.007	B	11	8	11	0.5	5	7	5	0.5	11	7	11	0.5	5	7	5	0.5
78	30.005	A	5	9	3	8	5	11	4	8	2	0.5	2	0.5	2	0.5	2	0.5
79	30.004	B	12	7	11	0.5	9	9	6	0.5	11	8	11	0.5	6	7	6	0.5
80	41.051	B	15	25	15	0.2	9	26	9	0.2	15	25	15	0.2	9	25	9	0.2
81	123.41.001	B	13	25	13	0.2	7	25	7	0.2	13	25	13	0.2	7	25	7	0.2
82	123.41.002	A	1	25	1	25	1	25	1	25	1	0.2	1	0.2	1	0.2	1	0.2

Appendix 10.1: Sub-optimal configuration Due date Quotation λ=1.6 (Exp 1 - 8)

Nr	Minox	Class	K Exp1	Y Exp1	K Exp2	Y Exp2	K Exp3	Y Exp3	K Exp4	Y Exp4	K Exp5	Y Exp5	K Exp6	Y Exp6	K Exp7	Y Exp7	K Exp8	Y Exp8
1	65.042	B	13	13	13	0.2	7	13	7	0.2	13	13	13	0.3	7	13	9	0.3
2	65.025	B	15	13	15	0.3	11	13	10	0.3	15	13	15	0.3	10	13	15	0.4
3	999.21.006	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.3
4	999.21.005	B	9	15	9	0.2	4	16	4	0.2	9	15	9	0.2	4	17	4	0.2
5	999.21.009	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
6	999.20.020	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
7	999.20.019	A	7	16	9	18	8	16	6	17	7	0.2	8	0.2	7	0.3	7	0.3
8	999.20.018	A	8	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
9	999.20.015	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
10	999.20.014	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
11	999.20.0111	A	8	15	8	15	8	15	8	15	8	0.2	8	0.2	8	0.2	8	0.2
12	999.20.011	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
13	999.20.0121	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	8	0.2
14	999.20.012	A	7	15	7	16	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
15	999.20.009	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
16	999.20.008	A	7	15	7	15	12	19	7	15	7	0.3	7	0.2	7	0.2	7	0.2
17	999.20.006	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
18	999.20.005	A	7	15	7	15	7	15	7	15	8	0.2	7	0.2	7	0.2	7	0.3
19	999.20.004	A	7	15	7	15	7	15	7	15	7	0.3	7	0.3	7	0.3	7	0.3
20	999.20.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
21	999.20.002	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
22	999.20.0011	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
23	999.14.002	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
24	999.14.001	B	9	15	9	0.2	5	15	3	0.2	9	15	9	0.2	4	15	4	0.4
25	999.13.002	B	11	15	11	0.3	5	15	5	0.2	11	15	11	0.2	5	15	5	0.2
26	999.13.003	A	7	15	7	15	7	16	7	15	7	0.2	7	0.2	7	0.2	8	0.2
27	999.12.005	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
28	999.10.020	A	7	15	7	15	7	16	7	15	7	0.2	7	0.2	7	0.2	7	0.2
29	999.10.019	B	9	15	9	0.2	3	15	3	0.2	9	15	9	0.2	3	15	3	0.2
30	999.10.0191	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
31	999.10.018	B	9	15	9	0.3	7	15	7	0.3	9	15	9	0.3	7	15	7	0.3
32	999.10.015	A	7	15	7	15	8	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
33	999.10.013	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	8	0.2	7	0.2
34	999.10.012	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
35	999.10.008	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
36	999.10.007	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
37	999.10.006	B	11	15	11	0.2	5	16	5	0.2	11	15	11	0.2	5	15	5	0.2
38	999.10.004	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
39	999.10.003	A	7	15	7	15	7	15	7	15	7	0.2	7	0.2	7	0.2	7	0.2
40	65.04	A	7	9	7	9	7	9	7	9	7	0.2	7	0.2	7	0.2	7	0.2
41	65.029	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
42	65.026	B	13	13	13	0.3	7	13	7	0.2	13	13	13	0.3	7	13	8	0.2
43	65.0091	B	16	6	17	0.6	9	6	9	0.4	18	6	16	0.6	9	7	9	0.4
44	65.007	A	9	9	9	9	9	9	9	9	9	0.2	9	0.2	9	0.2	9	0.2
45	65.005	A	7	9	7	9	7	9	7	9	7	0.2	7	0.2	7	0.2	7	0.2
46	65.004	B	13	9	13	0.2	7	9	7	0.2	13	9	13	0.2	7	9	7	0.2
47	54.2051	B	13	15	13	0.2	7	16	7	0.2	13	15	13	0.2	7	15	7	0.2
48	54.201	B	11	11	11	0.2	5	12	5	0.2	11	11	11	0.2	5	11	5	0.3
49	54.023	B	9	11	9	0.2	3	11	4	0.2	9	11	9	0.2	3	11	3	0.2
50	54.02	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
51	54.017	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
52	54.016	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
53	54.011	A	7	11	7	11	8	12	7	11	7	0.2	7	0.2	7	0.2	7	0.2
54	54.0062	B	11	13	11	0.2	5	13	5	0.2	11	13	11	0.2	5	13	5	0.2
55	54.024	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
56	54.0201	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
57	54.021	B	11	11	11	0.2	5	11	5	0.2	11	11	11	0.2	5	11	5	0.2
58	54.022	B	9	11	9	0.2	5	12	3	0.2	9	11	9	0.3	4	11	3	0.2
59	54.005	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
60	54.004	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	8	0.2	7	0.2
61	54.003	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
62	54.002	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
63	54.001	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
64	124.54.001	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
65	54.023	A	7	11	7	11	7	11	7	11	7	0.2	7	0.2	7	0.2	7	0.2
66	53.004	A	7	19	7	19	7	19	7	19	7	0.2	7	0.2	7	0.2	7	0.2
67	53.003	A	7	19	7	19	7	20	7	19	7	0.2	7	0.2	7	0.2	7	0.2
68	53.002	A	7	19	7	19	7	19	7	19	7	0.2	7	0.2	7	0.2	7	0.2
69	53.001	B	11	19	11	0.2	5	19	5	0.2	11	19	11	0.2	5	19	5	0.2
70	51.004	B	11	7	11	0.3	5	7	5	0.3	11	7	11	0.3	5	7	5	0.3
71	51.003	A	5	7	5	7	5	7	5	7	5	0.3	5	0.3	5	0.3	5	0.3
72	45.2	B	9	7	9	0.3	5	9	3	0.3	9	7	9	0.3	5	7	3	0.3
73	41.068	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
74	41.062	B	13	7	13	0.5	7	7	7	0.5	13	7	13	0.5	7	7	7	0.5
75	41.056	B	9	7	9	0.5	3	7	3	0.5	9	7	9	0.5	3	7	3	0.5
76	41.045	A	9	7	9	7	9	7	9	7	9	0.5	9	0.5	9	0.5	9	0.5
77	30.007	B	11	7	11	0.5	5	7	5	0.5	11	7	11	0.5	5	7	5	0.5
78	30.005	A	7	7	7	7	7	7	7	7	7	0.5	7	0.5	7	0.5	7	0.5
79	30.004	B	11	7	11	0.5	6	7	6	0.5	11	7	11	0.5	6	7	6	0.5
80	41.051	B	15	26	15	0.3	21	32	9	0.2	15	25	16	0.2	12	27	10	0.2
81	123.41.001	B	13	25	13	0.2	7	25	7	0.2	13	25	13	0.2	7	25	7	0.2
82	123.41.002	A	7	25	7	25	8	25	7	25	7	0.2	7	0.2	7	0.2	7	0.2

Appendix 10.2: Sub-optimal configuration Due date Quotation λ=1.6 (Exp 9 – 16)

Nr	Minox	Class	K Exp9	Y Exp9	K Exp10	Y Exp10	K Exp11	Y Exp11	K Exp12	Y Exp12	K Exp13	Y Exp13	K Exp14	Y Exp14	K Exp15	Y Exp15	K Exp16	Y Exp16
1	65.042	B	18	18	15	0.2	7	13	7	0.2	14	13	13	0.2	10	18	7	0.2
2	65.025	B	23	25	18	0.6	10	13	11	0.3	16	19	15	0.4	14	19	10	0.3
3	999.21.006	B	13	21	9	0.2	3	15	3	0.2	9	15	9	0.2	4	21	3	0.2
4	999.21.005	B	12	22	9	0.3	4	15	4	0.2	11	18	9	0.2	6	22	4	0.2
5	999.21.009	A	1	21	1	15	2	15	1	15	2	0.3	1	0.2	1	0.3	1	0.2
6	999.20.020	A	1	21	2	15	1	15	1	15	2	0.2	1	0.2	1	0.3	1	0.2
7	999.20.019	A	1	23	1	16	1	16	1	16	1	0.2	1	0.2	1	0.3	1	0.2
8	999.20.018	A	3	21	1	15	2	15	1	15	1	0.2	1	0.2	2	0.3	1	0.2
9	999.20.015	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
10	999.20.014	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
11	999.20.0111	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
12	999.20.011	B	13	22	9	0.2	3	15	3	0.2	9	15	9	0.2	4	22	3	0.2
13	999.20.0121	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
14	999.20.012	A	1	21	1	15	2	16	1	15	3	0.4	1	0.2	1	0.3	1	0.2
15	999.20.009	A	1	21	1	15	1	15	1	15	1	0.2	2	0.2	1	0.3	1	0.2
16	999.20.008	A	7	26	1	15	7	16	1	15	1	0.2	1	0.2	6	0.4	1	0.2
17	999.20.006	A	1	21	1	15	4	17	1	15	1	0.2	1	0.2	1	0.3	1	0.2
18	999.20.005	A	1	21	1	15	1	16	1	15	1	0.2	1	0.2	1	0.3	1	0.2
19	999.20.004	A	0	21	0	15	0	15	0	15	0	0.3	0	0.3	0	0.4	0	0.3
20	999.20.003	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
21	999.20.002	A	1	21	1	16	2	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
22	999.20.0011	A	3	21	1	15	1	18	1	15	1	0.2	1	0.2	1	0.3	1	0.2
23	999.14.002	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
24	999.14.001	B	13	21	9	0.2	3	15	3	0.2	9	15	9	0.2	4	21	3	0.2
25	999.13.002	B	14	21	11	0.2	6	15	5	0.2	11	15	11	0.3	8	19	5	0.2
26	999.13.003	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.4	1	0.2
27	999.12.005	A	3	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
28	999.10.020	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
29	999.10.019	B	12	21	9	0.2	3	15	3	0.2	9	15	9	0.2	4	21	3	0.2
30	999.10.0191	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
31	999.10.018	B	13	21	9	0.3	7	15	7	0.3	9	15	9	0.3	11	22	7	0.3
32	999.10.015	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
33	999.10.013	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
34	999.10.012	A	3	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
35	999.10.008	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
36	999.10.007	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
37	999.10.006	B	14	21	11	0.2	5	15	5	0.2	11	15	11	0.2	7	21	5	0.2
38	999.10.004	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
39	999.10.003	A	1	21	1	15	1	15	1	15	1	0.2	1	0.2	1	0.3	1	0.2
40	65.04	A	1	13	1	9	1	9	1	9	1	0.2	1	0.2	1	0.3	1	0.2
41	65.029	B	20	16	13	0.2	8	9	7	0.2	17	13	13	0.2	10	10	7	0.2
42	65.026	B	21	25	16	0.4	7	13	7	0.2	16	15	16	0.3	10	14	7	0.2
43	65.0091	B	32	13	20	0.7	9	7	9	0.4	29	14	21	0.5	14	7	9	0.4
44	65.007	A	4	13	3	9	3	9	3	9	3	0.2	3	0.2	4	0.3	3	0.2
45	65.005	A	3	13	1	9	2	11	1	9	1	0.2	1	0.2	2	0.4	1	0.2
46	65.004	B	17	13	13	0.2	7	9	7	0.2	13	9	13	0.2	10	10	7	0.2
47	54.2051	B	17	22	13	0.2	9	20	7	0.2	15	16	13	0.3	11	21	7	0.2
48	54.201	B	16	16	11	0.2	5	11	5	0.2	13	11	11	0.2	7	12	5	0.2
49	54.023	B	12	16	9	0.2	3	11	4	0.2	9	11	9	0.2	4	12	3	0.2
50	54.02	A	1	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
51	54.017	A	1	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
52	54.016	A	3	16	2	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
53	54.011	A	1	16	1	11	2	11	1	11	1	0.2	1	0.2	1	0.4	1	0.2
54	54.0062	B	14	18	11	0.2	5	13	5	0.2	11	13	12	0.2	7	14	5	0.2
55	54.024	A	1	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
56	54.0201	B	14	16	11	0.2	5	11	5	0.2	11	11	11	0.2	7	12	5	0.2
57	54.021	B	16	16	11	0.2	5	11	5	0.2	11	11	11	0.2	7	12	5	0.2
58	54.022	B	12	16	9	0.2	3	11	3	0.2	9	11	9	0.2	4	12	3	0.2
59	54.005	A	3	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
60	54.004	A	1	16	1	11	2	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
61	54.003	A	1	16	1	11	1	14	1	11	1	0.2	1	0.2	1	0.3	1	0.2
62	54.002	A	1	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
63	54.001	A	4	17	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
64	124.54.001	A	1	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
65	54.023	A	1	16	1	11	1	11	1	11	1	0.2	1	0.2	1	0.3	1	0.2
66	53.004	A	1	26	1	19	1	19	1	19	1	0.2	1	0.2	1	0.3	1	0.2
67	53.003	A	3	29	1	19	1	19	1	19	1	0.2	1	0.2	1	0.3	1	0.2
68	53.002	A	1	26	1	19	1	19	1	19	1	0.2	1	0.2	1	0.3	1	0.2
69	53.001	B	14	27	11	0.2	5	19	5	0.2	11	19	11	0.2	7	21	5	0.2
70	51.004	B	16	10	11	0.3	5	7	5	0.3	11	7	11	0.3	7	8	5	0.3
71	51.003	A	0	10	-1	7	-1	7	-1	7	-1	0.3	-1	0.3	0	0.4	-1	0.3
72	45.2	B	13	10	9	0.3	9	10	3	0.3	9	7	9	0.3	7	9	3	0.3
73	41.068	B	17	10	13	0.5	7	7	7	0.5	13	7	13	0.5	10	8	7	0.5
74	41.062	B	17	10	13	0.5	7	7	7	0.5	13	7	13	0.5	10	8	7	0.5
75	41.056	B	12	10	9	0.5	3	7	3	0.5	9	7	9	0.5	4	8	3	0.5
76	41.045	A	4	10	3	7	3	7	3	7	3	0.5	3	0.5	4	1	3	0.5
77	30.007	B	14	12	11	0.5	5	7	5	0.5	11	7	11	0.5	7	8	5	0.5
78	30.005	A	7	13	3	8	5	11	4	8	2	0.5	2	0.5	3	1	2	0.5
79	30.004	B	16	10	11	0.5	9	9	6	0.5	11	8	11	0.5	8	8	6	0.5
80	41.051	B	26	35	20	1.1	9	26	9	0.2	20	29	19	0.4	32	32	9	0.2
81	123.41.001	B	21	34	14	0.2	7	25	8	0.3	13	25	14	0.2	10	28	7	0.2
82	123.41.002	A	3	34	1	25	1	25	1	25	1	0.2	1	0.2	1	0.3	1	0.2

Appendix 11: Sub-optimal objective values Due date Quotation

	Lambda		
	0.4	1	1.6
Exp 1	19.43857	18.71044	18.62494
Exp 2	20.37716	21.10279	21.46268
Exp 3	22.23097	18.89888	17.98513
Exp 4	16.58092	17.74487	18.76803
Exp 5	21.79535	21.70353	20.44006
Exp 6	21.07815	21.45896	21.8636
Exp 7	21.63952	20.80591	19.3701
Exp 8	20.3602	20.53669	20.54933
Exp 9	20.57686	19.94153	19.3112
Exp 10	19.50057	19.3849	19.34812
Exp 11	18.08578	17.66349	16.36131
Exp 12	18.2037	18.44108	17.61787
Exp 13	22.80766	20.02769	18.23667
Exp 14	20.52421	20.08551	20.29751
Exp 15	19.55737	19.10353	16.11898
Exp 16	19.90016	19.04653	17.72926