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Alignment of the Nedap UV Order Fulfilment Process

technology that matters

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Henri Arkink

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Abstract

This research is introduced to align the order fulfilment process at Nedap UV with the product and market characteristics of the products involved. Nedap UV manages the supply of UV drivers to customers and is the product group of Nedap this research is focussing on. In the UV product group delivery and workload problems arose frequently due to an ineffective, inefficient and uncontrolled order fulfilment process. Order fulfilment is interpreted in this research as the complex process composed of several activities undertaken by different functional entities, starting with planning the future orders up to delivering the customer orders at the right time and right place. To achieve the research goal*, a more effective, efficient and controllable order fulfilment process,* we stated the research problem as: “*How to align the tactical order fulfilment process to the product and market characteristics of Nedap UV?”* Tactical decision making based on procedures, rules and control systems is what is missing at Nedap UV to make the order fulfilment process operate effective and efficient. The tactical decision level has been overlooked as the high workload for the operational manager resulted in a lack of attention to structural problem solving. Analysis towards this tactical level of order fulfilment at Nedap UV revealed a lack of cooperation and alignment of internal order fulfilment processes. We solved this business process problem guided by the improvement framework of Rohleder and Silver (1997).

The focus of this research is set to three essential tactical order fulfilment processes, all controlled by Nedap UV. The remaining processes were not in control of Nedap UV or not significantly influencing the order fulfilment process performance. These three processes comprise the sales planning, service and inventory management and the supply planning. These processes were researched in combination with the UV product range to obtain a complete understanding of the current situation. Hereafter, we constructed a guide for aligning the three processes with the UV products’ product and market characteristics. The alignment process needs to be initiated for all product types individually as the alignment process is depending on the specific product and market characteristics of the products. To provide more understanding and clearance of the alignment process we introduced a set of pilot implementations according to the constructed process alignment guide. The selection of these processes is based on multi criteria analysis of three characteristics of the product groups. These characteristics influence the need for an aligned process per product and are the demand variability, the growth potential and the importance of the product group. Scoring these characteristics for the three product groups made us conclude that Product Group 1 and Product Group 3 are the most interesting pilot product groups to start a pilot alignment process for.

The research structure presented above resulted in an aligned order fulfilment process in which introduced rules and procedures provide structure to the processes involved. Results could not exactly be valued as performance was not measured formerly. However, for the selected pilot product groups we have proven that Nedap is able to improve their service conditions significantly in combination with a decreased inventory level. An example of these results is presented here for Product Type C. Aligning the processes for this product group resulted in a reduced safety stock level of 25%. But most important, 88% of the Nedap UV products are supplied within one instead of eight weeks in the aligned process. Concluding, aligning the order fulfilment for this product type results in less inventory costs while service conditions are improved significantly for 88% of the orders.

The process alignment was based on a targeted service level of 97.5% of the products supplied before the agreed delivery date. This service level is not monitored so far, however, employees involved assume this service level not to be attained structurally before. These findings suggest that the order fulfilment process alignment will result in significantly improved service conditions while Nedap UV requires fewer resources. Besides these effects on the customer satisfaction, the aligned order fulfilment process will have a significant effect on the workload problem as well. We expect the average effort to fulfil an order to decrease significantly because of the formalisation of the process. Formalisation of processes increases the standardisation of them which leads to clarified tasks and clear responsibilities for the employees. Apart from that, orders are fulfilled in a smaller time frame. While these orders are completed earlier, customer complaints or order modifications will appear less frequently. We expect all of this to lead to more efficient and effective fulfilment of orders, with a decreased amount of delivery and workload problems.

To increase the targeted controllability of the processes we suggested Nedap UV to introduce a performance management system. This system should expose the performances of the processes by measuring several key performance indicators. We introduced a set of performance indicators for this performance management system which measure the sales planning reliability and the stock and delivery performance. These performance indicators are:

- (*1.1) Nedap 12-month sales planning versus actual sales per product type*
- *(2.1) On-hand stock level per product type*
- *(2.2) Stock turnaround time per product type*
- *(2.3) Total inventory value UV in Euro's*
- *(3.1) Percentage of products delivered on time per product type*
- *(3.2) Lateness per supplied product in days*

The performance management system with these performance indicators should aim for a continuous improving process of order fulfilment. This continuous improvement should be attained by learning from and acting on appeared problems and deviations from set targets. After designing a performance management system Nedap UV should implement the order fulfilment process for its complete product range.

Table of Contents

List of Terms and Abbreviations

- ATO *Assemble-To-Order*
- AVI *Automatic Vehicle Identification business unit*
- BPM *Business Process Mapping*
- BWM *Ballast Water Management convention*
- Ch. *Chapter*
- CODP *Customer Order Decoupling Point*
- Conf. *Confidential*
- Curing *The drying process of a wide range of products in digital printing/coating and painting applications*
- CV *Coefficient of Variation*
- Effectiveness *The extend of efforts or expenses actually contributing to the realisation of set goals*
- Efficiency *The extend of processes using a small amount of resources compared to standards*
- EP *Explosion Proof product group*
- ETO *Engineer-To-Order*
- HID *High Intensity Discharge lamp*
- Lamp Driver *Intelligent ballast to power and operate lamps*
- LC *Light Controls business unit*
- MPSM *Managerial Problem Solving Method*
- MSE *Mean Square Error*
- MTO *Make-To-Order*
- MTS *Make-To-Stock*
- Nedap *Nederlandse Apparatenfabriek*
- PLC *Product Life Cycle*
- PCB *Printed Circuit Board*
- QL *Induction Lighting product group*
- R *Review period*
- R&D *Research and Development*
- R&I *Retail & Industry product group*
- S *Order-up-to-level*
- s *Reorder point*
- SCM *Supply Chain Management*
- SKU *Stock Keeping Unit: item of stock that is completely specified as to function, style, size, colour and location.*
- UV *Ultra Violet product group*

List of Figures

List of Tables

1. Introduction

Nedap is a growing company that provides intelligent technological solutions concerning worldwide relevant themes, such as the lack of clean drinking water. This rapid growth and innovative attitude caused a downgraded attention for structural process improvement in the company. Nedap is now facing the question how to handle this growth. The board of Nedap decided to implement the 'Road to Excellence' program to challenge this question in several company segments. This research focuses on one of the aspects of this "Road to Excellence" program; improving the order fulfilment process for a specific product group at Nedap. The first chapter provides the reader an introduction to the company Nedap and its problem situation. In Section 1.1 the company Nedap N.V. is described and its problem situation is introduced in Section 1.2. The information presented in these two sections originates from the company's website (Nedap, 2012) and from interviews with the employees involved in the problem situation. In Section 1.3 the problem is more exactly stated, where after we introduce the research objectives and deliverables in Section 1.4. The research approach to achieve the stated objective is presented in Section 1.5 and this chapter end with an outline of the scope and boundaries of the research in Section 1.6. In the remaining of this research we present some confidential information only in Appendices to prevent this information from appearing in any public version of this research.

1.1 Introduction to Nedap N.V.

Nedap N.V. is a developer and manufacturer of innovative solutions for worldwide relevant issues. These solutions include products such as self-sufficient water purification systems and sustainable energy control systems. The company was established in 1929 in Amsterdam and has been listed on the stock exchange (NYSE/Euronext) since 1947. In that same year Nedap relocated to Groenlo because of a lack of opportunities to expand in Amsterdam. In those years Nedap was one of the first Bakelite processing companies. Nowadays Nedap has evolved to a company with a yearly turnover of over 170 million Euros, as is visualised in Figure 1.1. The company currently employs over 700 people and runs sales offices in different countries in Europe, the Middle East, Asia and North America. Inside Nedap nine business units are separated based on the functionality of the business units' products:

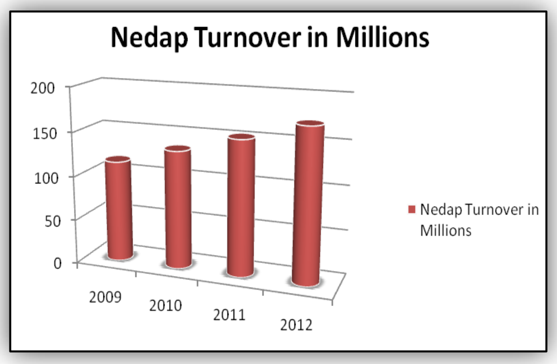

Figure 1.1: Nedap Turnover 2009-2012

- AVI (Automatic Vehicle Identification)
- Energy Systems
- Healthcare
- Library Solutions
- Livestock Management
- Light Controls
- PEP (hour registration system)
- Security Management
- Retail

1.3 Problem Statement

The growth in turnover of the UV product group has resulted in a decreased level of control over the order fulfilment activities. Problems and issues are mainly treated on an ad-hoc basis because of a growth in workload for the specific employees. This has resulted in an unstructured order fulfilment process. Currently it is unclear to the employees in the product group how to handle the prospective growing amount of orders. Examples of recurrently occurring problems are given below:

1. Dependency on the operational manager is large due to a lack of structure in processes
2. Response to demand changes is not immediately apparent
3. New customers cannot be supplied within a week which is inconsistent with goals
4. Small and irregular orders are delivered late which is inconsistent with promises

These problems were repeatedly mentioned in the introductory interviews with Nedap employees. For the first of the aforementioned problems we want to indicate that the absence of the operational manager leads to multiple order fulfilment problems. As the operational manager function became unstructured and uncontrollable, the current operational manager is the only employee at Nedap UV knowing what this function entails. This example provides insight in the lack of structure in the order fulfilment processes. We define order fulfilment in this thesis as: *The complex process composed of several activities undertaken by different functional entities, starting with planning the future orders up to delivering the customer orders at the right time and at the right place.* This definition originates from Chapter 3 but is given here for the reader to achieve similar understanding of the term.

The unstructured way of working has resulted in a situation in which the operational manager controls the situation by managing processes based on experience. There are no clear mechanisms or policies defined to measure control or coordinate the order fulfilment process. Examples of this lack of structure are missing performance indicators to control the process and inconsequent due date quotations. As the UV product group is successful from a financial perspective this unstructured way of working has so far been condoned. Now that problems affect the customer satisfaction, Nedap UV wants to solve this problem. The solution to hire additional employees to manage growth is not desired as it contrasts with the efficiency goals stated by the CEO of Nedap. (Wegman, 2012)

The unstructured order fulfilment process implies a need for control and coordination over this order fulfilment process. Daft (2007) prescribes the installation of rules, procedures and control systems to increase control and coordination in processes. New coordination and control systems enable organisations to continue growing more formalised. The formalisation of processes creates more structure and coordination between activities. From the recurring problems, employee experiences and the Daft (2007) theory mentioned we conclude that order fulfilment at Nedap UV is suffering from a lack of structure in rules, procedures and control systems. Tactical decision making based on procedures, rules and control systems is what is missing at Nedap UV to make the order fulfilment process operate properly. The tactical decision level has been overlooked as the high workload for the operational manager resulted in a lack of attention to structural problem solving. The tactical level includes translating the company strategic goals into operational management on the mid-term, referring to weekly or monthly planning decisions. (Hans & Schutten, 2012) We outline the focus on the tactical level and its function more explicitly in Chapter 3.

Analysing the tactical level of order fulfilment at Nedap UV reveals a lack of cooperation and alignment of internal order fulfilment processes. By aiming for a more effective and efficient order fulfilment process we need to create alignment between operations in this process. The lack of alignment in the tactical level of order fulfilment is concluded to be the main cause for the growing amount of problems and issues. The different tactical process steps involved in order fulfilment need to include the effects of product and market characteristics to create a streamlined process. The effects of these product and market characteristics have to become evident by researching them for different process steps. An example of these characteristics is the variability of demand for customer specific products or products with multiple customers. As risks in these two situations differ, adapted inventory management policies have to be installed. Aligning the various processes involved with the product and market characteristics will result in a correctly functioning tactical order fulfilment process. Summarising this section leads to the research problem of this research:

How to align the tactical order fulfilment processes to the product and market characteristics of Nedap UV?

1.4 Research Objective and Deliverables

To solve the research problem we need to design a tactical order fulfilment process that is aligned to the Nedap UV product and market characteristics. The formalisation of the tactical process has to facilitate the decision making and clearance of the order fulfilment process. With formalising the order fulfilment process we aim to decrease the occurrence of problems and issues and increase the control over the process. This should result in a more effective and efficient order fulfilment process which is able to handle more orders with less effort. The overall research objective for this thesis is:

A more effective, efficient and controllable order fulfilment process

The deliverables accompanying this research objective are:

- A description of (the current) order fulfilment processes
- A description of products and markets and their characteristics
- A formalised tactical order fulfilment process taking the product characteristics into account
- An aligned order fulfilment process for pilot products
- A set of key performance indicators to monitor and control the order fulfilment process

The deliverables introduced are the foundation of the research approach and will be closely related to the upcoming research questions. Accomplishing the research goal and its deliverables will result in a more effective, efficient and controllable order fulfilment process. As Nedap is currently not registering the experienced problems or delivery performance, effects of this implementation cannot be measured. By installing a set of key performance indicators for the order fulfilment process we make future processes and their performance measurable. Implementing this measuring and control system will also help to identify and solve future problems.

1.5 Research Approach

In order to accomplish the research goal and deliverables we introduce a research approach based on two scientific methods. First of all we used the Managerial Problem Solving Method (MPSM) by Heerkens (1997) to define a structured approach for the Nedap UV problem situation. The problem identification and problem approach by Heerkens are the foundation for this research. These two steps comprise Chapters 1 and 2 of this research. These chapters identified the research problem which involved the tactical business process of order fulfilment. To actual improve the business process we use the model on business process improvement by Rohleder and Silver (1997). Figure 1.3 illustrates the method of Rohleder and Silver (1997) to establish business process improvements. The flowchart in this figure is equal to the original model of Rohleder and Silver (1997), but the figure is adapted to the style of this report. The figure also illustrates the scope of this research with selecting process steps in the dotted focus area. The Rohleder and Silver model distinguishes itself from other improvement models as it uses elements of both re-engineering and TQM. This makes the model comprehensive and well suitable for the situation at Nedap UV in which is aimed for a continuous improvement business process.

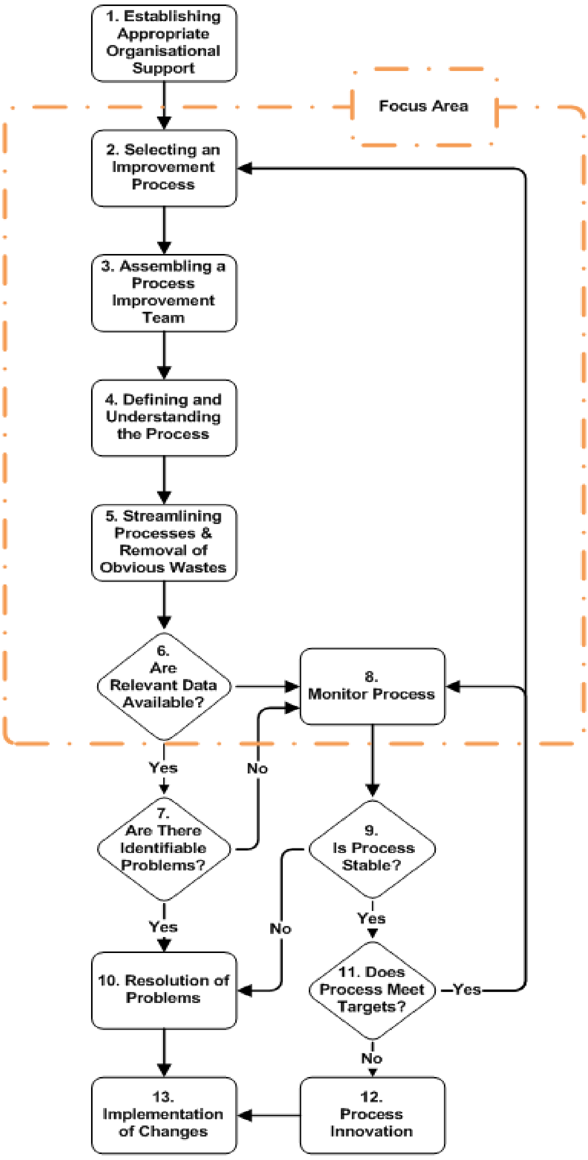

Figure 1.3: The Business Process Improvement Framework (Rohleder & Silver, 1997)

According to the framework *Step 1* includes establishing appropriate organisational support for the problem situation. We consider this step to be completed as the problem is recognised by multiple persons involved in the problem situation. The recognition of the problem introduced before has even led to the initiation of this research aiming to resolve the problem situation. As top management of Nedap is committed to this research as well we conclude the problem situation to have appropriate organisational support. In the first two chapters we identified the order fulfilment process as the root cause for the organisational problems. The selection of this process as improvement process finishes *Step 2* in the framework of Rohleder and Silver framework.

To clarify exactly what an order fulfilment process encompasses we introduce Research Question 1:

1. *"What is an order fulfilment process?"*

This knowledge problem will be solved by initiating a literature research towards the order fulfilment process. Amongst other theoretical subjects the order fulfilment subject will be discussed in the next chapter. This Chapter 2 provides an insight in the state-of-the-art theory related to this research. As such it provides a foundation for the remainder of the research. Collecting the required theory for this research has been an iterative process with other upcoming chapters to make sure all required theory will be available in the theoretical chapter. *Step 3* in the business process improvement framework includes assembling a research team. This research team consists of the employees involved in the order fulfilment activities at Nedap. The team includes the general manager, the operational manager and two account managers. This team will be managed and led by the researcher and advised by an external consultant. Involving the Nedap UV employees is essential in this team to develop a sense of process ownership. This will encourage the employees in the implementation and execution phase of the outcomes of this research. (Olsson, Johansen, Langlo, & Torp, 2008) The organisational chart of this research team is presented in Appendix C.

The fourth step according to the Rohleder & Silver framework is defining and understanding the process. To define and understand the order fulfilment process we introduce Research Question 2:

2. "*How is the Nedap UV order fulfilment process operating currently?*"

The answer to this research question will result in a representation of the current Nedap UV order fulfilment process. This question is researched empirically by observing the current processes and interviewing the specific process' employees. To ensure the correctness of this representation an interactive meeting with the employees involved is organised to discuss the research outcomes. The research question will be answered by a phased plan of three subsequent steps:

1. *Visualise the current order fulfilment process in a map*
2. *Describe the current order fulfilment process*
3. *Define the tactical order fulfilment process*

The first step of this phased plan provides a visualisation of the order fulfilment process at Nedap UV in the current situation. This visualisation aims to provide the reader a flowchart to see the different process steps for order fulfilment in perspective. After the visualisation of the order fulfilment process we describe the visualised process to add clarification to certain process flows. The last step in our phased plan to fulfil *Step 4* of the Rohleder & Silver framework includes clarification of the order fulfilment processes on the tactical process level. With this step we clarify which order fulfilment processes at Nedap are influenced by the tactical level we focus on in this research. The phased steps for answering Research Question 2 will be executed in Chapter 3, in which we aim for a complete understanding of the current situation at Nedap UV. This complete understanding also includes the products and markets of Nedap UV. From these findings we attempt to find the most appropriate pilot products for this research by answering Research Question 3:

3. "*What products are the most appropriate to function as pilot products for Nedap UV?*"

Finding an answer for this research question starts with introducing the products and markets that are supplied by Nedap UV. This first phase will be completed by gathering data about the products and markets complemented with the product and market knowledge of the Nedap UV employees. After completion of this first step we research what product and market characteristics are affecting the found tactical order fulfilment processes most significantly. These characteristics are included in aligning the order fulfilment processes to create a dynamic process which is able to handle products with different characteristics. Once the characteristics description is completed we select a number of pilot products to align the order fulfilment process for. This selection will be based on scaling the product's characteristics on several criteria indicating the potential influence on the order fulfilment process. Concluding, Research Question 3 will be answered in three separate phases:

1. *Describe the different products and market Nedap UV supplies*
2. *Describe the product and market characteristics that might influence the order fulfilment process*
3. *Decide for which pilot products we align the order fulfilment process*

A combination of theoretical knowledge, empirical research and knowledge of the employees involved is required to complete these phases. To verify the findings in this chapter we will organise a meeting with the employees involved to check its completeness and correctness. The next step in the framework of Rohleder and Silver (1997) is streamlining the processes and the removal of obvious wastes. As mentioned by Rohleder and Silver (1997) and Trietsch (1992) an example of this waste is an overly complicated or unclear process. The lack of clarity of processes is solved in the first two research questions. With the next research question we aim to streamline the order fulfilment processes, like *Step 5* of the business improvement framework suggests. We introduce Research Question 4 to show how to align the order fulfilment processes:

4. "How to align the order fulfilment processes to the product and market characteristics of Nedap UV Products?"

Answering this question has to result in a streamlined order fulfilment process which takes different product and market characteristics into account. This renewed process will result in a more effective, efficient and controllable order fulfilment process. Aligning the processes will be mainly based on theory for establishing order fulfilment processes and is presented in Chapter 4. In the next chapter this process alignment is put into practice by the implementation for the chosen pilot products in Research Question 3. This pilot product implementation will provide Nedap UV a good example to carry out the order fulfilment process alignment for all of its individual products.

Streamlining the order fulfilment process finishes the fifth step of the business process improvement framework. *Step 6* includes a decision step which questions if relevant process monitoring data is available. As the performance measurement process at Nedap UV is far from complete we have to continue to S*tep 8*. This step includes the introduction of a monitoring process to measure the process performance. As not for all products an aligned process will be designed in Chapter 5 Nedap UV has to learn from the pilot alignment processes. This learning process will be more effective when effects and performances of the aligned process can be monitored. For that reason we finish the research with designing a set of monitoring indicators to measure the performance of the order fulfilment process. Also for this last step a research question is introduced:

5. "What indicators are required to monitor and control the order fulfilment process performance?"

The answer to this question encompasses a set of performance indicators to measure the order fulfilment performance of Nedap UV. This question will be answered by literature research on key performance indicators in relation with order fulfilment. The theoretical information found forms input for a discussion with employees involved about which indicators to use at Nedap UV.

The framework of Rohleder and Silver (1997) suggests additional steps are required, while this research is bounded to a time limitation we end the process at Step 8. As pointed out by Zangwill (1995), proceeding until the 'streamlining processes'-step of this framework can lead to substantial benefits already. The further steps of the framework will be discussed in the recommendations to Nedap in Chapter 7. Ultimately this research will provide an answer to the main question in this research: *"How to align the tactical order fulfilment processes to the product and market characteristics of Nedap UV?"* The answer to this question is provided by aggregating the results of all stated research questions and has to leads to the final research goal: *"A more effective, efficient and controllable order fulfilment process".* The research structure of the thesis to achieve this goal is presented in Figure 1.4. The research has an iterative structure as is emphasised by the red backwards arrows. These arrows represent the iterative process of this research in such a way that chapters will have regular backwards interaction to form an aligned whole.

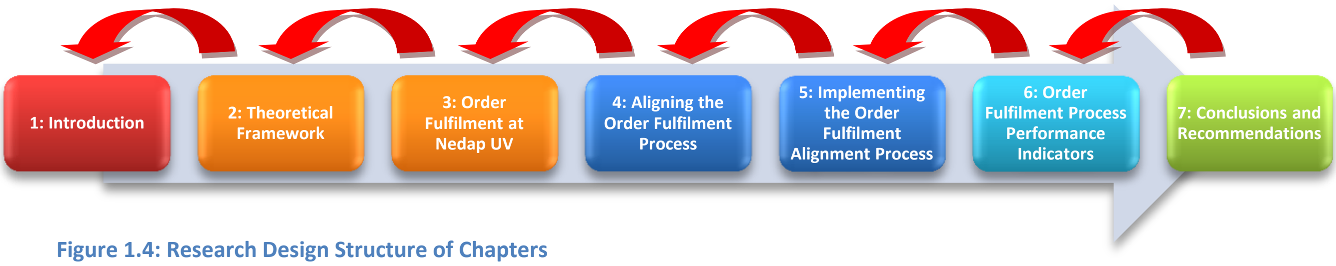

Figure 1.4: Research Design Structure of Chapters

1.6 Research Restrictions

The research is limited to the order fulfilment activities at Nedap as most problems are observed in this process. The purchasing, production, marketing, after-sales, and research and development activities are not included in this research. These activities are not part of the research focus or managed by the subsidiary of Nedap; Inventi. This does not imply that this research will not affect these activities; it only states that there is no focus on. After all, a streamlined order fulfilment process can only be achieved by cooperating and exchanging information with all other processes involved in the supply chain. (Bilgen & Ozkarahan, 2004)

To decrease the complexity of this research we assume all processes at Inventi to have fixed parameters. For example this includes the standardised production throughput time from Inventi of eight weeks. This standardised throughput time is agreed upon between Nedap and Inventi. We do not research the necessity of this eight weeks lead-time as Inventi is not the focus of this research. Other examples of these fixed parameters are the capacity of the production location or inventory location. Furthermore, we consider Inventi as Nedap UV's only supplier, however this is not necessarily so in practice. Time limitations affect the earlier mentioned partial implementation of the Rohleder and Silver framework and the implementation of the process alignment of only pilot products.

2. Theoretical Framework

This chapter describes and explains the required theory for the execution of the research. We start with a theoretical description concerning the process of order fulfilment in Section 2.1. With this theoretical description of the order fulfilment process we intent to answer Research Question 1: *“What is an order fulfilment process?”* With answering this question we provide the theoretical background for the description of the Nedap UV order fulfilment process in Chapter 3. Section 2.2 focuses on the theory of the characteristics of products and markets that might influence the order fulfilment process. The last section of this chapter provides the foundation for answering the last research question: *“What indicators are required to monitor and control the order fulfilment process?” A* definition of key performance indicators and their function will be presented in this section. In the end this chapter provides the theoretical information required to answer multiple research questions.

2.1 The Order Fulfilment Process

This section describes the order fulfilment process in general based on literature research. In the first subsection the process of order fulfilment process will be highlighted, while the second subsection highlights the order fulfilment processes on the tactical aggregation level.

2.1.1 Order Fulfilment

Lin & Shaw (1998) see an enterprise as to be supported by the following three core business processes: the product development process, the order fulfilment process and the customer service process. “These three core processes support an enterprise just as pillars support the roof of a building”, as asserted by Lin & Shaw (1998). The complexity of the order fulfilment process is clarified by Johnson and Davis (1998): “Order fulfilment sounds like a simple matter, however, order fulfilment is not merely a routine task performed by a material handler, shipping clerk or cashier. More importantly, it is the desired result of many complex processes undertaken by the entire business”. It has become a complex process as it is composed of several activities, executed by different functional entities which have strongly interdependent tasks, resources and agents involved in the process (Lin & Shaw, 1998). This composition of activities and functional entities is explained by Johnson and Davis (1998): Four functional entities are involved in order processing. The first entity is the R&D and marketing entity which has to fulfil the product design and the forecasting process of the products involved. A second entity is the production facility which has to handle supplier management and production planning. The sales and support entity has to support and manage the quotations and processing of incoming orders. The last entity is the delivery management which is conducted by the distribution unit. A well-performing order fulfilment process arises from the successful interaction of these entities to deliver exactly what the customer wants. Central to order fulfilment excellence is the mastery of the network of processes by which the product physically moves through the processes to the final customer. (Johnson & Davis, 1998)

Bozart and Chapman (1996) present a distinction between on-line and off-line activities in the order fulfilment process. The on-line activities can only be started when a customer order arrives and ends when an order is delivered. The off-line activities are those that can be completed before the arrival of a specific order, such as order planning, procurement and component manufacturing. In the end, including the off-line process broadens the total process by including the planning stages. In literature there is some ambiguity to the process boundaries of order fulfilment. The perception of the order fulfilment we will use in this research accords with Shapiro et al (1992) and Kritchanchai and MacCarthy (1999). They argue that a comprehensive on-line and off-line view of the order fulfilment process is necessary for researching this process. For that reason we define order fulfilment as: *the complex process composed of several activities undertaken by different functional entities, starting with planning the future orders up to delivering the customer orders at the right time and right place.* The main objectives of order fulfilment introduced by Christopher (1992) and Goldman, Nagel and Priss (1995) are stated as: "(1) delivering qualified products to fulfil customers' orders at the right time and right place, and (2) achieving agility to handle uncertainties from internal or external environments". Now the general order fulfilment process is defined we specify this process on the targeted tactical aggregation level of the process.

2.1.2 Tactical Order Fulfilment Processes

The lack of structure with regard to the tactical aggregation level of order fulfilment is stated as the main problem of Nedap UV. Now that the general order fulfilment process is defined we want to specify the tactical aggregation level of this process concretely. The foundation of the tactical aggregation level is required to provide an answer to the third step of the second research question: "*Define the tactical order fulfilment processes".* In literature three hierarchical aggregation levels for business processes are distinguished (Schmidt & Wilhelm, 1999) (Bilgen & Ozkarahan, 2004). A company can only operate to its full potential if these three hierarchical levels are aligned:

- Strategic
- Tactical
- Operational

Strategic decision making handles the overall vision of the business. The strategic level aims to set and enable long term company and process goals for generally a couple of years in advance. Its focus is typically external to the business and concerns the future of the company. For example, it prescribes production technologies or plant capacities. The next hierarchical level is the *tactical* aggregation level. The tactical level involves the question: "How are we going to achieve the overall strategy?" In this level tactics have to be developed to achieve the outcome of the company's future goals. This tactical level is included in businesses to translate the long term company goals to operational management of the daily activities. It focuses mostly on the mid-term, which can be interpreted as a few weeks up to a year in advance. The tactical level prescribes for example material management policies, inventory levels and lot sizes. The lowest aggregation level is the *operational* level. This level indicates how activities are actually operated. The operational level mainly involves the small adjustments to current processes to still reach the desired outcome. As such, it controls the actual execution of processes on the short term. At a higher level of aggregation, decisions and functioning contain more impact, uncertainty, flexibility and investments. (Bilgen & Ozkarahan, 2004)

To clarify these aggregation levels with regard to actual business processes Hans et al (2007) introduced the Planning and Control Hierarchical Framework. We present this framework in Figure 2.1 as planning and control is closely related to the order fulfilment process as is introduced in the previous subsection. This model is mainly based on the modern Manufacturing Planning and Control Reference Architecture model by Zijm (2000). The model of Hans paves the road for more intelligent planning and control systems in companies in which processes are separated on their hierarchical levels. Hans et al introduce a separation based on managerial areas as well. The three managerial areas covered are technological planning, resource capacity planning and material coordination. The technological planning concerns all technological information in process planning and research and development. Resource capacity planning concerns the capacity management of production processes. And the last managerial area involves material management issues, like procurement and inventory management.

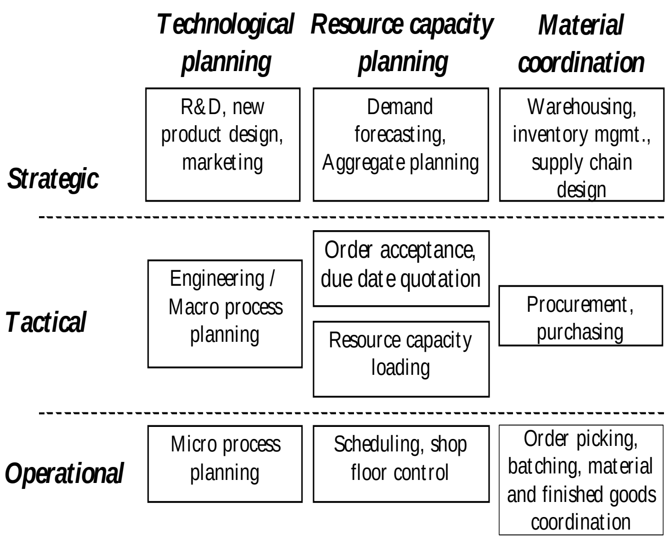

Figure 2.1: Planning and Control Hierarchical Framework (Hans et al, 2007)

Almost all control functions in the framework are related. For that reason insufficient coordination or communication between different functions may lead to problems. A clarifying example of this lack of communication and coordination is the salesman who attempts to sell as much as possible. In case the salesman does not consider the status of the production system nor the inventory, problems with agreed due dates might occur. In Figure 2.1 this concerns a lack of communication between the order acceptance function and resource capacity loading or inventory management processes.

The framework model by Hans et al (2007) provides a good overview over the supply side of the supply chain. However, as the translation of this model to the actual supply chain and business processes in a company is in our vision not completely clear we introduce a comparable model: The Business Reference Model of Schermers (2011). This model is based on the model of Hans et al (2007), but includes a more direct connection to business processes in the supply chain. For example, it includes the sales planning side of a supply chain process as well. Hans et al made a horizontal distinction based on managerial areas. Schermers not only identifies managerial areas but added the complete supply chain process over the horizontal lanes. Also, the model of Hans et al (2007) is specifically designed for a make-to-order process, while the model of Schermers can be interpreted as more general. The model of Schermers (2011) is illustrated in Figure 2.2 on the next page.

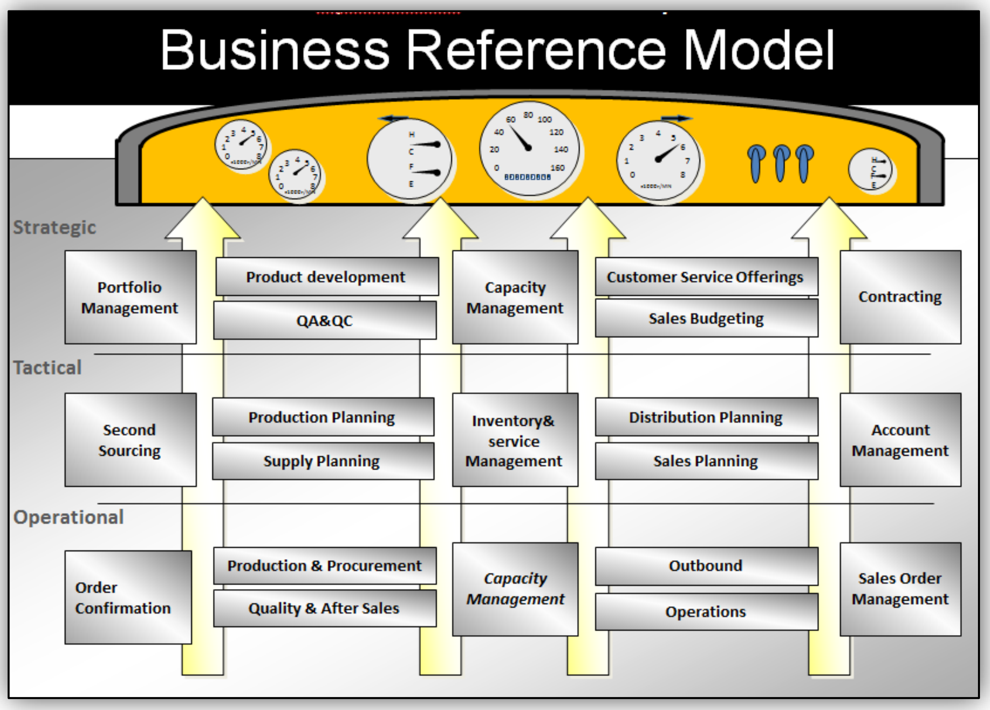

Figure 2.2: The Business Reference Model by Schermers (2011)

The model indicates the same hierarchical level separation as Hans et al, but it differs in the separation on a horizontal basis. Business processes in the supply chain are closely linked from side to side. Our research focuses on the tactical aggregation level of business processes. For that reason we explore this level more concrete here. The left side of the model comprises the sourcing process of components and raw materials. This process is depicted on the right side in the tactical level of the model of Hans et al (2007). A supply planning is then introduced to base the production planning on. The production schedules and plans are integrated in the tactical technological planning in the model of Hans et al (2007). The linkage between the supply and demand sides is introduced as inventory and service management by Schermers (2012). Inventory management has a hedging function because demand and supply will never exactly be similar. Service management concerns here the order acceptance and due date quotations to align supply and demand. This process of the model also forms the resource capacity planning in the middle of the model by Hans et al (2007). The right side of the model by Schermers (2011) functions as the demand side of the model. This part of the model is not considered by Hans et al. Schermers introduced account management as the input for the sales planning. The account management process is the closest link to the customer and requires customer and market knowledge. For satisfying customers' demand according to the constructed sales planning a distribution planning is required. And to be able to deliver according to the distribution planning supply and demand have be tuned by the inventory and service management function. (Schermers, 2011)

The two models described above are introduced here to place the order fulfilment theory described in Subsection 2.1.1 in contrast to the tactical Nedap processes in Chapter 3. We use the model of Schermers to identify the individual tactical processes of order fulfilment at Nedap. This model is used as it provides a practical and complete approach to the order fulfilment process.

2.2 Product and Market Characteristics

The goal of this second theoretical section is to provide the reader the required knowledge of product and market characteristics. The outcomes of this section form the foundation for answering Research Question 3: "*What products are the most appropriate to function as pilot products for our research?*" For example, key characteristics which require some theoretical background before they can be included in the alignment of the order fulfilment process are explored in this section. First, a more general indication of the influence of product and market characteristics will be described for different types of products. This classification method is required to scale individual products to be able to answer Research Question 3.

2.2.1 Product and Market Characteristics in General

Product and market characteristics influence the order fulfilment process for example by their degree of uncertainty. Demand uncertainty is closely related to the predictability of demand for a product. Fischer (1997) distinguished two different categories of products: functional and innovative products. Demand for functional products is relatively easy to forecast while demand for innovative products is highly unpredictable and contains much uncertainty. Functional products tend to have lower product profit margins for a given demand in general, while innovative products bring more risks but higher profits as well. The inclusion of these uncertainty characteristics is essential for aligning business processes to their products. For functional products with predictable and stable demand patterns an order fulfilment process should be completely standardised in a cost efficient way. For innovative products with high variable demand which is difficult to forecast a very specific process should be designed. This section provides an indication of how different product characteristics can influence the design of an order fulfilment process. For example the innovative products will require relatively high inventory levels to hedge against the high variable demand while for functional products the cost efficiency regarding inventory levels is considered to be most important. (Lee, 2002) This general product and market characteristic section gives an introduction to the more specific product and market characteristics in the upcoming section.

2.2.2 The Product Life Cycle

To continue describing the influence of product characteristics on business processes we introduce the product life cycle. This characteristic requires additional exploration before usage in this research. A visual representation of the product life cycle and its stages is provided in Figure 2.3 and the four product life cycle stages are described below:

1. *Introduction/Development stage:* The product development stage until the market introduction
2. *Growth stage:* The period between product take-off and the eventual decline in sales rate growth
3. *Maturity stage:* The period in which product sales are stable until a steady decline of sales arises
4. *Saturation/Decline stage:* The period in which sales rate steadily decreases until the end of product demand

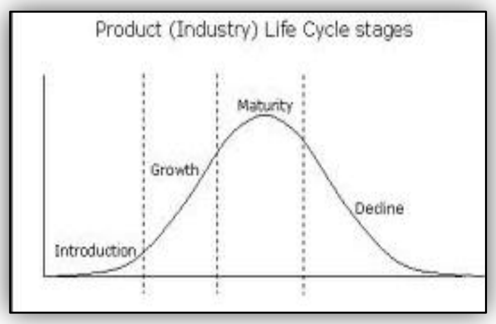

Figure 2.3: The Product Life Cycle (Barksdale & Harris, 1982)

The *introduction stage* of the PLC is often seen as a trial period and sales do often only increase once this trial period shows satisfying experiences at customers. This can result in depressed early sales and the development stage to be longer than seems justified, considering the potential of the new product (Tellis, Stremersch, & Eden, 2003). At the next stage, a significant portion of consumers has adopted the new product and other consumers might use general adoption to decide to buy the product as well. In this *growth stage* product sales can increase steeply. This increasing growth rate is likely to end somewhere as potential triggers result in a decline of this growth rate. Examples of these potential triggers are new rival technologies or changes in the economic environment. Triggers can result in a slowdown in market sales up to a flattened or decreasing sales line. This saturating period is indicated as the *maturity stage* of a product life cycle. Finally the product will be overtaken by newer versions and demand will decline up to the end of product life. This final period of the product life cycle is referred to as the *decline stage.* (Golder & Telis, 2004)

The stage of the Product Life Cycle (PLC) of a specific product can be of essential importance in businesses processes as is stated by Hofer (1975): “The most fundamental variable in determining an appropriate business strategy is the stage of the product life cycle. Major changes in product strategy are usually required during the stages in the life cycle.” Hofer (1975) provides an indication of the importance of this product life cycle to the business processes involved. Managers need to be aware of the growth rate of products to accurately plan sales, production and inventory levels. For that reason the Product Life Cycle (PLC) stage is an essential characteristic of a product group for aligning business processes.

Predicting the turning point of a life cycle stage of a product is essential to avoid premature withdrawal of or excessive investments in products. As Golder and Tellis (2004) indicate the turning points in the life cycle can be identified by accurate performance indicators, such as sales rates and forecasts performances. These indicators can prevent businesses from having excessive amounts of products on stock or making big investments on products in a declining product life cycle stage. The length of the PLC appears to be governed by the rate of technological change, the rate of market acceptance and the ease of competitive entry. (Silver, Pyke, & Peterson, 1998) These market characteristics are a good indication for the perspectives of the products future. The perspectives of a product should be involved in the redesign of an order fulfilment process to make the redesign dynamic and complete. Identifying the perspectives of a product by the product life cycle is for that reason a main aspect for aligning order fulfilment processes based on product characteristics.

2.2.3 The Customer Order Decoupling Point (CODP)

The Customer Order Decoupling Point (CODP) is added here as it indicates the degree of influence the customer has in the order fulfilment process. This CODP indicates where the product flow changes from a push to a pull situation. In a pull situation the considered process waits until the order is requested by its next stage in the process. While in a push situation the product is ‘pushed’ forward by its preceding process through the production process. Jobs are planned in advance for a series of work centres in this situation (özbayrak, Akgün, & Türker, 2003).

The CODP was first described by Hoekstra and Romme (1992), and is formally defined by them as: *"The point in the product axis to which the customer's order penetrates. It is where order driven and the forecast driven activities meet. As a rule, the CODP coincides with an important stock point from which the customer has to be supplied".* A more current version of the CODP is visualised by Olhager (1994) in Figure 2.4.

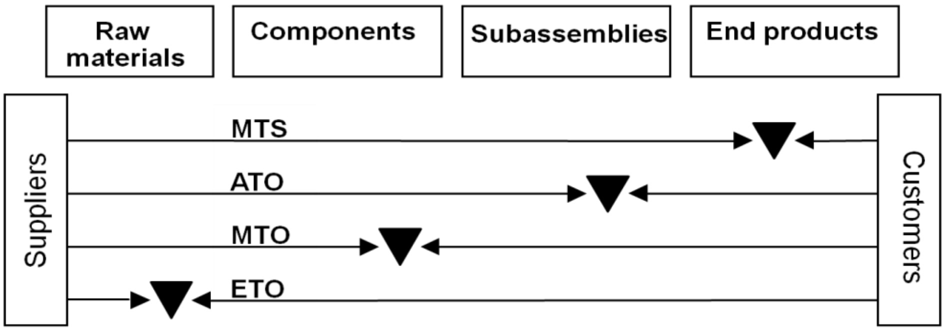

Figure 2.4: The Customer Order Decoupling Point (Olhager, 1994)

In this figure the arrows pointing to the right indicate to what extent forecasts are integrated in the production process. The opposite arrows to the left indicate to what extent production is based on customer orders. In between the two arrows a triangle is given which indicates the Customer Order Decoupling Point.

The first given CODP is a *Make-To-Stock (MTS)* situation. This is the typical production philosophy for the main part of the consumer products such as food and drugs. Products are in this situation manufactured without interference of the consumer. While the relationship between the manufacturer and the market is only indirect, end products are produced on stock. And quantities are bases on forecasts. *Assemble-To-Order (ATO)* is the second point in the CODP; this often indicates that a large variety of products are assembled out of a small range of components. All these components are produced on stock and will be assembled based on consumer demand. Car manufacturing is a good example of this ATO system, while high stocks of final products are avoided manufacturers are still able to react relatively fast. The *Make-To-Order (MTO)* decoupling point is the production system in which only materials are procured on basis of forecasts. Companies that produce in this mode face a wide range of finished goods and components. This often indicates small batch manufacturing and is common in the metal industries. The last CODP defined is *Engineer-To-Order (ETO).* Products in this system are designed and engineered based on functional specification of the customer. A close cooperation with the customer is required and only when agreements over the design are reached materials are purchased. Mostly highly specialised products are produced in an ETO system.

This separation of decoupling points is presented here as it influences an order fulfilment process. The integration of the customer in a process is of key importance for the construction of a sales and supply planning and in decision making for use of inventory. For example inventory of finished goods is only required for a product with a make-to-stock decoupling point. And if products have a MTO decoupling point a sales planning and inventory model can be ignored as orders are only produced on order. In this way the order decoupling point of products has an essential influence on establishing an aligned order fulfilment process.

2.3 Performance Measurement

In the PLC description in Subsection 2.2.2 performance indicators are already mentioned as important measures to identify product trends and life cycle stages. In general, successes of order fulfilment processes depend on monitoring and controlling possible gaps between planning and execution. In practical business cases it turned out that it is impossible to remove these gaps completely from your processes. As long as the future cannot be fully known decision-makers have to develop their operational plans under uncertainty. To perform successfully in operations organisations have to monitor how planning and execution are in line with each other. Performance measurement and monitoring is the term for a set of metrics and processes related to assessing and evaluating how accurate the planning is and how well the execution is carried out, according to Chae (2009). Important to succeed in performance management are incentives to work on this performance measurement and the required support from top management. (Chae, 2009)

Performance measurement is advised by Cox, Issa and Arens (2003) to be done on basis of Key Performance Indicators (KPIs). KPIs are compositions of different data measures used to measure the performance of a certain operation. (Cox, Issa, & Ahrens, 2003) The amount of KPIs a company introduces is suggested to be 'less is better' for developing performance measures. A focus on a small list of KPIs in a range from 5 to 10 which measure only the critical performances of operations is the most effective following industry standards and best practices (Chae, 2009) (Fortuin, 1988). Managers know that relevant metrics and performance objectives are fundamental to a successful business. Still many of the implementation efforts for KPI's are fruitless, to become effective in measuring managers must rise to several challenges: measure only the right things, avoid meaningless efforts and use the results productively. (Johnson & Davis, 1998) Furthermore, objectives should be clear to everybody, results should be shown and progress should be rewarded. Focus should be on these challenges to make a performance management work. (Fortuin, 1988)

Johnson and Davis (1998) stated that successfully managing the order fulfilment process usually requires several metrics. Important measures are for example the *lead time* of the order fulfilment process and the *amount of order defects*. A process needs a general measure of performance that is immediately able to provide an indication of the overall performance of the order fulfilment process. To satisfy this fast performance check, Johnson and Davis (1998) suggest a service measure and an inventory measure. This service measure should measure the service quality, such as the *reliability of the delivery to a customer's desired delivery date.* This reliability measure can be extended by adding a measure for *the lateness of a shipment* in case is was delivered after the desired delivery date. (Schneiderman, 1996) To compensate this reliability a measure for inventory investment is required, like the *stock turnover time.* (Johnson & Davis, 1998) The most important performance indicators for an order fulfilment process can be summed as:

- Process lead time
- Amount of order defects
- Service performance
    - Reliability of delivery to a customer's desired delivery date
    - The lateness of a specific shipment
- Stock performance
    - Stock turnover time

In order to implement tactical key performance indicators the data must be stable over time, so that results will be consistent across reports from a variety of perspectives for analysis (Schuelke, 2001). When this kind of analysis is performed on operational data it will be inconsistent as it is subject to constant additions, updates and deletes. Tactical measuring should therefore be implemented only with stable or stabilised data. Key performance indicators should become a standard tool for control of business processes in all its aspects. However, they will only be successful in combination with a drive for continuous improvement in a company. For that reason the management team should constantly provide feedback on the process and the reporting to improve the performance measurement continuously. (Lohman, Fortuin, & Wouters, 2004)

2.4 Summary of the Theoretical Framework

We have introduced the theoretical foundation for several aspects of this research and are now able to start the empirical research of this thesis by researching the current situation at Nedap UV. We explored in this chapter the order fulfilment process in Section 2.1 and provided a general answer to Research Question 1: *"What is an order fulfilment process?"* This process is interpreted in this research as: *The complex process composed of several activities undertaken by different functional entities, starting with planning the future orders up to delivering the customer orders at the right time and right place.* Furthermore this thesis has provided a theoretical foundation for the tactical aggregation level of order fulfilment, for multiple product and market characteristics and the implementation of a performance measurement system. We introduce the overall theoretical framework for this section in Figure 2.5. This framework represents the influences of the discussed sections on the upcoming chapters. The arrows towards the Chapter 2 sections indicate the structure of this chapter. And the arrows in between the sections of Chapter 2 and the upcoming chapters indicate exactly where found information will be applied. For example, the Section 2.3 information will only be applied in Chapter 6 where we introduce performance measurement indicators of the order fulfilment process.

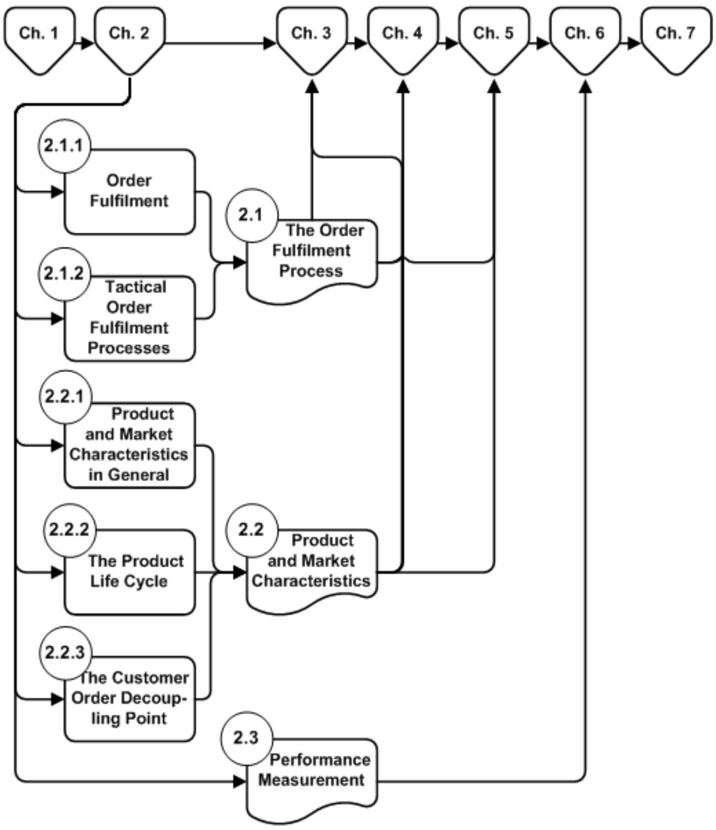

Figure 2.5: The Theoretical Framework of this Research

3. Order Fulfilment at Nedap UV

This chapter will present the order fulfilment process at Nedap. In Section 3.1 we will provide an answer to Research Question 2: *"How is the Nedap UV order fulfilment process operating currently?"* In this section a business process map and a description of the current order fulfilment process at Nedap UV is presented. Section 3.2 provides an answer to Research Question 3: *"What products are the most appropriate to function as pilot products for Nedap UV?"*

3.1 Nedap UV Order Fulfilment Process

The first part of this chapter will outline the order fulfilment process of the UV product group. This section provides a structured answer to Research Question 2 presented above. Answering this question starts with visualising the current order fulfilment process in a business process map, preceded by an explanation of the method of business process mapping. Mapping the current order fulfilment situation at Nedap UV will be continued by a description of the obscurities in the process map. Finally, the tactical order fulfilment processes relevant for this research will be clarified.

3.1.1 Order Fulfilment Process Map

Business Process Mapping (BPM) is the procedure of visually illustrating a business process in a flow chart. The purpose of BPM is to define the steps in a specific business process and to understand the flows between these steps. Process mapping assigns the responsible business unit for activities and decisions by classifying them in swim lanes. BPM can convey essential details of a process in one page, while a description in words would not provide enough detail and clarity in cohesion between process steps (University of California, 2012). Specific shapes display specific process aspects, processes and decision points for example are shaped differently in BPM. To explain these specific process aspects we depicted a business process map example in Figure 3.1, based on Henley (2008).

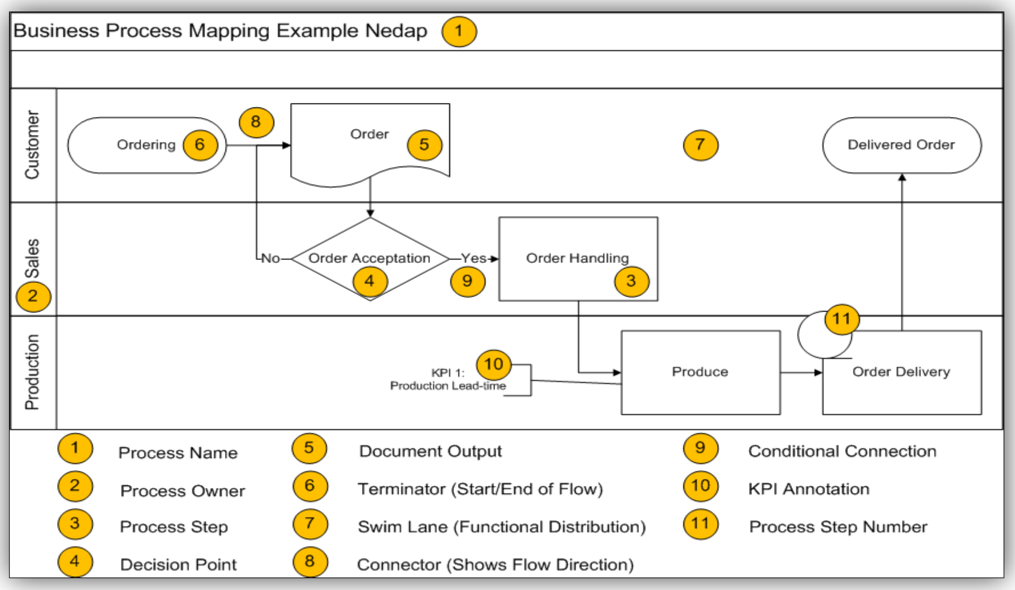

Figure 3.1: A Business Process Map Example

This example depicts possible process objects which can be used to visualise a complete process. The figure contains numbered nodes referring to the descriptions of the relevant object shape. Based on this business process mapping technique the order fulfilment process for the Nedap UV product group is visualised in Figure 3.2. With this business process map we aim to present a detailed understanding of the actual processes with its process flows. The process map visualises the activities, decisions and relations involved for the order fulfilment process at Nedap UV. Different processes in Figure 3.2 are numbered to indicate relations between the visualised processes and the order fulfilment processes described later on. The most complex and relevant process relations of this figure will be more extensively described in the upcoming section.

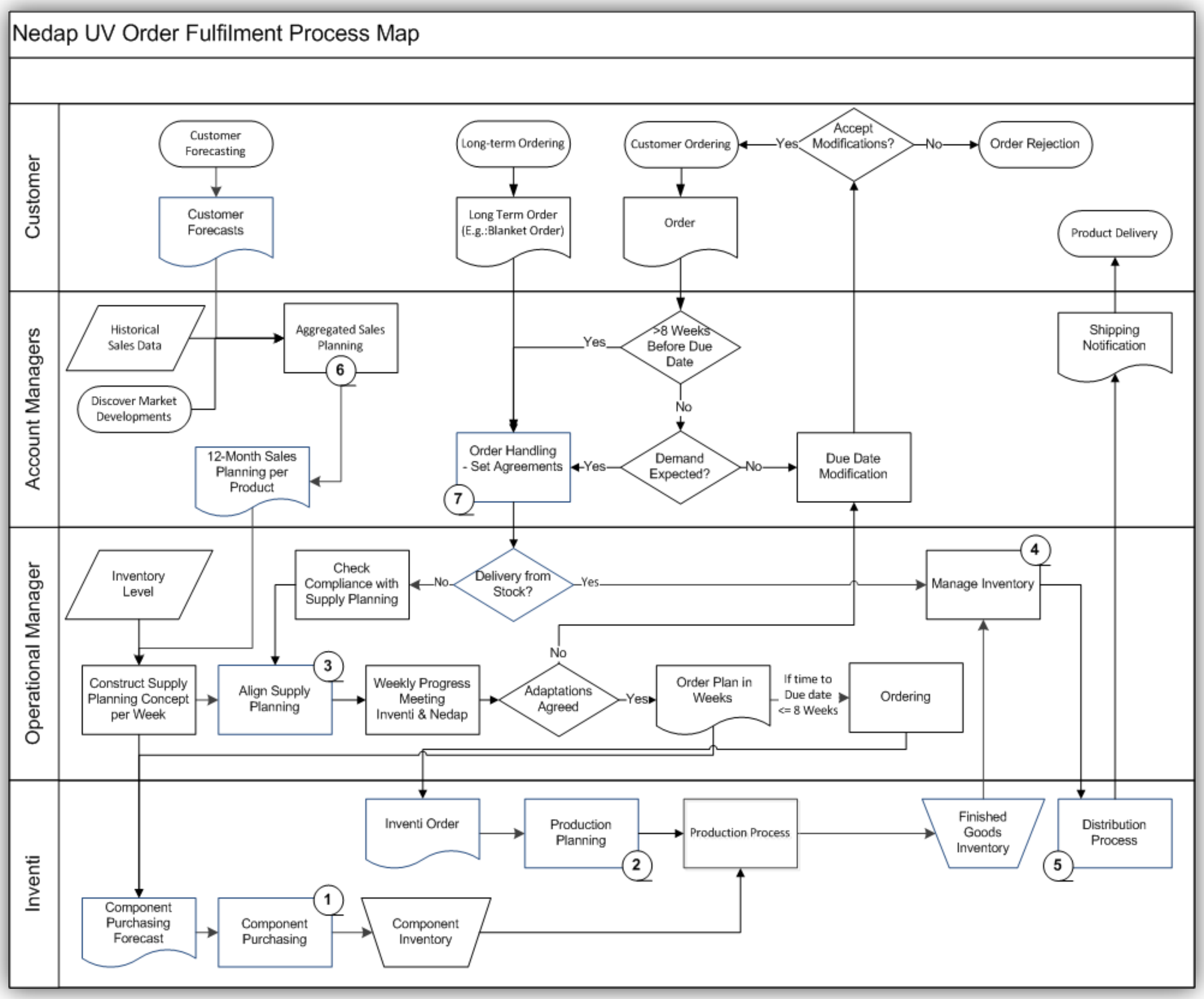

Figure 3.2: Nedap UV Order Fulfilment Process Map

3.1.2 Nedap UV Order Fulfilment Process Description

The visualisation of the order fulfilment process for Nedap UV makes us conclude that the process is comprehensive and complex. This descriptive subsection will provide the reader a more complete understanding of the process by describing the most essential processes per actor. This subsection completes *Step 2* of the second research question: “*Describe the current order fulfilment process”.*

Customer

The process of order fulfilment starts at the customer who gets pushed by the Nedap account managers to provide forecast information for their future demand. These customer forecasts initiate the current sales planning process at Nedap UV. Once a product forecast from a customer turns into an actual order, order conditions have to be agreed with Nedap. These agreements might have to be adapted by Nedap if the customer order deviates significantly from demand forecasts. A subsequent step is the acceptation or rejection by the customer of these new order conditions.

Account Managers

The account managers complete the sales planning process by processing historical data and discovered market developments into an aggregated sales planning. Once the constructed 12-month sales planning is completed it will be updated when new essential information is gained. The constructed sales planning fulfils an input function for the component purchasing process at Inventi. The account managers are furthermore responsible for the order conditions negotiation process and the remaining communication with the customers.

Operations Manager

The constructed sales planning is translated into a supply planning by the operational manager. The operational manager is responsible for inventory control and adapts the sales planning based on the inventory levels and products on order. Also new incoming orders and Inventi production capacity restrictions are integrated to construct a complete supply planning. If incoming orders deviate significantly from planned order quantities the acceptation and service conditions of these orders are discussed in a supply meeting with Inventi. This weekly meeting discusses orders eight weeks before the agreed shipping date. A production decision has to be made in that meeting to start or delay the production of the planned items and incoming orders. The goal of this meeting is to achieve a satisfying supply planning for both Inventi and Nedap after discussing the demand variations. The production quantities can from that moment on only be adapted in case of emergencies for small product quantities to not disturb the production process. This way of processing orders includes that relative high quantity and late incoming orders can only be supplied on time if the demand was planned or if required products are available at stock. As most of the customers are familiar with the throughput time restrictions of Nedap they order more than eight weeks in advance. Nedap aims to make an exception on this rule by delivering new customers within a week from inventory to prevent losing potential new market share.

Inventi

Once the supply planning is finalised in the weekly meeting Inventi can start constructing a production planning to fulfil the supply planning. The production planning is dependent on the available production resources and on the component purchasing process. This purchasing process is managed by Inventi based on the sales planning constructed by Nedap UV. In case the sales planning does not comply with the supply planning a probable deficiency of components will arise at the production process. For that reason it is important that the sales planning is accurate to be able to start the production process according to the production plan. For this Inventi production process standardised throughput time for UV products is agreed of 8 weeks. Seven out of these eight weeks are required for the actual production process. An additional week is added to the production throughput time to hedge against variability for both demand variations and production uncertainties. Once the production process is finished, these finished goods end up in inventory and will be distributed by Inventi to the demanding customers. The transport process is managed by the customers, so Inventi fulfils the distribution process by preparing shipment documents and by preparing the orders ready for transportation.

3.1.3 Order Fulfilment Process on the Tactical Level

In Chapter 1 we presented the lack of structure in tactical order fulfilment process at Nedap UV. With focusing on aligning the tactical order fulfilment business process we want to improve the cooperation and alignment of internal processes. This aligned process should result in the final research goal: *"A more effective, efficient and controllable order fulfilment process"*. This subsection clarifies the tactical order fulfilment process steps to provide an answer on Research Question 2. This subsection completes the last step of this research question: *"Define the tactical order fulfilment process".* We consider all process steps as Lin and Shaw (1997) stated that one should spend the efforts to improve a process throughout its complete process network for order fulfilment process re-engineering. The following step is for that reason the identification of all tactical order fulfilment process steps at Nedap UV.

The individual tactical order fulfilment processes at Nedap will be clarified based on the adapted Business Reference Model of Schermers (2011) shown in Figure 3.3. The model is adapted by indicating numbers to the tactical order fulfilment process steps in the original figure presented in Chapter 2. This allocation of numbers to processes is added to connect the order fulfilment process map in Figure 3.2 to the Business Reference model in Figure 3.3. In this way we present the seven main tactical processes in relation to our business process map. This analysis resulted in the seven numbered process steps involved in the order fulfilment process at Nedap UV, presented on the next page.

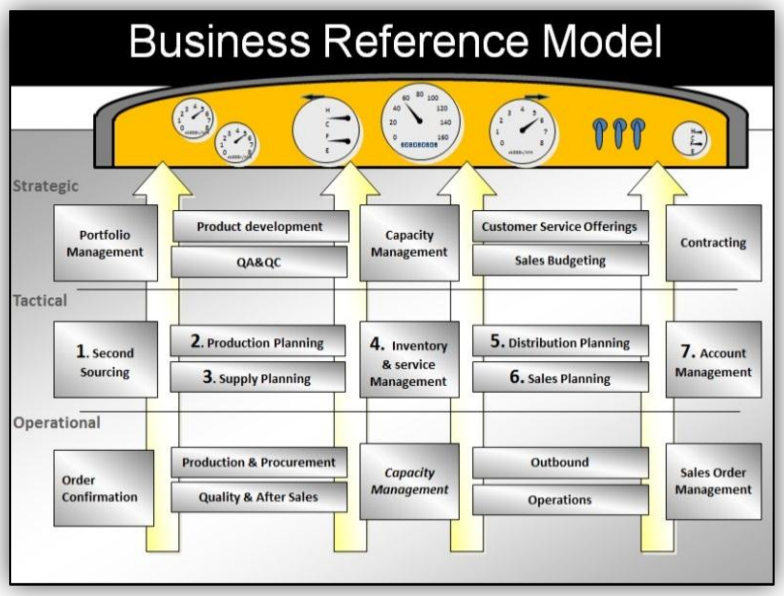

Figure 3.3: Adapted Business Reference Model

1. Purchasing
    - *The Inventi process of acquiring raw materials and components for the production process, indicated in Figure 3.3 as second sourcing.*

2. Production Planning
    - *The planning of the Inventi production process to be able to provide the demanded finished goods following the supply planning.*

3. Supply Planning
    - *The Nedap planning process of products required to fulfil customer demand, taking into account the sales planning, actual orders and finished goods availability.*

4. Inventory and Service Management
    - *Inventory management involves the management of finished goods stock to hedge sales and supply imbalances. The service management process manages the service standards, like due date quotations, order acceptances and service level goals.*

5. Distribution Process
    - *Involves the process of product distribution from inventory to the carrier. This process is indicated in Figure 3.3 as Distribution Planning.*

6. Sales Planning
    - *Involves the demand planning; translates market developments, historical sales data, and customer forecasts in a periodic demand forecast.*

7. Account Management
    - *Involves managing customer contact, making and handling order proposals*

The purchasing, production planning and distribution process functions are managed by Inventi and for that reason out of scope in this research. These processes cannot be completely excluded as the total set of processes has to be aligned to create a properly functioning overall process. For that reason we consider the Inventi processes as conditions in the alignment of the focus processes. Next to the processes at Inventi we do not focus on the account management process either. This process handles customer contact and has no specific tactical role in the actual order fulfilment process. Once the alignment of the remaining order fulfilment processes results in a cooperative and aligned process we expect the account management function not to have a significant influence on the overall process. Also this account management process is therefore interpreted as a side condition for the overall alignment process. These process exclusions results in three remaining process steps of order fulfilment to focus on in this research. These three processes will be further analysed and explored in Chapter 4, but are introduced below:

- (3) The Supply Planning Process
- (4) The Inventory and Service Management Process
- (6) The Sales Planning Process

In this section we provided an answer to Research Question 2, by showing how the current order fulfilment process is operating. This process is illustrated in Figure 3.2 by the Nedap UV order fulfilment process map. The flow between specific processes is further clarified by the process description per actor in Subsection 3.1.2. This section ends with the clarification of the three relevant tactical order fulfilment processes regarding this research, the supply planning process, the inventory and service management process and the sales planning process. The next section continues with a clarification of the Nedap UV product and market range.

3.2 Nedap UV Product and Market Range

The products and markets of Nedap UV and their characteristics have to become evident to be able to provide an answer to Research Question 3: “*What products are the most appropriate to function as pilot products for Nedap UV?”* We start answering this question with clarifying the Nedap UV strategy and the product and market range. This is continued with an outline of the characteristics influencing the order fulfilment process. Based on these product and market characteristics we end this section with a selection of pilot products to continue our research with.

3.2.1 Strategic Vision on Products and Markets

We clarify the strategy of Nedap before introducing the product and market range to create a more general overview for the reader. The behaviour of the company is of crucial importance for redesigning tactical order fulfilment processes. (Mintzberg, Quinn, & Voyer, 1991) The behaviour of companies and markets is captured in distinguished levels of strategy. Although these levels of strategy can be interpreted as being distinct, they must fit together to form a coherent and consistent whole. Distinctive strategic levels given in literature (Porter, 1980) (Dean & Cassidy, 1990) are the enterprise strategy, corporate strategy, business strategy and the functional area strategy. This subsection aims to clarify the company strategy by applying these strategy levels to Nedap UV.

The *enterprise strategy* encompasses the role the organisation plays in the economy and society. For Nedap this includes the company conducting business for profit seeking purposes. The company maintains its moral value by striving to play a sustainable and innovative role in the economy and society. The *corporate strategy* indicates the businesses or markets the company should serve. Nedap intends to be a supplier for the end customer in innovative technological markets. Although this focus on end consumers the product group Nedap UV has a strong subcontractor role as well. The subcontractor role is maintained at this product group because of its major share in the profitable UV market. The *business strategy level* of a company provides the way of competing in each particular industry and product segment in more detail. Empirical research and strategy theories consistently stress four basic capabilities, including cost, quality, flexibility and delivery for the operational business strategy (Schmenner & Swink, 1998) (Ward, McCreery, Ritzman, & Sharma, 1998). Nedap UV has a customer focussed business strategy in an innovative market. Customer focus is essential for companies with innovative products, they need to be able to supply as fast, flexible and dependable as possible (Fischer, 1997). The Nedap UV business strategy should for that reason focus on a flexible and dependable delivery process to pertain their market leadership.

The *functional area strategy* level comprises the maximisation of resource productivity and the development of distinctive competencies. It should be based on the business strategy and for that reason have a customer focus. Hayes and Wheelwright (1984) stress the importance of setting focus in operations and manufacturing on one of these capabilities to prevent from losing distinctive abilities regarding the customer. The functional strategy should pursue a highly reliable and quick order fulfilment process. The order fulfilment focus should lead to satisfied customers, provided with products of high quality in the right amount and on the right time. To perceive these goals Nedap UV needs to create a reliable, responsive and flexible order fulfilment process. This research aims to contribute to these Nedap UV goals by aligning its order fulfilment process.

3.2.2 Nedap UV Product Assortment

In the upcoming subsection we introduce the UV products Nedap supplies. In this subsection the first step is set for answering the third research question: *"Describe the different products and markets Nedap UV supplies"*. The introduction of this product assortment provides insight to the reader of the supplied products and its characteristics. Nedap offers 53 types of UV SKU's to the market. As for many industries it also applies for Nedap that only a couple of these product types are responsible for the main part of the total turnover. Only eight of the 53 Nedap UV SKUs account for over 81% of the yearly turnover. This indicates a clear distinction in the importance of products based on their turnover share. Many of the SKUs are related to each other in terms of their functionality and construction. For that reason Nedap UV introduced 11 product groups covering all 53 SKUs. These SKUs are categorised to obtain a better overview of the total range of products. This categorisation provides a better overall perspective to the product range as many of the product types do only distinguish on their exterior or some small product features. Only minor differences between the SKUs do appear in the product groups with regard to product and market characteristics. To pertain the product analysis to be structured and transparent we analyse these groups as general as possible with regard to product and market characteristics. For that reason in this chapter we assume the products in the product group to be homogeneous by product and market characteristics.

To provide the reader an overview of the product and market characteristics of the 11 product groups we present Table 3.1. In this table we withhold from presenting exact figures which could possibly violate the confidentiality agreements with Nedap. Neither do we describe all the product groups in the main part of this research as this could violate confidentiality restrictions as well. The detailed descriptions of all product groups are presented in Appendix F. Table 3.1 presents the number of product types per group, the number of customer specific product types in the group, the product life cycle stage and the customer order decoupling point. We present these four aspects of the Nedap products in the table to provide an insight in the differences between product groups which do not violate confidentiality restrictions.

Product life cycles of the Nedap UV products are multiple years as it concerns technological advanced products. The introduction phase of the product often takes more than a year as customers have to test the functionality to satisfy all set standards in the water purification or curing market. As the UV market is relative small, but includes highly advanced technologies it is unattractive for competitors to invest in this market. For that reason the Nedap UV products in general have relative long product life

Product Group:	Number of Product Types:	Number of Customer Specific Types:	Product Life Cycle:	Customer Order Decoupling Point:
1	3	3	Growth	MTS
2	1	1	Decline	MTO
3	4	3	Growth	MTS
4	1	1	Mature	MTO
5	14	2	Mature	MTS
6	2	1	Growth	MTS
7	4	0	Growth	MTO
8	4	1	Mature	MTS
9	1	1	Mature	MTO
10	16	8	Growth	MTS
11	3	2	Mature	MTS
Total:	53	23		

Table 3.1: Summary of Product Group Characteristics

cycle of multiple years. In case the Nedap UV products are substituted by newer products it is mostly because Nedap invented an improved version itself. The length of the PLC is considered to be comparable for all products, while the PLC stages are indicated individually in Table 3.1 as the life cycle stage does deviate per product group. The life cycle stage of these products is important with regard to the potential sales volume of the products.

Also the *customer order decoupling point* is depicted in Table 3.1 as this point is of crucial relevance towards the establishment of the order fulfilment process per product group. We exclude the assemble-to-order way of production as Inventi does not produce subassemblies on stock. Neither do we consider the engineering-to-order decoupling point as an option for UV products. High potential products are engineered-to-order for certain customers, but this process is managed by the research and development department which is out of our research scope. The CODP of the product groups indicate whether the specific products are made on stock or made to customer orders.

Summarising, we state that all product groups have different product and market conditions. Within these product groups multiple all 53 different SKUs Nedap UV supplies are covered. The SKUs are assumed to be homogeneous by product and market characteristics in the remainder of this chapter. Most of the customer specific products are produced on a make-to-order basis, while the more general products for multiple customers are made-to-stock. This can be explained by the risks of stocks involved in the different markets. We continue in the next subsection with the characteristics of the product groups which could possibly influence the order fulfilment process.

3.2.3 Characteristics Influencing the Order Fulfilment Process

Now that we have elaborated on the product groups and their accompanying markets we want to clarify the product and market characteristics that could influence the order fulfilment process. This subsection provides an outcome for the second step of the third research question; "*Describe the product and market characteristics that might influence the order fulfilment process".* Once this step is completed we identified the influencing characteristics for the order fulfilment process alignment. This subsection is structured according to the three tactical order fulfilment processes identified in this chapter. The required theory of this chapter is presented in Chapter 2.

Sales Planning

The first process we want to address is the sales planning process of Nedap UV. Sales' planning at Nedap involves the planning of demand which functions as input for the procurement process at Inventi. We designed a framework which visualises the process of constructing a sales planning. This process is illustrated in Figure 3.4 and combines a quantitative and qualitative analysis. The quantitative analysis considers for example a data analysis over historical demand. In Nedap *historical demand data* functions as the starting input for a mathematical model which produces a statistical forecast. We start the quantitative analysis over the historical demand data with the <u>*annual order frequency*</u>. The annual amount of orders is important for Nedap regarding the planning of future sales.

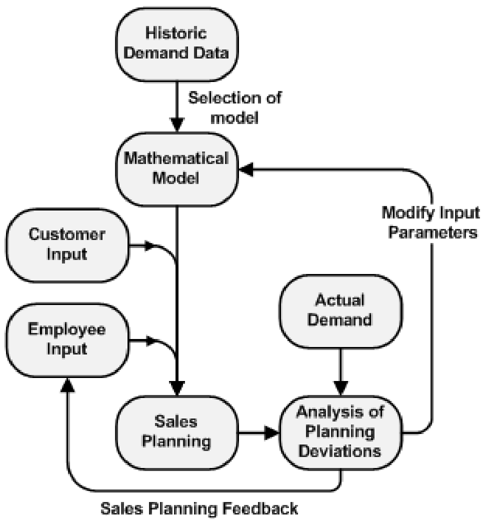

Figure 3.4: Nedap Sales Planning Framework

Nedap bases its order frequency at Inventi on the historic order frequency of the specific product. A high order frequency should for example lead to a frequent planning of orders at Inventi as well. Another important historical demand aspect is the *order quantity*. This order quantity influences the sales planning by the amount of products planned at certain moments in time. In case of a fixed order quantity for customer specific products, this quantity should be the standard order quantity in the sales planning as well. Also historical patterns are included in the sales planning of the products. The *growth trend* of historical demand is analysed to forecast the growth or declining trend of future demand. Other demand patterns such as cyclic and seasonal patterns can influence the accuracy of the sales planning significantly. *Seasonality* is added to the historical demand analysis when a demand series is structurally influenced by the moment of time during the year. As Nedap UV provides water purifying products seasonal trends cannot be excluded as the need for water changes over time during the year. The cyclical movements of demand are excluded for Nedap UV, identifying these patterns requires more historical data than available and will be partially included in historical demand analysis as the patterns only reveal slowly.

The next input factor for the construction of a sales planning concerns the *customer input*. The account managers at Nedap try to convince customers that an accurate forecast of their demand will lead to a higher service performance. The incoming *customer forecasts* originate in general from the most frequent ordering customers. As these customers represent a significant part of the total demand of Nedap UV these customer forecasts can be considered to be essential for an accurate sales planning. The second identified influencing factor of customer input is the *moment of ordering*. In case customers order more than half a year in advance of production these early orders are integrated in the sales planning to increase the sales planning accuracy. If orders arrive at Nedap UV before the start of the actual production process they are compared to the sales planning to prevent major sales planning deviations. Order conditions have to be modified when a modified sales planning can no longer be supplied by Inventi.

A third input factor for the sales planning is *employee judgement,* which finalises the constructed sales planning. The employee input contains market and customer knowledge from the account managers. This knowledge combined with the feedback originating from the sales planning deviations will form the final judgement over the constructed sales planning. The employee judgement can overrule all historical or customer input as they provide the final sales planning. Employee judgement input can for example include lost customers, knowledge of contract wins by customers or expected demand from new customers. Employee judgemental input will be an indicator of the upcoming *expected growth or decline of demand*. The expected growth or decline is leading in determining trends as historical data only indicates growth or decline of demand based on historical information. Combining these input factors will provide a more accurate sales planning in comparison to only using one of these two input factors. An important factor of the growth or decline of sales not considered in the historical trend is the *product life cycle stage*. The sales planning is affected by the stage the product remains in as explained in Subsections 2.2.2 and 3.2.2. This life cycle stage indicates the uncertainty and market potential of the specific product group.

The combination of the presented quantitative and qualitative analysis will result in a comprehensive sales planning. The last input factor is a feedback loop comparing the sales planning to the observed demand. This feedback loop is added to create a continuously improving sales planning process by analysing sales planning deviations from observed demand. This feedback step will be further explored in the performance management system introduced in Chapter 6. The sales planning process forms the basis of the component availability at the moment of production at Inventi. Variations in the need for these components are managed by Inventi's component order process. They order for example based on economic order quantities instead of the exact supply planning provided by Nedap UV. Furthermore, Nedap does not use advertising campaigns or price changes which can influence the sales rate of their products. For that reason these internal sales factors are excluded from the analysis towards the sales planning.

The importance of the individual characteristics is dependent on the other characteristics included in the sales planning. For example if the order moment is in advance of the component purchasing process, the historical sales data can be ignored as the actual orders are leading in the sales planning construction. In Figure 3.4 the historical demand data precedes the customer input as the customer input can overrule the mathematical sales model. A summation of the given sales planning characteristics is presented between the brackets at the right side of this page.

The Sales Planning Process

Historical Sales Data:

- Annual order frequency
- Order quantity
- Growth trend
- Seasonality

Customer Input:

- Customer forecast
- Moment of ordering

Employee Judgemental Input:

- Expected growth or decline of demand
- Product life cycle stage

Inventory and Service Management

The order fulfilment process considered next is the inventory and service management process. We start here analysing the *service management* process and the possible product and market characteristics that might influence this process. Service management involves the communication and agreement setting process with customers. This can involve the communication of attainable shipment dates of incoming orders or setting a delivery reliability goal. The reliability of delivery is amongst others dependent on the *service level goal* Nedap wants to offer its customers. The service level, also referred to as the fill rate, includes the fraction of demand supplied on-time. The remaining fraction of demand which cannot be supplied on-time will be backordered. This set goal for Nedap UV will affect the inventory management process as certain service conditions can only be met with accompanying inventory levels. Aside from the service level, the service conditions with regard to time to shipment are important characteristics. In case Nedap wants to change its *shipment policy conditions* to be able to ship all orders earlier they will have to adapt the settings of their order fulfilment process. Delivering orders earlier will for example require higher inventories or a more responsive or flexible supply chain. A last influencing characteristic we add to the service management process are the *specific customer agreements.* For some customers, special agreements are set to satisfy customer requirements. These agreements can for example include fixed order quantities or a fixed minimum stock level to hedge for variability at the customer. In this research these agreements are considered to be fixed as our research scope excludes account management.

The *inventory management process* will be influenced by multiple characteristics of the sales and supply side. In Subsection 2.2.4 we have shown that there is a significant difference in processing orders with uncertain and certain demand characteristics. One of the main indicators for the inventory management process flowing out of that subsection is the *variability of demand.* The variability of demand is measured in this research over the historical demand data of the specific product. If historical demand turns out to be highly variable, Nedap will require a higher inventory level to deliver according to the same service standards. This higher inventory level is required to cope with the demand fluctuations. Also the frequency of ordering, the average order quantities and the product life cycle stage are important factors in inventory management. Since we have included these factors in the sales planning we can exclude them for inventory management. And the sales planning process will be aligned with this service and inventory management process.

Inventory costs are the balancing factor over the level of inventory. These inventory costs prevent the inventory levels to rise in such a way that all demand can be immediately satisfied from shelf. This will incur additional costs and decreases the available liabilities for Nedap. For that reason we want to limit the value of the available inventory. Inventory costs include inventory handling costs, inventory insurance costs and inventory obsolescence risk costs. The insurance and handling costs are excluded from this research as these costs are managed by Inventi and not transparent to Nedap UV. The *obsolescence risk* is clearer for Nedap as this involves the complete cost price of products in case a product becomes obsolescent. For that reason obsolescence risk is included in our research. A related factor to this inventory risk is the amount of customers. For a customer specific product the risks of obsolescence are more significant than for products with multiple customers. For that reason *the amount of customers* is considered to be an input factor as well. A list of the characteristics influencing the service and inventory management process is presented at the right side of this page.

The Service and Inventory Management Process:

- *Service Management:*
  - *Service Level Goal*
  - *Shipment Policy Conditions*
  - *Specific Customer Agreements*
- *Inventory Management:*
  - *Demand variability*
  - *Obsolescence risks*
  - *Amount of customers*

Supply Planning

The last process of order fulfilment analysed at Nedap UV is the supply planning. The characteristics that can influence this process consider mainly production capacity restrictions at Inventi. Although the processes at Inventi are out of this research scope, we add some fixed parameters to make the supply planning more comprehensive. As mentioned before the lead time of all products is assumed to be eight weeks. The lead times will for that reason not be considered to be an influencing characteristic for the production process. However, Inventi has some specific capacity restrictions with regard to their production facility. Including these restrictions in the supply planning will prevent a large amount of unnecessary modifications later on in the supply planning process. One of these limitations we take into account is the *maximum production rate* per week for some specific products. As Inventi can only produce a limited amount of products a week this restriction is included in the Nedap supply planning. Another restriction is a minimum order quantity before a production run will be started. This *minimum order quantity* is based on the batch quantity per product group. The last characteristic we include encompasses a special Nedap UV characteristic which is relevant for the supply planning process. The *ability to interchange products* up to a certain point of time in production provides Nedap an additional ability to hedge uncertain demand. Specific product types in product groups can be switched in the production process up to a certain process step. The characteristics able to influence the supply planning process are again summarised between the brackets at the rights side of this page.

The Supply Planning Process

- *Supply Planning Characteristics*
  - *Maximum production rate a week*
  - *Minimum order quantity a week*
  - *Switching ability of product types*

3.2.4 Pilot Product Group Selection

In this subsection we make a choice for two pilot products appropriate to align the order fulfilment process with. A decision for two pilot product groups is made to represent different groups with different characteristics to form a comprehensive example of the process alignment to the products. Time restrictions of this research prevent us from demonstrating the alignment process for all products. In combination with the previous subsections we provide an answer to Research Question 3 here: “*What products are the most appropriate to function as pilot products for Nedap UV?”*

The decision for two pilot groups will be based on three main ‘order fulfilment alignment’ characteristics of the products group introduced before. Not all product and market characteristics introduced are included in this product group selection as only three of the characteristics introduced are considered to be important regarding the selection of pilot products for Nedap UV. The remaining characteristics will be used later on in this research at the alignment process. The first choice characteristic is the *variability of demand,* as the degree of variability of products has clear consequences for the alignment of the order fulfilment process. Aligning products with a highly variable demand will require more flexibility of the order fulfilment process than products with lower demand variability and will for that reason be more complex. As we want the pilot product examples to be comprehensive we aim for pilot products with high demand variability. Another characteristic we include for the pilot products choice is the *potential growth of demand*. For Nedap this is an important aspect for a pilot product choice as demand for these products is most likely to change. Again a flexible aligned order fulfilment process will be required. Besides, this characteristic indicates one of the main problems at Nedap UV stated in Chapter 2: “How to handle the growth in demand?” With using high potential products as pilots we illustrate in the implementation process how to handle the potential growth. The last characteristic included is the *product group importance for Nedap UV.* The importance of the product group for Nedap UV is included as it indicates the product alignment process which is the most important for Nedap UV. In this way the employees involved are more attracted to the alignment process as it involves important products. Furthermore, an improvement to an important product will have more effect than the same improvement to a less important product group. In Subsection 3.2.2 we have shown for Nedap UV that there is a significant importance difference between products, for example with regard to the yearly turnover. Besides, the most important product groups should have the most extensive outlined order fulfilment process as is highlighted in Chapter 2. Including this product group importance in the pilot product choice will lead therefore to an extensively aligned pilot order fulfilment process.

Pilot Product Group Selection Characteristics:

- *The demand variability*
- *The potential growth of demand*
- *The importance for Nedap*

These three product characteristics are chosen as they provide insight in the relevance of the order fulfilment process alignment for Nedap UV. The exact definitions and criteria we score the product groups on will be presented in the upcoming subsections. Before we actually start scoring the product groups on the characteristics we emphasize that we score the product groups in general rather than specific for all SKUs. Next to the enormous efforts required to score all SKUs, the product groups all consist of SKUs which are mostly homogeneous by product and market characteristics. We use historical data of only 2012 as significant changes in these figures appeared over the last years. This data represents the most relevant and accurate information for forecasting the upcoming years.

Demand Variability

The *demand variability* metric indicates the variability degree of the product group demand. This metric is important as the establishment of the order fulfilment process is heavily dependent on the variability of the product group demand. A high variable demand will require a flexible order fulfilment process which will include more variables and parameters to become flexible. Product groups with high variance scores are interesting to align the order fulfilment process with as their process will be the most extensive. So, high criteria scores in the demand variability scoring Table 3.3 concerns high variable product characteristics. We quantify the score for demand variability per product group based on several criteria. All criteria are scored on a scale from one to ten with respect to the other product groups by a scoring methodology presented later. The exact figures on which the scores are based are only presented in Appendix H as these figures are confidential.

First of all the average *order quantity* is included, as higher average order amounts represent more missing products once an order is incomplete and for that reason more demand variability. The *order frequency* is included as this measure indicates the amount of order lines a week. A higher order frequency means a more dependable and stable order fulfilment process because of the risk pooling effect. (Gerchak & He, 2003) Variability of demand will be reduced when adding multiple single variances, this is assumable as high demand from one customer will be offset by low demand from another. For both of these frequency and quantity criteria we add an individual *coefficient of variation* criterion, also referred to as CV. This coefficient of variation provides us an indication of the stability of the order amounts and the order frequency. When these amounts and frequencies are stable it is more easy to plan and process demand. Next to these four introduced variability criteria a criterion for the *lateness of ordering* and its variability is included. This metric is used as the lateness of ordering influences the variability of the process as planning can be done more accurately when orders are in relative early. The *variability of the lateness of order placement* indicates the modification frequency of these orders placed. The last criterion included is the *dependence on the customer* based on the amount of customers. If a product has only one customer, demand variability will in general be more significant compared to demand with multiple customers as the demand variability will be suppressed by the risk pooling effect.

Now all criteria are clear we start scoring all criteria on their demand variability. To show the scoring methodology we present one specific scoring example for the coefficient of variability of the order frequency. We only present one of these scoring methodologies to prevent from using too much confidential information and to prevent this report to become too extensive. The scoring methodology of the coefficient of variation for the order frequency will be clarified here to provide an example of the scoring methodology used. This criterion is chosen as the exact scores of this

Product Group Number:	Sorted Coefficients of Variation:	Score Steps:	Border Values:	Scale:	Final Score (CV Score <= Border Value):
3	0,69	0,69	0,00		1
5	0,81	0,96	0,82	1	1
2	0,92	1,22	1,09	2	2
8	1,16	1,49	1,36	3	3
1	1,26	1,76	1,63	4	3
4	1,32	2,03	1,89	5	3
10	1,74	2,30	2,16	6	5
6	1,93	2,56	2,43	7	6
7	2,02	2,83	2,70	8	6
11	2,24	3,10	2,96	9	7
9	3,10			10	10

Figure 3.2: Scoring Methodology Table Order Frequency CV

criterion do not significantly influence the confidentiality of this report. The coefficients of variation (CV) scores are presented per product group in the first two columns of Table 3.2 sorted on their (CV) score to clarify the used scoring methodology. In the 'Score Steps' column we introduce the score steps based on the exact difference between the actual scores, all steps have an additional value of $\frac{3.10-0.69}{9} = 0.267 \dots$. To calculate the threshold values for the actual scoring procedure we use the average of the two score steps. Then we base the final score in the last column on these found threshold values. Product groups are scored in a certain category if the actual CV score is below the threshold value of the CV scale. In this the given coefficients of variations are given the scores presented in the last column of Table 3.2. These scores appear in the final scoring Table 3.3 for all demand variability criteria as well. This scoring methodology is used for all introduced criteria in this section, except for criteria which cannot be scored based on exact data, such as the product life cycle score. These criteria can only be scored manually based on the product and market knowledge by Nedap UV employees and are highlighted in the scoring Table 3.3 with an asterisk. This scoring methodology is used for all three introduced characteristics we score the product groups on. The results of the degree of variability scores for the product groups are presented in Table 3.3. All criteria are assumed to be of equal importance as no clear criteria importance distinction could be identified by and for Nedap UV. All individual criteria scores are summed and divided by the amount of criteria to find the average criteria score in which on a scale from 1 to 10 in the last column.

Product Group Number:	Order Quantity Score:	Order Quantity CV Score:	Order Frequency Score:	Coefficient of Variation of Order Frequency:	Order Frequency CV Score:	Lateness of Ordering Score: *	Variability of Lateness of Ordering Score: *	Customer Dependence Score:	Average Score:
1	1	7	3	1.26	3	5	10	10	5.57
2	10	2	1	0.92	2	1	1	10	3.86
3	2	7	3	0.69	1	10	3	3	4.14
4	8	1	4	1.32	3	1	1	10	4.00
5	2	9	7	0.81	1	7	7	1	4.86
6	3	9	6	1.93	6	8	5	4	5.86
7	4	1	8	2.02	6	1	2	10	4.57
8	2	6	7	1.16	3	4	6	5	4.71
9	5	4	9	3.10	10	1	2	10	5.86
10	2	10	8	1.74	5	6	4	3	5.43
11	8	6	10	2.24	7	2	2	8	6.14

Table 3.3: Demand Variability Scores of all UV Product Groups

We want to emphasize here that a high score on a criteria represents much variability. This method of scoring helps us finding the most variable product groups, which are the most interesting products to align the order fulfilment process for. From Table 3.3 we conclude that demand for Product Group 11 includes the most demand variability. However, we can conclude from these tables that the relative end scores do not differentiate much as all product groups do have some high variability scores on different characteristics. For example, Product Group 2 presents the lowest demand variability score, but has high scores on the order quantity and customer dependence criteria. We discussed the outcomes of the table with the employees involved to validate the final results. This method of scoring the demand variability characteristic is also used for scoring the product groups on the two remaining characteristics. Having mentioned this, we will present the other two characteristics and their product group scores in a more brief description.

Growth Potential

The second criterion in deciding which pilot product group to align is the *growth potential* of the product group. This metric indicates the future potential growth of demand in quantities as well as in amount of orders. This growth potential characteristic will indicate the product importance in the future based on its potential demand. The first criterion included for scaling this growth potential is the *historic turnover growth* over the last three years, in which a decline of turnover is interpreted as a negative growth. The next scaled criterion is the *expected turnover growth* for the upcoming year. The expected turnover growth metric is scaled based on the demand growth expectation from the account managers for the upcoming year. Like all manual scored criteria also this criterion is indicated with an asterisk in its scoring table. Another included criterion is the *growth of order frequency* as this criterion can be an indicator of upcoming growth of the demand. After these three criteria a criterion is introduced to present *the variability of the demand growth*. This metric is scored by the Nedap UV employees based on the uncertainty of the growth. The last criterion includes the product life cycle stage of the product group. These metrics provides us an indication of the long-term perspective of the growth for the concerning products. All criteria are again scored on a scale from 1 to 10 respective to the other product groups. A high score on all criteria represents a high potential demand criteria score for the product group. Again the exact figures behind the presented scores have to remain confidential and are for that reason only included in Appendix H. The criteria introduced are assumed to be equally important regarding the potential growth situation per product group. Although most criteria are interrelated, we assume no correlation over the included criteria because all criteria encompass different independent information sources. The scores per product group are presented in Table 3.4.

Product Group Number:	Historic Turnover Growth Score:	Expected Turnover Growth Score: *	Order Frequency Growth Score:	Growth Variability Score: *	Product Life Cycle Score: *	Average Growth Potential Score:
1	10	8	10	8	8	8.80
2	1	2	2	3	1	1.80
3	8	7	7	5	7	6.80
4	5	3	2	2	3	3.00
5	6	5	5	3	5	4.80
6	9	10	8	10	10	9.40
7	6	1	5	7	6	5.00
8	6	6	6	4	5	5.40
9	6	6	4	7	4	5.40
10	8	7	10	6	10	8.20
11	1	3	1	1	2	1.60

Table 3.4: Growth Potential Scores of all UV Product Groups

Product Group 6 has the highest growth potential in Table 3.4 based on our criteria included. In this table a wide score range with regard to the scores for potential growth appears. This means that there is a significant growth potential difference between the product groups. For example, Product Group 11 has a relative low growth potential based on all criteria while Product Group 1 scores relatively high on all included criteria. Again the findings are validated in a group discussion with Nedap UV employees. The difference in scores compared to the product groups' variability is validated as well as there is a significant growth potential difference between the products with respect to the difference of variability between the product groups.

Importance

Our last decisive characteristic included for the choice of pilot product groups is the *importance of the product groups.* The criteria scored for this characteristic are the *turnover percentage* of the product group for all UV product groups, *the margin percentage* on this turnover and *the importance of the customers involved*. We exclude other relevant criteria here to remain independence between the decisive characteristics as these criteria have been used before. An example of such a characteristic that is included yet is the growth potential of the product groups. An ABC analysis is introduced to indicate the importance of the group with regard to the turnover percentages. The actual results of this ABC analysis are only presented in Appendix K to prevent including confidential information in this report. The margin percentage of the product group is based on the average difference between the cost price and the sales price of which the exact information is confidential as well. Customer importance is included here as some customers are considered to be more important than other customers by Nedap. Customer importance is measured based on the customer's total historic demand for UV products at Nedap. For these two importance measures the exact figures are again only presented in Appendix H as they are considered to be confidential for Nedap. Again all these criteria have been scored on a scale from one to 10 presented in Table 3.5.

Again we assume independence of all criteria and equal importance for all criteria, which results in the average products group scores in the last column of Table 3.5. From this column we can conclude that Product Group 1 is the most important product group considering the used criteria and Product Group 10 is the least important product group for Nedap UV. Again the found scores per product groups are validated in a group discussion with Nedap UV employees.

Product Group Number:	Turnover Percentage Score:	Margin Percentage Score:	Customer Importance Score:	Average Importance Score:
1	*10*	*6*	*10*	**8.67**
2	*8*	*2*	*10*	**6.67**
3	*7*	*5*	*5*	**5.67**
4	*5*	*6*	*10*	**7.00**
5	*4*	*8*	*1*	**4.33**
6	*2*	*3*	*3*	**2.67**
7	*2*	*1*	*10*	**4.33**
8	*1*	*10*	*2*	**4.33**
9	*1*	*4*	*5*	**3.33**
10	*1*	*5*	*3*	**3.00**
11	*1*	*7*	*6*	**4.67**

Table 3.5: The Importance Scores of all Nedap UV Product Groups

Product Groups Selection

Having scored the three characteristics all product groups, we can start to combine the characteristic scores to come to a selection of two pilot product groups. The growth and variability metrics play a significant role in the importance for Nedap UV in case the product groups are important for Nedap UV as well. This can be clarified with an example: the growth of turnover with 20% of a product group with €100.000 on sales has less influence than a growth of 2% for a product group representing over €2.000.000 of sales. For that reason we start making a selection of the most important product groups of Table 3.5. From this table a significant difference in importance of the product groups for Nedap UV appears between the first four product groups and the remaining seven product groups. For that reason we aim to select two out of these four product groups based on the two other characteristics.

We introduce Table 3.6 to illustrate our final product group selection. Only the first four product groups are available for the selection process based on their importance, the remaining product groups are faded in this table. The final product group selection is based on the two remaining scored characteristics. Nedap UV considers the growth potential and the demand variability to be of equal importance, for that reason we inserted an additional column which shows the averages of these two characteristics. As we can conclude from Table 3.6 Product Group 1 scores highest on the average score as well as on the importance characteristic. From these findings we conclude that Product Group 1 is the most useful product group to align the order fulfilment process for.

Next to the first product group, Product Group 3 has a significant higher average variability and potential score than the remaining two product groups. This implies the product group to be a good second pilot product group choice. However, to prevent from imitating the alignment process for Product Group 1 we take a quick look at the characteristics chosen in Subsection 3.2.3. Product Group 3 differs from Product Group 1 as the group considers multiple customers. Also the order patterns of the product groups differ significantly as Product Group 3 comprises high order quantities and frequencies compared to the first product group. These differences are relevant for the alignment of the order fulfilment process and for the amount of issues and problems appearing. Concluding, we state that it is legitimate to use Product Group 1 and 3 as pilot products to research for Nedap UV. These product groups are the most interesting with regard to the upcoming process alignment and are of significant importance for Nedap UV as well. As the employees involved at the Nedap UV support this choice we continue this research with these two pilot product groups. All SKUs out of these two product groups will be aligned to the order fulfilment process in Chapter 5. This process is executed per SKU as SKUs in a product group can contain different characteristics, although we considered them to be homogeneous in this chapter.

Product Group Number:	*Importance Score:*	*Growth Potential Score:*	*Demand Variability Score:*	*Average Uncertainty & Potential Score:*
1	*8.67*	*8.80*	*5.57*	**7.19**
2	*6.67*	*1.80*	*3.86*	**2.83**
3	*5.67*	*6.80*	*4.14*	**5.47**
4	*7.00*	*3.00*	*4.00*	**3.50**
5	*4.33*	*4.80*	*4.86*	4.83
6	*2.67*	*9.40*	*5.86*	7.63
7	*4.33*	*5.00*	*4.57*	4.79
8	*4.33*	*5.40*	*4.71*	5.06
9	*3.33*	*5.40*	*5.86*	5.63
10	*3.00*	*8.20*	*5.43*	6.81
11	*4.67*	*1.60*	*6.14*	3.87

Table 3.6: The Final Product Group Scores:

3.3 Conclusion

From the order fulfilment analysis in this chapter we concluded three main steps to be interesting for our remaining research. These process steps which could be influenced at Nedap are: the sales planning process, the service and inventory management process and the supply planning process. Once the process steps for the remainder of this research were clarified a further research towards the products Nedap UV supplies was required. After a brief summary of the Nedap UV product groups a set of characteristics was introduced to be considered at the alignment phase of the processes and products. The final step in this chapter was a selection of two pilot product groups to implement the alignment process for. Based on the importance, the demand variability and the potential growth of the product groups we decided to execute the pilot alignment process for Product Group 1 and 3. We continue this research in Chapter 4 with a general structure for aligning the processes with the product characteristics. And in Chapter 5 the chosen pilot product groups will be aligned to the order fulfilment processes for all SKUs they comprise.

4. Aligning the Order Fulfilment Process

This chapter aims to provide guidance for aligning the three identified order fulfilment processes to the Nedap UV SKUs. This chapter will only provide guidance to the alignment processes, while Chapter 5 will implement this alignment to the chosen product groups in Chapter 3. With this chapter we provide an answer to Research Question 4: *"How to align the order fulfilment processes to the product and market characteristics of Nedap UV?"* The aligned order fulfilment processes will result in a more effective and efficient order fulfilment process as the process will be aligned with the product and market characteristics. This effectiveness and efficiency increase involves a more responsive order fulfilment process which will lead to less order fulfilment problems and issues.

The research question in this chapter will be answered by literature research on the establishment of order fulfilment processes. The main source for the alignment of these processes is the *Inventory Management and Production Scheduling* book of Silver, Pyke and Peterson (1998). So if not specifically referred to any other source at certain formulas or theoretical information in this chapter, we used the Silver, Pyke and Peterson (1998) book as our main source of information. We use this book because of its insight in the three selected order fulfilment processes. Furthermore, from extensive experiences with this book we accredit it as pleasurable to work with. It provides more structure to this chapter to combine theoretical information with the actual processes of Nedap UV here, instead of relocating the theoretical information to Chapter 2.

4.1 Alignment of the Sales Planning Process

In Chapter 4 we described the product and market characteristics that might influence the sales planning. This section describes the possible effects of these characteristics on the sales planning. All products of Nedap UV contain long lead-time components. From interviews with employees involved at Inventi we found out that component lead times can take up to 30 weeks and that the purchasing process of these components is based on the Nedap UV sales planning. For that reason an accurate sales planning is crucial for being able to initiate the production process at the desired moment. The sales planning will never become fully reliable, for that reason the construction of a sales planning should be a balanced process between invested efforts and the product importance. For example sales planning errors will be large when models naively project past patterns. On the other hand, costs will be extensive when exact underlying costs are researched for all forecast deviations. A decent balance between these two options results in an effective and efficient forecasting process. (Silver, Pyke, & Peterson, 1998) The sales planning process we introduce for Nedap UV is visualised in Figure 4.1.

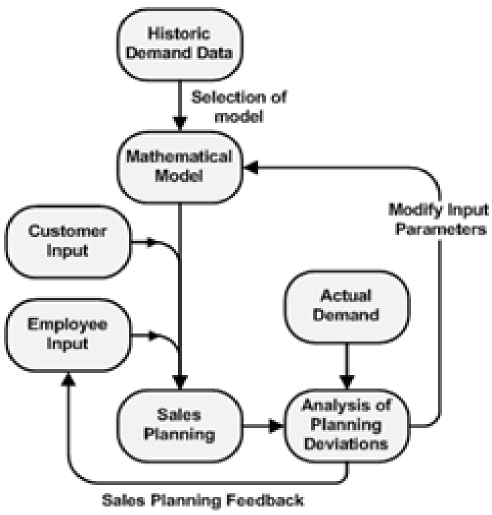

Figure 4.1: The Nedap UV Sales Planning Process

4.1.1 Input from Historical Demand Data

The process of sales planning by our designed model starts with an analysis of the historical demand data to make a draft of the sales planning. Based on the historical demand data we construct a mathematical forecast model. For Nedap UV we construct a medium-range aggregate sales planning as Nedap requires its sales to be planned up to 40 weeks in advance. For the required medium term sales' planning the medium-range aggregate sales planning model is the most appropriate. (Makridakis & Wheelwright, 1979) A forecast of the demand over a time series can be composed of five demand components. First we have a level 'a' component which illustrates demand if it was constant in time. Then a trend component 'b' is included to represent a rate of growth or decline in demand. Additional to these two components a seasonal $'F_t'$ or cyclic $'C_t'$ component can be added to represent seasonal booms and busts in demand over time. The cyclic element is, as described in Chapter 4, not considered in this research. The last demand factor is the irregular fluctuation 'ε_t' in a time series which represents the residue of variability in demand that remains after the removal of the first four components. This component will not be included in the remaining of this research but is indicated here to highlight its presence in the sales planning. The selection process of a model is dependent on the choice for including these described components. For important items in the product range a mathematical sales planning model should include as much available information as possible. But when considering the sales planning for B and C items one should consider the additional value and degree of complexity before including additional components to a sales planning model. (Silver, Pyke, & Peterson, 1998) The possible sets of demand characteristics will be described in this section.

Level and trend components demand

For a medium-range forecast model there is a relatively simple additive method for demand forecasting while excluding the seasonality component of demand. This method is called the regression procedure and assumes demand to be a linear function of time. The expected demand $\hat{x}_t$ at a period t is equal to:

$$\hat{x}_t = \hat{a} + \hat{b}t \tag{4.1}$$

In this formula the $\hat{a}$ parameter represents the estimator for the level component of a forecasting model. The $\hat{b}$ parameter represents the trend component for the expected demand. On the right side of the formula a formula indicator is presented to be able to refer to formulas presented before, in the remaining chapters of this research. This formula indication methodology will be used in the remainder of this chapter. To calculate the demand $\hat{x}_t$ the $\hat{b}$ parameter has to be calculated based on historical demand by the next formula:

$$\hat{b} = \frac{\sum_{t=1}^{n} t x_t - \left(\frac{n+1}{2}\right) * \sum_{t=1}^{n} x_t}{n(n^2-1)/_{12}} \tag{4.2}$$

N represents the number of historical observations included in the calculation of the expected demand. The $\hat{b}$ value is required to find the expected level $\hat{a}$ component with the formula below:

$$\hat{a} = \frac{\sum_{t=1}^{n} x_t}{n} - \frac{\hat{b}(n+1)}{2} \tag{4.3}$$

Then we calculate the aggregated expected demand for a period t by adding the $\hat{a}$ component to the multiplied $\hat{b}$ and t value. To sum up, the regression analysis is used to calculate the expected demand for a medium-range term model with only a level and trend component. To calculate the expected demand $\hat{x}_t$ based on the regression analysis we use Formula 4.1. (Silver, Pyke, & Peterson, 1998)

Level, trend and seasonal components demand

To design a model which includes a seasonal component as well we introduce the Winters' exponential smoothing method. This methodology is potentially useful in aggregate, medium-range mathematical forecasting. With both trend and seasonal components included, the forecasting procedure becomes more complex. The underlying model for calculating expected demand at time t with this exponential smoothing methodology of Winters is:

$$\hat{x}_t = \left(\hat{a} + \hat{b}t\right) * \hat{F}_t \tag{4.4}$$

In which F_t represents the seasonal index appropriate for period t. To estimate the seasonal factor in time we have to filter the trend factor from the historical demand data. To filter the trend component from the historical data we calculate the moving averages over the historical periods. The moving average is the average over a fixed period in time. This period should cover a full season to have the moving average free of seasonal effects. For example, the quartile moving averages over a year can be calculated by the average of four quartiles. In general an even number of periods is chosen so the moving average ends up being centred between two periods and not in the middle as desired. For that reason we make two moving averages, for example for quartile 3 which covers in 1: quartiles 1, 2, 3 and 4 and in the second moving average quartiles 2, 3, 4 and 5. The average of these two moving averages is the centred moving average. This centred moving average indicates the trend and level indication line of the historical data.

Now the centred moving averages are found we can filter them from the historical data to find the seasonal factors. The seasonal factor can be calculated by dividing the actual historical demand values by the centred moving averages. This results in multiple estimations of F_t for the calculated periods. To arrive at a final estimation of F_t we take the averages of the seasonal factors over all calculated periods. This requires a summation of the seasonal factors per period divided by the total amount of estimation of F_t found. The final seasonal factors of the periods need to be normalised to the value of the number of periods used in your method. This is done by multiplying the values with a factor that can be found by dividing the total assumed number of periods by the summation of the seasonal factors.

In the Winters' exponential smoothing method the a and b components can be found by an updating procedure. To find the initial parameter values $\widehat{a_0}$ and $\widehat{b_0}$ for this updating procedure we use the following formulas to calculate the initial level and trend values:

$$\widehat{a_0} = \frac{6}{n(n+1)} * \sum_t tx_t + \frac{2(2n-1)}{n(n+1)} * \sum_t x_t \tag{4.5}$$

$$\widehat{b_0} = \frac{12}{n(n^2-1)} * \sum_t tx_t + \frac{6}{n(n+1)} * \sum_t x_t \tag{4.6}$$

These initial values indicate the initial level and trend components of the forecasting methodology. With these values the basic forecast for period 0 can be calculated by Formula 4.4. However, to use this model repetitively for forecasting purposes we need to update the parameters of Formula 4.4 This requires a slightly different underlying model of this forecasting technique:

$$\hat{x}_{t,t+\tau} = \left(\widehat{a_t} + \widehat{b_t}\tau\right) * \hat{F}_{t+\tau-P} \tag{4.7}$$

In which $\hat{x}_{t,t+\tau}$ is the forecast made at the end of period t and for periods τ in advance out of a range of P periods a year. For the seasonality factor $\hat{F}_{t+\tau-P}$ this includes it is last updated in period t + τ – P. However, to follow the methodology of the Winter's exponential smoothing method we include an updating procedure for the forecast value once new data comes in. The updating procedure contains recalculations of the $\widehat{a_t}$, $\widehat{b_t}$ and $\widehat{F_t}$ values by the updating formulas presented below:

$$\widehat{a_t} = \alpha_{HW}\left(\frac{x_t}{\hat{F}_{t-P}}\right) + (1-\alpha_{HW}) * (\hat{a}_{t-1} + \hat{b}_{t-1}) \tag{4.8}$$

$$\widehat{b_t} = \beta_{HW}(\widehat{a_t} + \hat{a}_{t-1}) + (1-\beta_{HW}) * (\hat{b}_{t-1}) \tag{4.9}$$

$$\widehat{F_t} = \gamma_{HW}\left(\frac{x_t}{\widehat{a_t}}\right) + (1-\gamma_{HW})\hat{F}_{t-P} \tag{4.10}$$

By calculating these formulas the updated forecasts can be calculated by the Winters' seasonal smoothing methodology. The $\gamma_{HW}, \beta_{HW}\ and\ \alpha_{HW}$ values are three smoothing constants. These constants all lie between 0 and 1 and can be calculated by the methodology introduced in Appendix I. (McClain & Thomas, 1973)

The calculation method used for demand with level, trend and seasonal components can also be implemented for demand with only a level and seasonal component. In that specific case the $\widehat{b_t}\tau$ component is left out of the expected demand calculations and the $\widehat{a_t}$ is the average level over historical demand. We include the validation of the model and the measures of forecast errors in the performance management chapter. In this chapter the feedback step in our sales planning framework analysis the forecast errors and seek its underlying causes. From this analysis corrective action should appear to reduce the bias of variability. However, we want to recommend Nedap UV to implement this measurement of forecast errors more specifically in the future as it brings additional value to your forecast error analysis. (Silver, Pyke, & Peterson, 1998)

4.1.2 Input from the Customer

Now we have a basis model based on historical demand we start introducing the input from the customer for the Nedap UV sales planning, which can include demand forecasts or early orders. In case specific customers always provide in time and accurate forecasts of their demand the mathematical modelling of the sales planning might become redundant. In this situation the sales planning should be based on the customer forecasts, because customers are assumed to have more accurate market knowledge about their customers than Nedap does. Another situation in which the mathematical modelling of the sales planning becomes redundant appears if customers always order in advance of the procurement process. However, as this situation only applies for a small set of customers, it is recommended to start generally with a mathematical model based on historical sales. In case customer forecasts turn out to be more accurate than the formed sales planning by Nedap UV, these customer forecasts should become leading in the sales planning process. The account managers have to try to get more input from the customers. Employees of Nedap UV should spend efforts to convince customers of the necessity of an accurate customer forecast to reduce their sales planning errors. However, customers will not invest much effort in an accurate forecast if Nedap is not an essential supplier. Nedap UV wants to deliver these customers as well to prevent from providing competitors the opportunity to join the market. However, the most frequent ordering customers do provide Nedap with regular forecasts of their upcoming demand. Nedap has to handle these different attitudes of customers to prevent the loss of market share.

In the sales planning model the accuracy of historical customer forecasts determines the usefulness of the customer forecasts versus the historical demand model input. If these customer forecasts have proven to be accurate, they will become leading in the sales planning over the historical demand model. Nonetheless, if historical forecasts have been observed to be inaccurate the historical demand model will be leading in the sales planning. Another important characteristic of the customer for the sales planning process is the moment of ordering. A sales planning can only be based on actual orders in case orders arrive in advance of the production process start. In practice some customers order even before the component purchasing process starts. The considered orders are final and can for that reason be translated directly into the sales planning for the specific products. For customer specific products this includes the sales planning to be completely reliant on these early customer orders. For non-customer specific items this includes the availability of demand information for only a specific customer in the total range of customers for the product. In case orders arrive when the sales planning has been provided to Inventi, the actual orders have to be compared with the provided sales planning. If the order is expected and therefore included in the sales planning no action is required. But if incoming orders do deviate significantly from the sales planning, the sales planning has to be modified in consultation with Inventi. In case these modifications are accepted by Inventi the order can be accepted, otherwise agreed order conditions with the customer have to be modified. Next to this regular demand, also exceptional demand turns up, which can consist of emergency orders or exceptional order quantities. If the sales planning has not included this exceptional demand the customer cannot be supplied in general. In this situation the desired shipment date has to be delayed unless products are available in inventory.

4.1.3 Input from the Nedap UV Employees

The last input factor considered for a final sales' planning model is the Nedap UV employee input. The experience and market knowledge of the Nedap UV employees should always be the final check for a sales planning. For non-specific customer products these employees have to make an aggregated sales planning of multiple information sources. Also customer specific demand should always be checked for inconsistencies with general demand. Next to checking the sales planning so far the employees of Nedap UV can perceive a more complete vision over the growth expectations of their products as they can combine many information sources. This additional information, next to historical data and customer input, can for example include new product developments and certain influencing market developments which have substantial effects on the sales planning. The employees do also consider the product life cycle stage in the sales planning by preventing an overrated sales planning for products at the end of their life cycle. The other way around, the employees can plan some additional sales for products in the introduction or growth phase of their life cycles. The employee input can significantly influence the sales planning as the employees have the ability to overrule customer forecasts and historical demand models.

In the sales planning framework in Figure 4.1 a feedback loop is included to evaluate the sales planning based on actual sales. Including this feedback loop provides account managers with an evaluation of their historical sales planning inputs. Deviations between actual sales and historical sales planning should be analysed to evaluate their own and customers' input. Based on the evaluations of their sales planning potential improvements or demand trend can be identified and used for the sales planning for the upcoming periods. Only in this way a continuously improving sales planning process can be established. To make sure these evaluation moments will take place we plan four quarterly meetings to evaluate the sales planning process. This meeting is introduced to make it a working standard at Nedap UV to evaluate your own performance.

Based on the mathematical model, customer inputs and employee judgemental input an aggregated sales planning can be created for a year in advance. The degree of influence of the different input factors has to be based on the account managers and operations managers' experience. In general the aggregated sales planning will be forecasted in weeks for all product types as Inventi plans their production process weekly. The complete sales planning process is illustrated in Chapter 5 for some chosen pilot products. This illustration forms a manual and example to clarify the different steps of the sales planning process. Firstly, we continue this chapter with the introduction of the service and inventory management process.

4.2 Alignment of the Service and Inventory Management Process

In the last section we presented guidance for the sales planning process alignment with the product and market characteristics. The output of this sales planning model is used in the alignment process of the service and inventory management process to form an aligned order fulfilment process. The service management part of the order fulfilment process involves the process of setting service conditions and policies with regard to the shipment of products. It encompasses, for example, the order acceptation process and due date setting process as described in Chapter 2. Inventory management functions as the hedging linkage between these service management policies and the actual supply of the products. If for example customers are promised certain orders before a specific unattainable delivery date Nedap has to hedge against this demand with inventory. While these two processes are closely linked we handle them in one section.

4.2.1 Alignment of the Service Management Process

Already mentioned in Chapter 4 is that we introduce a new standard delivery policy to become more flexible toward the Nedap UV customers. Nowadays, customers have to accept that the lead time for all products is generally eight weeks for expected demand. In case demand is unexpected and not included in the sales planning this order fulfilment process can take up to 38 weeks after ordering. Only in exceptional situations such as a new customer's demand Nedap aims to deliver their products earlier for example out of inventory.

As described before in Chapter 2 Nedap aims for a more flexible, responsive and transparent order fulfilment process. Improving the flexibility and responsiveness for the UV order fulfilment process includes redesigning the general service management policy. The new policy includes that Nedap UV will ship small quantity orders generally within a week and “large” orders within the current eight weeks. The exact threshold quantities between “large” and “small” orders cannot be introduced here as this is dependent on the specific SKU. Demand patterns for SKUs do differ significantly in quantities and variability, for that reason the classification of order quantities can only be presented per SKU and not for all Nedap UV products in general. The separation between the relative small and large orders will be indicated in the remainder of this research as small orders and large orders. This separation of order conditions will lead to more satisfied small and new customers, which is the high potential group of customers with regard to growing demand. Besides, it will decrease the average order handling time as orders have to be passed on to the distribution process immediately and can for that reason no longer be modified by customers. The order handling process for small orders takes on average significantly more processing time per sold item compared to the average large orders. Another advantage of redesigned service conditions is the fixed order conditions situation. For customers, account managers and the operational manager the situation for order requests became significantly more simple and clear.

Large orders are aimed for to be shipped within the eight weeks lead time which equals the current situation. These large orders originate generally from frequent ordering customers. The necessity for decreasing the lead time is significantly lower as these customers are used to the current situation and often manage inventories of the Nedap products themselves. Their demand can also be planned more accurately as it is more regular than for customers with small demand. Including these large orders in the new faster shipping policy will lead to a heavily increased inventory level as it considers high order quantities. Also, the account managers of Nedap do not expect the demand of these customers to increase significantly if lead times will be reduced. For this reasoning we decided together with Nedap to introduce service conditions distinctions depending on the order quantity.

For excessive order quantity demand, which are referred to as “projects” in this research, project specific agreements have to be set depending on the order characteristics. The excessive amount of order quantities indicated as “project” orders in this research will be in general based on a make-to-order process. In case no demand forecasts for these projects are provided to Nedap they will in general not be able to deliver excessive amounts before the total process lead time. Customers with potential project demand will be prepared by the account managers for this situation to prevent surprises regarding the lead time of 38 weeks without any form of a demand forecast. In case these excessive orders do arise unexpectedly the demand will be supplied as far as possible by spreading orders in multiple supply moments in time. In this way Nedap is able to deliver at least a portion of demand on time which allows the customer to start the project. However, this spreading of the orders should not be at the expense of the customers who provided demand indications.

Before starting to configure the inventory management process we require a service level goal for the new Nedap UV service management policies. The transport process itself is organised by the customer, for that reason the performance measure of Nedap UV should exclude the shipment process itself. In Nedap a general service level goal of 97.5% is strived for. This includes that only 25 in 1000 items on average are accepted to be backordered. Nedap wants us to bring this service level in practice at the UV product group as well. The performance of the delivery process is not measured at Nedap UV currently. In addition, the service level metric is interpreted as useless by the employees involved as customers change their desired shipping dates regularly after the first agreed due date. Despite of these restrictions we want to implement a service level metric in the product group for measuring the service performance. While a service level goal is unrealistic if we include last week's order due date modifications from customers we exclude these changes. For that reason we change the service level metric to the percentage of on-time delivered items based on the first agreed shipping date. These firstly agreed shipping dates exclude last moment changes in the desired shipping date and will for that reason be more representative for service performance measurement. We assume no orders to be postponed after the firstly agreed shipping date in this measurement.

For the alignment of the service management process with the product and market characteristics some customer specific agreements have to be included. An example of these special agreements is a certain stock level of a product kept for a specific customer to guarantee certain shipment flexibility. Also these agreements have to be integrated when aligning the service and inventory management process with specific product types. Concluding, for service management we introduced a new service policy. The shipping date quotation process and order acceptance for customers' orders depend on the product type, the order quantity and the moment of ordering. All the processes and agreements involved should be aligned to satisfy the Nedap service level goal.

4.2.2 Alignment of the Inventory Management Process

Now the process for service management has been aligned to its product characteristics we continue with the inventory management process. Main reason for holding inventory at Nedap is the ability it provides to deliver customers faster than the Nedap production lead time. Other significant important functions of the inventory are the hedging function against unexpected changes in customer demand and the uncertainty hedge for many other situations, such as production errors or component unavailability. Altogether, Nedap UV holds inventory to improve the delivery performance to aim for customer satisfaction. On the other hand inventories are classified as one of the current assets of an organisation which is explained in Chapter 2. In general all other things being equal, a reduction in inventories lowers assets relative to liabilities. (Axsäter, 2006) Concluding, a balance has to be found between the advantages of holding Inventories and the costs it involves.

The inventory management process will be influenced by the desired service level and the shipment conditions agreed with the customer. For the inventory management process alignment we introduce guidance for aligning such a process with the Nedap UV products. For inventory levels at Nedap we use the general term inventory position. This inventory position is defined as:

Inventory Position = (on hand stock) + (items on order) – (backorders) – (committed products)

The *on-hand stock* is the actual stock available on the shelf. The *items on order* are the products remaining in the pipeline of Inventi that will become available once the production process is finished. The subtracting side of the inventory position relation covers the backorders which include the delayed shipments because of product unavailability. The committed item quantity is also subtracted as it includes products which cannot be used for upcoming sales for multiple causes. (Silver, Pyke, & Peterson, 1998) The inventory position is the key quantity of inventory in the remainder of the inventory management process alignment. It is chosen as key quantity for Nedap UV as it provides a broader perspective to the actual available stock level and the stock that will become available in the upcoming weeks. For Nedap UV it is critical to include the pipeline stock in calculations with the eight weeks lead time at Inventi.

For the inventory management system at Nedap UV we have to choose between a continuous versus a periodic review system. Nedap UV can only place orders weekly at the weekly supply meeting with Inventi mentioned in Chapter 3. As the order quantities for the specific week will only be evaluated at that moment, we use a one week review system for inventory management at Nedap UV. The order fulfilment process considers 24 incoming orders on average a week. This order frequency seems manageable within one week and therefore we decide to consolidate this current weekly ordering and inventory monitoring system. The periodic review system used is also decisive for the selection of an inventory policy form. With using a periodic review system the two most appropriate forms of inventory policies are the (R,S) and (R,s,S) system. In these systems the R indicates the review period of the inventory model, which is equal at Nedap UV to 1 week. Both of the systems include a capital character S, indicating the order-up-to-level. The order-up-to-level indicates the required inventory position at the moment of ordering. In case the inventory position drops below the order-up-to-level at the moment of ordering an order should be placed to fill the gap between the actual inventory position and the order up to level. For the (R,S) policy this includes an order to be placed every time the inventory position is lower than the S level. The difference between the two analysed systems is the small character s in the (R,s,S) inventory policy. This character indicates the reorder point of the inventory position. This reorder point indicates the minimum inventory position, if the inventory level drops below level s an order should be placed to fill the gap between the inventory position and level S. (Silver, Pyke, & Peterson, 1998)

Scarf (1960) showed that under general assumptions concerning the demand pattern and the cost factors, the (R,s,S) system produces a lower total of replenishment, carrying, and shortage costs than does any other system. However, Zheng and Federgruen (1991) showed that the three parameters are only easy to solve based on algorithms computed by programming language. For Nedap, where inventory costs are not essential for inventory management, the time and skills required to calculate these required levels will be too extensive. As all products at Nedap have different product characteristics the (R,s,S) policy is not suitable because of its complexity for determining parameters. For that reason we decided together with Nedap the simpler (R,S) policy to be the most appropriate for the Nedap inventory process. This means we base the ordering behaviour on the order-up-to-level S instead of including a reorder point s as well.

An inventory system can be optimised based on several goals. These goals include the minimisation of costs, the customer service level or aggregate considerations. As introduced in Chapter 4 Nedap considers itself to be an innovative company with customer satisfaction as one of their key goals. Costs are important as for all companies but are not of key importance for the Nedap strategy. For that reason we base the inventory system on the customer service level. This service level goal is determined to be 97.5% at the preceding subsection and is the basis for the inventory model.

As the review period R for the (R,S) policy is clear and one week we can immediately start with the process of determining the order-up-to level S. The actual parameter calculation process is based on the knowledge provided by Silver, Pyke and Peterson (1998) mainly, when other sources of knowledge are addressed this will be mentioned. The order-up-to level is calculated by adding the demand during lead time to the safety stock level for the specific product situation. This safety stock SS can be calculated by the formula below:

$$SS = k * \sigma_{R+L} \tag{4.11}$$

The k value indicates a safety factor in inventory management and is based on the service level goal of the company. For an (R,S) policy this k value can be calculated based on the following formula which originates from de Kok (1990):

$$P_2 = 1 - \frac{\sigma_{R+L} * G_u(\frac{\sigma_{R+L}}{\sigma_L} * k + \frac{\widehat{x_R}}{\sigma_L})}{\hat{x}_R} \tag{4.12}$$

The P_2 value used in the formula of de Kok refers to the service level goal. For Nedap this value equals 0.975. The second part of the formula covers the standard deviation of the demand over the review period and the lead time. This standard deviation is the deviation of actual versus the average sales per period over the historical sales data of 2012. The standard deviation of the periodic demand can be calculated by the following formula, in which n represents the number of the periods:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{4.13}$$

This formula covers the standard deviation for an individual period n, this standard deviation has to be translated into the standard deviations for multiple periods required in Formula 4.12. These standard deviations can be found by Formula 4.14, for which we assume the demand to be normally distributed with$N(\mu, \sigma^2)$. (Welford, 1962) For Formula 4.14 we use L+R as a multiple period example, in which L represents length of the lead time and R the length of the review period:

$$\sigma_{L+R} = \sigma * \sqrt{L+R} \tag{4.14}$$

Now the standard deviation formula is clarified we continue with the elaboration on Formula 4.12. The next expression that requires some further exploration is the $G_u(k)$ expression. This function is used in finding the expected shortages per replenishment cycle. The value of this function can be distracted from the normal distribution function, dependent on the value k. These parameters and their normal distribution functions are presented in Appendix J. For the expected demand during the review period $\hat{x}_R$ we use the findings of the sales planning process introduced in the previous section. Now all parameters of Formula 4.12 are clarified the k value can be found, to be implemented again in Formula 4.11 to find the safety stock SS. This safety stock is the level of stock that should cover variations in demand during lead time and the review period. The last formula we include at the inventory management system concerns the average on-hand stock. This parameter provides an insight in the actual available stock level compared to the average on hand stock level. The average on-hand stock level can be calculated by adding the safety stock to the average incoming demand during the review period:

$$Average\ On\ Hand\ Stock\ \approx\ SS + \frac{\hat{x}_R}{2} \tag{4.15}$$

At the end of the inventory management process the average on hand stock should be checked by the account managers and operational managers. This employee involvement provides the ability to overrule calculated order levels. This validation step is taken to prevent unaccountable stock levels in practice. The average on hand stock level is for example compared to the risk of the stock to become obsolescent. This validation step is only inserted to make sure the inventory policy system used does not create unacceptable risks with regard to obsolescence of stock. We do not consider the capacity of the finished goods warehouse as this capacity forms no restriction currently.

4.3 Alignment of the Supply Planning Process

The supply planning process starts at Nedap with making a desired supply plan. This supply plan will be based on the sales planning and inventory management system introduced and varies for different types of products. The sales planning will be reconsidered based on current inventory positions and actual orders to form a supply plan. The required order quantity per product can be calculated according to the (R,S) policy. The order quantity will equal the order-up-to-level S minus the current inventory position. The order-up-to-level S can be calculated by adding the safety stock level SS to the expected demand during lead time and review period. The added safety stock has a hedging function against variations of this demand during the lead-time and review period. The safety stock SS calculations have been shown in the previous section. And the expected demand during lead time and review period can be derived from the sales planning of the specific product. The order-up-to-level S can be calculated by the formula below: (Silver, Pyke, & Peterson, 1998)

$$Order - up - to - level\ S = \hat{x}_{L+R} + SS \tag{4.16}$$

The order-up-to-level found has to subtract the on hand stock and items on order, and add the amount of backorders and committed products to find the desired order quantity for a specific week. This order quantity has to be checked with the sales planning to discuss major differences. Not for all products the order quantity has to be calculated this extensive, for example customer specific products which are made to order can be simply ordered at Inventi following the order quantity of the customer.

The last step before the order quantities result in a final supply planning is including the production restrictions at Inventi. The capacity restrictions can become quite complex as multiple products have to be processed by the same bottleneck machines. For that reason a list of capacity restrictions per product type should be provided by Inventi to prevent unrealistic supply plans. The supply plan constructed should consider the capabilities of the production facilities of Inventi as far as known. By delivering a supply plan which includes the Inventi capacity restrictions an extensive supply meeting can be avoided as less supply planning modification will be required. In case the supply plan quantity exceeds the available weekly production capacity, the remaining products should be planned and spread over multiple weeks in advance to prevent late shipments. To prevent these late shipments the upcoming weeks of the supply planning should be discussed in the supply meeting with Inventi.

The more comprehensive this supply plan is the faster progress can be achieved during the weekly meeting. The weekly supply meeting is required as Inventi is unable to handle all variation in the order plans from Nedap. This supply meeting is scheduled weekly and discusses the production in the upcoming eight weeks and the supply planning for two additional weeks to prevent exceeding capacities at Inventi. Also the sales planning of the products will be discussed in this meeting to control the deviations between the sales planning and the incoming orders. This deviation has to be limited to prevent component shortcomings at the start of production. Discussing unplanned demand in this meeting leads to a compromise for the acceptation or rejection of certain orders because of the component availability. Also the conditions for acceptance of "project" demand should be discussed here. For this demand specific supply, plans have to be designed which take the production capabilities, availability of components and the customer wishes into account.

A last point of discussion during this meeting is the required modification of the current products in production. These pipeline modifications can include current orders in progress which can be delayed or should be given higher priority to be able to ship the items on time. Furthermore, these modifications can include switching product types in product groups during the production process. This switching procedure should only be called for in emergency situations to not prevent from disturbing the production process of component availability. Besides, it is only available for specific product types as is mentioned before in Chapter 3.

After the weekly supply meeting a production plan will be made by Inventi to start the production process. The production quantities and due dates can from that moment on only be adapted in emergency situations for small amounts of products to prevent from disturbing the production process. Nedap UV assumes the production process to consume standard eight weeks, including one week for the ’preparing for shipment’ process. If orders suddenly get an emergency priority an additional safety factor is the ability to transport the products by air freight. This can save up to 5 weeks of transport considering the other side of the world as the final destination. However, this requires additional costs for the customer once appealed for. The air freight transport can also be initiated by Nedap in case certain important order due dates cannot be met.

4.4 Summary and Conclusions

Now we have analysed and aligned the three order fulfilment processes we finalise this chapter. In this chapter we aligned the three identified processes in Chapter 4: the sales planning, service and inventory management and supply planning. These processes were not only aligned to each other but to the product and market characteristics that might influence the processes as well. By using the sales planning for aligning the inventory and service management process we combined the first two identified processes. All three process steps come together at the alignment of the supply planning. In this process we integrated the sales planning with the service and inventory management process. The guidance for aligning the three processes in this chapter provides an answer to Research Question 4: *“How to align the order fulfilment processes to the effects of different product and market characteristics?”* For some particular processes alignment was not enough to fulfil the stated goal, a redesign of the processes on itself was required as well. We introduced new processes, such as a mathematical sales planning model based on historical sales, a new service conditions system regarding customers, a new inventory management model and a new supply planning process based on the redesigned inventory model. This resulted in guidance for establishing a specific order fulfilment process for individual Nedap UV SKUs dependent on their product and market characteristics. After all this results in a more formalised process in which input is used more clever and structural for establishing the order fulfilment process. Based on this conclusion we reached for the set goal in this chapter following the research structure by providing a complete answer to Research Question 4. Now this guidance chapter has finished we recommend Nedap UV to establish their order fulfilment process based on this guidance. To help this establishment of the process we introduce some implementation pilots in the upcoming chapter. For several SKUs selected in Chapter 3 the order fulfilment process will be aligned, this pilot function not only as example but will form the validation step of the alignment process as well. The pilot implementation in Chapter 5 made us modify this guidance chapter by an iterative process as certain steps appeared to be missing. The upcoming chapter will for that reason confirm the completeness of this chapter.

5. Implementation of the Order Fulfilment Process Alignment

In the previous chapter guidance is provided for aligning the different product and market characteristics to the selected three order fulfilment processes. The basis of this chapter is a combination of the outcomes of Chapter 3 and 4. In this chapter we implement the guidance for aligning the order fulfilment processes of Chapter 4 on the two chosen pilot product groups of Chapter 3. The pilot groups presented encompass multiple deviating characteristics of multiple product types to create multifaceted examples. These multifaceted examples will provide Nedap UV with an extensive and complete insight in how to align the order fulfilment to its products.

The alignment process for the selected product types are subdivided in four sections, all sections represent one or multiple product types out of one product group. The first two sections present the three product types of Product Group 1. Product type A and B are covered in Section 5.1, these SKUs are covered together as they have a comparable set of product and market characteristics. Product type C is covered in a separate Section 5.2 as this product type has differing product and market characteristics which require a specific alignment of processes and characteristics. Product Group 3 is chosen as the second pilot product group as it adds value to the research with its different characteristics compared to the first product group. The difference between the product groups will for some product types lead to a different aligning process. These different aligning processes provide Nedap UV a more complete perspective to aligning the order fulfilment process.

Product Group 3 contains four different Product Types; D, E, F and G. Product Type D is completely equal, except for some final configurations, to Product type G, which is the standardised version of the product group with a wide range of customers. As Product Type D account for only 1.6% of the total sales of Product Type D and G we incorporate the demand of Product Type D in the alignment of the order fulfilment process of Product Type G. This process is only presented in Appendix L as the procedure is comparable to the earlier introduced product types of Product Group 1. For product type F the aligning process is comparable to earlier introduced order fulfilment processes of product types as well. For that reason also this product type is only included in Appendix L as it does not add significant value to this research. In the main section of this research we only present Product Type E of Product Group 3 in the main text of this report in Section 5.3. Product type E differs from the SKUs introduced before because of its demand which is influenced over time by seasonality. For that reason it adds value to this research as it contains a different characteristic to align the process for.

Before we start the implementation phase we are required to introduce some working standards integrated at Nedap UV to complete the process input for the reader. In this company a year consists out of ten periods, most of these periods contain five weeks. For Period 5 and 6 the periods contain six weeks as a dip in demand arises generally during this holiday period. Nedap introduced this ten period division over the year to have a stable trend throughout the year with regard to expected demand per period. As most of the Nedap products contain long lead time components Nedap needs to construct a sales planning in an early moment in time. This sales planning is the input for the actual procurement process at Inventi and has to be accurate to be able to start production according to the supply planning. Besides, the efforts spend to configuring these processes should depend on the importance of the product types for the Nedap UV product range as is explained in Chapter 4. Another issue we want to mention here is the confidentiality of the required data for all product types. Some tables and calculations contain confidential information and are therefore only presented in appendices to pertain the confidentiality of this report.

5.1 Process Alignment for Product Type A and B

5.1.1 Aligning the Sales Planning Process

We start the individual item analysis with a combination of Product Type A and B from Product Group 1 as explained in the previous section. These product types are subassemblies for a customer specific product from Customer Z. The product types of Nedap UV are used in high value and large scale projects and an order concerns for that reason a significant investment by the customer. As large investment decisions are prepared and carefully weighed by this customer, the customer orders at an early moment in time. This includes that demand is generally known for more than nine months in advance at Nedap UV. The early orders were the basis for an agreement between Nedap UV and the customer to make these products on order. This comprises that Nedap starts its order fulfilment process once orders are placed. Also the sales planning can be constructed from these orders as the customer provides Nedap generally with demand information before the required 38 weeks in advance of delivery. These 38 weeks cover the procurement and production lead time, which makes the order fulfilment process suitable for a make-to-order process. Basing the sales planning purely on the customer orders is accurate as only the customer knows the exact details about their project demand. So, for these two product types we do not make extensive use the designed sales planning process in Figure 5.1 as customer input is directly translated in a final sales planning.

Figure 5.1: Sales Planning Process Framework

Although ordering after the 38 weeks process lead time does not occur frequently, Nedap wants to be more flexible than only being able to make-to-order products in case of late ordering. In case no forecasts or orders have been placed 30 weeks in advance of production Nedap wants to provide Inventi with a sales planning indication for these product types. However, as the demand of product type A is very irregular we only plan Product Type B if orders stay out. With only four historical orders planning demand without actual orders of this product brings high stock obsolescence risks. The demand situation of Product Type B differs from Product Type A as orders are more stable and regular. In case customer demand is not available 30 weeks ahead of production orders should be planned according to the average order frequency and quantity. On average Product Type B is ordered once every three weeks with a fixed order quantity of six. This demand behaviour will also be used in the sales planning if orders are not in before the 38 weeks lead time. After planning this demand we warn the customer for the purchasing process start without demand forecasts or orders. In case the customer does not respond on this warning, Nedap UV has to stop planning these items. Demand trends are excluded as they are reflected in orders in the make-to-order system.

In conclusion, for Product Types A and B of the first product group we construct the Nedap sales planning on actual customer orders in a make-to-order process. Only in rare cases where demand of Product Type B is not indicated more than 38 weeks ahead of production, Nedap should plan the standard quantity of six units every three weeks. The demand behaviour for Product Type A is too irregular to base a sales planning on.

5.1.2 Aligning the Inventory and Service Management Process

No extensive set of service agreements is required for these products as Nedap agreed to a make-to-order process, in which the order moment is decisive for the moment of transportation. Nedap UV can exactly plan these orders to be finished on the desired shipment date. The make-to-order process of these products type also makes the order categorisation for these products useless. For Product Type A no safety stock is held in agreement with the customer because of the high risks for obsolescence with its irregular demand pattern. No stock is kept either for product breakdown risks because the products can be temporarily replaced by another product type from the product group. These product types have the same functionality and only differ by their exterior, however, these replacements can only be temporarily as the Nedap UV product is only a subassembly of the total product from the Nedap customer. In the meantime Inventi will manage the repairing or replacement process of the broken item. The same functionality of the product types in this product group also makes Nedap not completely dependent on the moment of ordering for Product Type A. In an emergency situation Inventi is able to interchange the product types during the production process. This ability is only valid for products no longer than three weeks in production and requires the availability of components for the required product type. However, it will include the cancellation of the order for the interchanged product type. This product type interchanging option is available for all product types in the product group but disturbs the production process heavily. For that reason the interchange ability should only be considered in emergency situations.

For Product Type B a comparable situation exists with regard to service and inventory management. Also this product type is made-to-order for specific projects and demand is generally known before the component purchasing process starts. The demand for Product Type B is more frequent and variable though, for that reason Nedap agreed with this customer to hold a safety stock of six items. This safety stock has a hedging function for the changes in the customers’ desired shipment date and equals exactly the fixed order quantity. While the demand for Product Type B is originating from long-term variable projects it cannot always be planned exactly on a specific date. The safety stock gives the customer the flexibility to request ordered products in advance of the agreed shipping date. The customer is obliged to buy the products in inventory, for that reason the obsolescence risks of this safety stock can be neglected. But as it concerns high value items, the costs of this inventory should be considered. Even though we have not researched the inventory costs thoroughly we assume the additional flexibility to the customer to be more valuable than the costs of inventory. This assumption is confirmed by the account managers as the risks of losing the customer to a competitor increases significantly in case of denying the customers’ desire for flexibility. As it is a high potential sales volume product Nedap UV considers it to be an important product. For that reason we assume the need to satisfy this customer outweighs the inventory costs involved for Nedap.

5.1.3 Aligning the Supply Planning Process

The last researched order fulfilment process for Product Type A and B concerns the alignment of the supply planning process. The supply part of this product can be planned completely based on the sales planning, because of the customers' 'early ordering' behaviour. The sales planning for these products is close to perfect as orders are in before the component purchasing process starts. The ERP system in combination with the purchasers of Inventi translates this sales planning in components availability at the initiation of production. After the production process of eight weeks the products will be ready to be expedited by the distribution department of Inventi. Also for Product Type B's safety stock the supply planning needs no modifications in case of usage. The agreed safety stock will mainly be used for shipping later planned orders in an earlier moment in time. This implies that the safety stock will be replaced automatically by the original ordered products in progress. In case the safety stock covers an additional order it takes 38 weeks maximum for the safety stock to be refilled, dependent on the component availability.

The supply planning for these products is restricted by the production capabilities of Inventi. These restrictions need to be included to generate a complete supply planning, otherwise modifications will be required afterwards. However, as these supply constraints concern the complete product group we introduce them at the end of the alignment process of Product Type C. In this way we generate a capacity restrictions set which covers the supply planning for all concerned SKUs of Product Group 1.

5.2 Process Alignment for Product Type C

5.2.1 Aligning the Sales Planning Process

Product Type C is the standardised version of Product Group 1 and is sold by customer Z to multiple end-consumers in varying order quantities. We analyse the sales planning process of Product Type C more thoroughly as this products' demand is more frequent and not only project based. To construct a sales planning for product type C we use the sales planning model from Figure 5.1. This model suggests including historical data, customer input and employee input to maximise the accuracy of the sales planning. We start with analysing the historical data, this teaches us that the coefficient of variation is 1.86 compared to the average weekly demand. As this coefficient is relatively high we analyse the order quantities more deeply by comparing the frequency of ordering with specific order quantities. The results of this analysis are presented in Table 5.1. This table shows us the frequencies of ordering in 2012 compared to the specific order quantity of the order in the order quantity row.

Order Quantity:	1	2	3	4	5	6	7	8	9	10	11	12
Frequency of Ordering:	23	8	7	0	0	0	0	2	0	0	0	3
Quantity Percentage:	53%	19%	16%	0%	0%	0%	0%	5%	0%	0%	0%	7%
Cumulative Percentage:	53%	72%	88%	88%	88%	88%	88%	93%	93%	93%	93%	100%

Table 5.1: Frequency of Ordering of Specific Order Quantities over 2012

From this table we conclude that 88% of the historical orders concerned smaller order quantities than four items. These small orders are generally unpredictable and unknown in advance of production. Additional research teaches us that, in contrast to the small orders, large order demand concerns expected project demand which is generally known before the 38 weeks lead time of

Nedap UV. The contrast between the small and large demand behaviour requires a separation between the orders based on their order quantity as is introduced in Chapter 4. 'Large orders' include orders with a higher order quantity than three items, and its sales planning will be based on actual orders. 'Small order' concerns the orders which require a maximum amount of three items, this demand is uncertain and unexpected and therefore unpredictable. To make sure components are available for these unpredictable orders as well we construct a sales planning for the small order demand. We start analysing the historical demand by using a mathematical model for forecasting upcoming demand. For Product Type C only the level and trend components are added to the sales planning as these components can be identified by analysing the trend lines in Figure 5.2. A seasonal component cannot be identified as the historical data is limited to only seven periods of historical data. A set up discussion with the Nedap UV account managers and the customer made us conclude to exclude the existence of a seasonal trend. For the demand situation in which only a level and trend component are considered, a regression analysis is initiated as demand is expected to be a linear in time.

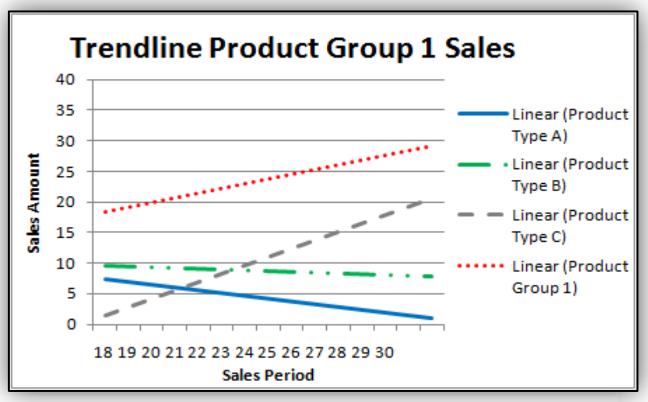

Figure 5.2: Trend lines of the Historical Sales of Product Group 1 over 2011-2012

There are only seven periods of historic sales data available for small quantity demand as the orders started in Period 4 of 2012. We forecast the upcoming demand in periods as is the standard time frame for demand forecasting at Nedap. In seven historic periods only 38 orders were placed. Analysing the data provides more stability when we consider these 38 orders over 7 periods instead of over 31 weeks, for that reason we use periods as a forecasting time frame. The regression analysis provided a $\hat{b}$ value of 0.863… and an $\hat{a}$ value of 5.119… by the calculations presented below:

$$\hat{b} = \frac{\sum_{t=1}^{n} t x_t - \left(\frac{n+1}{2}\right) * \sum_{t=1}^{n} x_t}{n(n^2-1)/_{10}} = \frac{269-(4*60)}{7*4.8} = 0.863\,\ldots \tag{4.2}$$

$$\hat{a} = \frac{\sum_{t=1}^{n} x_t}{n} - \frac{\hat{b}(n+1)}{2} = \frac{60}{7} - \frac{0.863\ldots*8}{2} = 5.119\,\ldots \tag{4.3}$$

The values found form the basis of the regression analysis results presented in the '*Periodic Forecast 2013'*-row of Table 5.2. The forecast of the first period of 2013 (in the table indicated as Period 8) will for example be calculated by: $5.119\ldots + (8 * 0.863\ldots) = 12.02\ldots$.

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Historic Sales 2012 (4-10):	5	3	11	10	11	10	10	-	-	-	-	-	-	-	-	-	-
Periodic Forecast 2013:	-	-	-	-	-	-	-	12.02	12.89	13.75	14.61	15.48	16.34	17.20	18.07	18.93	19.79
Recalculated Forecast 2013:	-	-	-	-	-	-	-	10.17	10.80	11.43	12.06	12.69	13.32	13.95	14.58	15.22	15.85
Periodic Forecast:	-	-	-	-	-	-	-	10	11	11	12	13	13	14	15	15	16

Table 5.2 Sales Planning Table for 2013 of Small Orders of Product Type C

The two remaining rows of Table 5.2 will be getting back to later on in this section. The final sales planning should also concern the customer input and employee input when following the sales planning model of Figure 5.1. As mentioned before, the customer input results in the sales planning of the large type of orders. The small order demand is interpreted as unpredictable by the customer and is for that reason not forecasted. For that reason we have to exclude customer input from the small items' sales planning. To check the mathematical model of the small orders we subject the mathematical forecast to the employee input. The product type is assumed by the employees to remain in an early stage of its life cycle. This early life cycle stage in combination with some special confidential circumstances, which are introduced in Appendix G, makes a growth in demand probable. Altogether, the account managers expect a growth of demand of 50% for the complete product group over 2013. This growth expectation is in line with the visualisation of the trend presented in Figure 5.2. The demand of Product Types A and B is expected to remain stable and for that reason all demand growth has to originate from Product Type C. This results in a demand increase for Product Type C of approximately 117%. The growth of this demand is assumed to be equally divided between the small and large quantity orders of this product type. This means the growth of demand for both of these order quantity categories is expected to be 117%. For the large orders this demand growth will automatically flow through the sales planning process as products are make-to-order driven. For the small quantity orders this growth should be implemented in the sales planning. For historical sales 54% of the items sold are quantified as small orders, this percentage represents a total demand of 60 items. The growth of 117% of this total quantity will result in a small order expected sales amount of 130 items in 2013. This sales expectation should now be aligned to the sales expectations from the regression analysis according to Chapter 4. The forecasted demand for 2013 by the regression analysis is 159 sold items. Analysing this gap of 29 items between the mathematical forecast and the employee forecast shows that the first two sales periods were far below the average sales rate over the analysed seven periods. This indicates an introduction period in the demand trend which is explained before in Subsection 3.2.2. We assume the regression analysis to have overestimated the trend growth of demand because of the included introduction period. So, in this situation the employee input overrules the regression analysis as we consider the employee input to contain less forecast errors.

Week Number:	Weekly Forecast:	Periodic Forecast:
1	2	
2	2	
3	2	10
4	2	
5	2	
6	2	
7	2	
8	3	11
9	2	
10	2	
11	2	
12	2	
13	3	11
14	2	
15	2	
16	2	
17	3	
18	2	12
19	3	
20	2	
21	2	
22	2	
23	3	13
24	2	
25	2	
26	2	
27	2	
28	2	
29	3	13
30	2	
31	2	
32	2	
33	3	
34	3	
35	2	14
36	3	
37	3	
38	3	
39	3	
40	3	15
41	3	
42	3	
43	3	
44	3	
45	3	15
46	3	
47	3	
48	3	
49	3	
50	4	16
51	3	
52	3	

Table 5.3: Sales Planning 2013 for Small Quantity Demand of Product Type C

To align the mathematical forecast to the employee input we calculate a new trend for the regression analysis which compensates for 29 items over Periods 8 to 17. The sum of the series of periods from 8 to 17 equals 125, to recalculate the trend we have to subtract $(\frac{-29}{125} =) - 0.232 \ldots$ from the trend value. The new trend value equals: $0.863 \ldots - 0.232 = 0.673 \ldots$. The results of these calculations are presented in the *'Recalculated Forecast'* –row in Table 5.2. The *'Periodic* Forecast'-row of this table presents the periodic expected demand rounded to complete products. To translate the periodic forecast into a weekly product sales planning we present Table 5.3. In this table we divided the specific periodic forecast over the amount of weeks like is done for Period 1. In case a week planning does not end in full items we plan the remaining items in the most central weeks of the period, such as for Period 2. This method is chosen to optimise the ability for hedging variances combined with avoiding excessive stocks. Table 5.3 presents the final outcomes for the weekly expected demand for small quantity demand of Product Type C. The total expected demand for small orders for 2013 will finally come down to 130 items in a growing trend throughout the year. The sales planning of the large quantity demand needs to be added to complete this sales planning for Inventi. This is done based on the input of actual orders and customer forecasts for the large quantity demand. These customer orders and forecasts are available, but excluded from this research for confidentiality reasons. Although the mathematical historical analysis was not essential as it was overruled by the employee input, it provided the basis of the forecasts. This total overrule will not occur regularly as in this case the introduction period of the specific product was the special cause.

5.2.2 Aligning the Service and Inventory Management Process

The product quantity categorisation also forms the basis of the service conditions for Product Type C. Small quantity demand concerns orders smaller than three items and Nedap UV wants to be able to ship these orders within a week after order arrival. Nedap aims to ship these orders quicker to improve its flexibility and delivery performance regarding the customer. Next to the positive effect on the customer satisfaction the new shipment conditions will have a positive effect on the required effort for processing orders. The amount of requests for rescheduling orders will decrease with a significant shorter lead time as orders have a faster throughput time. Furthermore, order information will be requested less frequent as the information will be more recent and up-to-date for one week than for eight weeks in advance of shipment. For these reasons we expect the efforts required for processing an order to decrease for the new service conditions. From Table 5.1 we can show that on a historical basis 88% of the incoming orders should be shipped seven weeks earlier considering the new shipment conditions. The remaining 12% of the orders will be shipped within the current standard of eight weeks if demand is expected. For the large items the order fulfilment process can be exactly planned on the desired shipment date because of the early orders. These new service conditions require a new aligned inventory policy which is introduced below.

Nedap currently handles a safety stock of eight items for Product Type C. To evaluate the quality of this standard stock level we calculate the required inventory position regarding the new service conditions. These calculations only concern the small quantity demand as the large orders will be supplied by a make-to-order process which requires no inventory. The required inventory level calculations for the small orders start with identifying the standard deviation of the small quantity demand. Formula 4.13 introduced in Chapter 4 will be used here to calculate this standard deviation:

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} = 3.207\ldots \qquad (4.13)$$

The standard deviation of the demand per period can be translated in a standard deviation of the demand during lead time and review period by Formula 4.14. In the Nedap UV specific situation the lead time L includes 8 weeks and the review period R includes one week. This results in the following standard deviation calculations over the standard deviation of the lead time and review period:

$$\sigma_L = \sigma_1 * \sqrt{L} = 3.207\ldots * \left(\sqrt{\left(8 * \left(\frac{10}{52}\right)\right)}\right) = 3.978\ldots$$

$$\sigma_{L+R} = \sigma_1 * \sqrt{L+R} = 3.207\ldots * \left(\sqrt{\left(9 * \left(\frac{10}{52}\right)\right)}\right) = 4.219\ldots \qquad (4.14)$$

In this formula the factor 10/52 is used for translating weeks into periods. The next step according to Chapter 3 is calculating the required safety factor by Formula 4.9:

$$P_2 = 1 - \frac{\sigma_{R+L} * G_u(\frac{\sigma_{R+L}}{\sigma_L} * k + \frac{\widehat{x_R}}{\sigma_L})}{\hat{x}_R} \tag{4.12}$$

To fill this formula we use the service level defined in Chapter 4, this value equals 0.975 and represents the P_2 parameter. Because of the growth trend in demand introduced in the sales planning, the calculation of the expected demand per week $\hat{x}_R$ should take the time of the year into account. This includes that only the expected demand of the first quartile should be used, only this period is used as these calculations will be update every quartile. The expected weekly demand is calculated based on the first quartile sales planning and represented by the following formula:

$$\hat{x} = \frac{\text{Expected Demand Q1 2013 (First 13 weeks)}}{\text{Amount of Weeks in Q1}} = \frac{(10+11+2+2+3)}{13} = 2.153 \ldots$$

Now the all required parameters to calculate the k value are available we start filling Formula 4.12:

$$0.975 = 1 - \frac{4.219 * G_u(\frac{4.219\ldots}{3.977\ldots} * k + \frac{2.153\ldots}{3.977\ldots})}{2.153\ldots} \rightarrow 0.0250 = 1.959 \ldots * G_u(1.060 \ldots * k + 0.541 \ldots)$$

$$\ldots \rightarrow 0.0127.. = G_u(1.060 * k + 0.541 \ldots)$$

From the normal probability distribution given in Appendix I, we can find the x value of $G_u(x)$ for 0.01276 to be 1.845. This leads to the following formula for finding parameter k:

$$1.845 = (1.060 * k + 0.541 \ldots) \rightarrow 1.303 \ldots = (1.060 * k) \rightarrow k = \frac{1.303\ldots}{1.060\ldots} = 1.229 \ldots$$

Now we found the safety factor we can start calculating the safety stock required for the service level of 0.975. Using Formula 4.11 for the safety stock calculations results in:

$$SS = k\sigma_{R+L} = 1.229\ldots * 4.219\ldots = 5.186\ldots \tag{4.11}$$

From this set of calculations we conclude that the safety stock level of this product type should equal 5.186… items. The order-up-to level S is rounded up to six items to make sure the service level goal is attained and one additional product will not result in significant inventory costs differences. Now the desired calculated safety stock (SS) for these items is clear we compare the found SS level with the current safety stock level. The current safety stock at Nedap UV is eight items, while the aligned order fulfilment process suffices a safety stock of six items. This equals that the redesigned service and inventory management policy delivers better service conditions for 88% of the orders with two products less on stock. So the current held safety stock level is not fully necessary and should be downgraded to only six items to attain the set service level target. In this way we are able to increase the Nedap UV flexibility while reducing the inventory costs.

In the exceptional situation a large quantity order arises more suddenly than expected the customer can decide to use this safety stock as well. However, this will lead to a situation in which Nedap is unable to supply the small quantity orders according to the set service conditions. This additional option for the customer should therefore only be called for in emergency situations. We end this section with determining the average on hand stock. This level can be used to benchmark the actual stock level on as described in Chapter 4 according to Formula 4.15:

$$\text{Average On Hand Stock} \approx SS + \frac{\hat{x}_r}{2} = 6 + \frac{2.153\ldots}{2} = 7.076 \ldots \tag{4.15}$$

5.2.3 Aligning the Supply Planning Process

The last researched phase of the order fulfilment process for Product Type C concerns the supply planning process. The large quantity demand supply planning is relatively simple. The demand is known in advance of the order fulfilment process start and can therefore be planned and produced on order according to its desired shipment date. The sales planning for these products is accurate as orders are in before the component purchasing process starts. After the eight weeks of the production process the products are ready to be expedited by the distribution department of Inventi.

For the small quantity orders of Product Type C a different supply planning process is required. We introduced an (R,S) inventory policy and now have to calculate the order-up-to level S to find the required order quantity for a certain week. This level S should be sufficient to cover all demand until the arrival of the next replenishment order. To calculate the level S we need the expected demand during lead time and review period according to Formula 4.11. The lead time of all products is eight weeks and the review period is one week with a weekly expected demand of 2.153…, only considering first quartile demand regarding the growth trend. So, the expected demand during lead time and the review period is equal to (8 + 1) * 2.153…= 19.384…. Now this expected demand is clarified we calculate the level S by Formula 4.11 introduced in Chapter 4:

$$S = k\sigma_{R+L} + \hat{x}_{L+R} = 5.186... + 19.384... = 24.570... \qquad (4.16)$$

The order-up-to level S is also rounded up to make sure the service level goal is attainable. So, for the small orders the order-up-to level is 25 items. This level can be illustrated by an example: If Nedap has a current actual stock level of 10 items and 14 items are processed in the pipeline, Nedap needs to order 27 – 10 – 14 = 3 items for the concerning week. So Nedap should reconsider the actual order level and products in progress every weekly meeting to come to an order plan for that specific week. The order-up-to-level calculated for this product only includes orders up to a level of 3 items, for that reason the make-to-order large orders should be added to this supply planning.

Within the supply planning of this product group there are some additional constraints regarding the supply process as indicated in Section 5.1. As Nedap's supplier Inventi has no unlimited production capacity these capacity restraints have to be taken into account in the supply planning process. Inventi is only able to produce 12 items a week for this product group, the supply planning for the total product group should therefore not exceed a total of 12 items a week. In case this demand level appears in a certain week the order plan should be adjusted by smoothing the additional demand over multiple weeks in advance. For that reason the supply meeting should discuss multiple weeks in advance concerning the supply planning of products.

A product in this product group contains three equal subassemblies, these subassemblies have one required production step in common with the products in Product Group 3. This process step can only be completed by one available machine at Inventi with a capacity of 60 items a week. This means that we can only produce 20 items of product group 1 or 60 items of Product Group 3. However, a combination of both product groups' products is the most regular. For that reason we implement a supply planning restriction combining Product Groups 1 and 3 here:

$$3 * (Order\ Quantity\ Product\ Group\ 1) + 1 * (Order\ Quantity\ Product\ Group\ 3) \leq 60$$

5.3 Process Alignment for Product Type E

5.3.1 Aligning the Sales Planning Process

The sales planning of Product Type E from Product Group 3 is more complex compared to the sales planning of the other product types presented. The order fulfilment process has to be aligned separately for this customer specific product as it differentiates in component composition from the basic version Product Type G. The specific customer for this product usually provides Nedap with an accurate demand forecast. This makes the customer input an important aspect in the sales planning. Next to these customer forecasts we setup a mathematical sales planning model as well as customer forecasts are not standard received in advance of the component purchasing process. So, this product is not completely produced on a make to order level as components are purchased in advance of incoming orders. The mathematical model based on historical figures forms the foundation of the sales planning up to the moment customer input is received. We research the historical demand to find the required parameters for the mathematical model.

The standard order quantity for this product type is 10 items. A total historical sales amount in 2012 of 130 items suggests 13 different order moments. The actual amount of order moments in 2012 was 18 because of some exceptional situations, like partial order deliveries or product failures at the customer. To generalise this order behaviour we consider 130 sold items in 13 order moments last year. As is visualised in the historical sales graph of Figure 5.3 the demand trend has been slightly growing during the last three years. The account managers expect this growing trend line to end in the upcoming year. This expected end of growth arises from the severe economic circumstances in the market the customer is operating in. As the customer expects no demand growth either we exclude a trend pattern in the mathematical model for Product Type E.

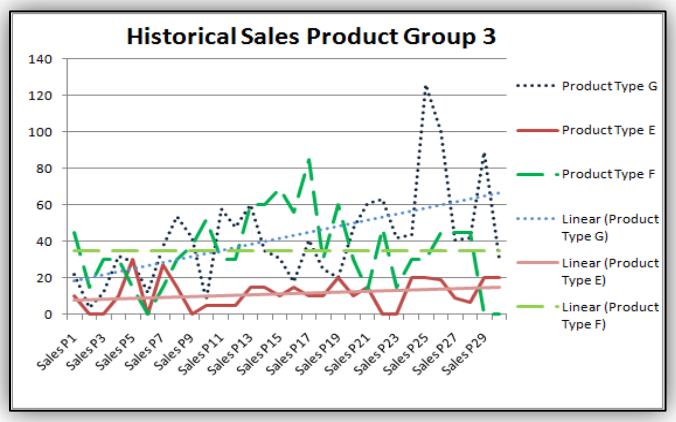

Figure 5.3: Historical Sales Product Group 3 2010-2012

Considering the seasonality of this demand some remarkable patters appear in Figure 5.3. In general the average periodic sales over the last three years were 34 items. The actual total demand per period over three years show that the second and third period sales are remarkably low according to the average demand. The sales for the fourth, fifth and seventh period are remarkable high. To get a more specific insight in this pattern we set off the sales per year against the different periods in Figure 5.4. From this graph we conclude

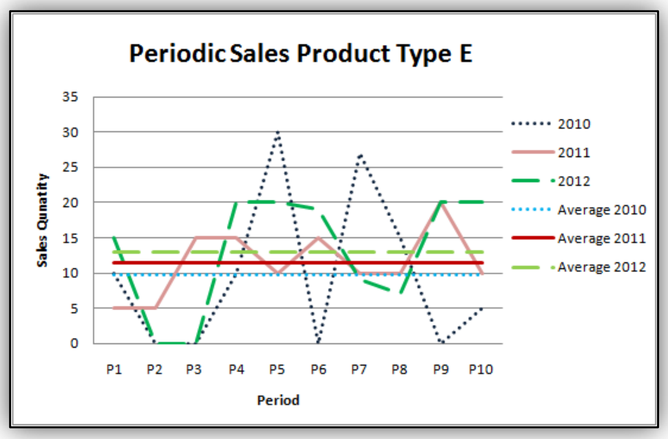

Figure 5.4 Periodic Sales for Product Type E (2010-2012)

that the sales in period two and three are significant lower than average in five out of six periods over the three analysed years. Also, in Period 4 and 5 the high amount of sales are not accidental. The sales are significantly higher in five out of six periods over three years. As the account managers are unfamiliar with this pattern we deepen the research.

The specific customer is a water disinfection system producer for the agricultural business in Europe. In this business water bacteria growth is high at the start of the summer. This bacterial growth could be a strong motivator for customers to buy a water purification system. For that reason it seems valid to conclude that demand increases for the specific product when the average temperature increases. The increasing temperature will normally appear around the spring period and will therefore be in Period 4 and 5. A decreasing trend in temperature has a negative effect on the sales amount at the customer as well. This unknown decrease in sales at the customer will lead to a higher stock amount at the end of the year as the average sales were overestimated. This explains why the sales rates drop significantly in Period 2 and 3 at the end of the winter period. We expect the seasonal pattern to continue for this product type, but in a wider trend as the customer will try to prevent the high stock levels at the end of the year now this sales pattern is known. For that reason we expect a decrease in demand for Product Type E in the winter period which will include Period 1, 2, 3 and 10. For Period 4 and 5 we expect a clear demand peak during the start of the summer. The other demand peak in Period 7 is denied in this research as it looks like an incidental demand peak in 2010 from Figure 5.4. It is for that reason be filtered out of the input data and downgraded to the average sales level of 13 items as is shown in Table 5.4. Concluding, we do exclude a trend component but include a seasonal trend in the sales planning for the upcoming year.

Year:	Period:	Demand Xt:	Moving Average 1:	Moving Average 2:	Centred 10-Periods Moving Average:	Estimate Ft:	Average Estimate Ft:	Validated Index Ft:	Normalised Index:	Forecasted Demand per Period:
2010	1	10	-	-	-	-	-	-	-	-
2010	2	0	-	-	-	-	-	-	-	-
2010	3	0	-	-	-	-	-	-	-	-
2010	4	10	-	-	-	-	-	-	-	-
2010	5	30	-	-	-	-	-	-	-	-
2010	6	0	8.30	7.80	8.05	0.00	-	-	-	-
2010	7	13	7.80	8.30	8.05	1.61	-	-	-	-
2010	8	15	8.30	9.80	9.05	1.66	-	-	-	-
2010	9	0	9.80	10.30	10.05	0.00	-	-	-	-
2010	10	5	10.30	8.30	9.30	0.54	-	-	-	-
2011	1	5	8.30	9.80	9.05	0.55	0.89	0.89	0.95	**12.34**
2011	2	5	9.80	9.50	9.65	0.52	0.26	0.26	0.28	**3.59**
2011	3	15	9.50	9.00	9.25	1.62	0.81	0.81	0.86	**11.23**
2011	4	15	9.00	11.00	10.00	1.50	1.58	1.58	1.69	**21.92**
2011	5	10	11.00	11.50	11.25	0.89	1.24	1.24	1.33	**17.23**
2011	6	15	11.50	12.50	12.00	1.25	0.63	1.00	1.00	**13.00**
2011	7	10	12.50	12.00	12.25	0.82	1.22	1.00	1.00	**13.00**
2011	8	10	12.00	10.50	11.25	0.89	1.27	1.00	1.00	**13.00**
2011	9	20	10.50	11.00	10.75	1.86	0.93	1.00	1.00	**13.00**
2011	10	10	11.00	12.00	11.50	0.87	0.70	0.90	0.90	**11.70**
2012	1	15	12.00	12.40	12.20	1.23	-	-	-	-
2012	2	0	12.40	12.30	12.35	0.00	-	-	-	-
2012	3	0	12.30	12.00	12.15	0.00	-	-	-	-
2012	4	20	12.00	12.00	12.00	1.67	-	-	-	-
2012	5	20	12.00	13.00	12.50	1.60	-	-	-	-
2012	6	19	-	-	-	-	-	-	-	-
2012	7	9	-	-	-	-	-	-	-	-
2012	8	7	-	-	-	-	-	-	-	-
2012	9	20	-	-	-	-	-	-	-	-
2012	10	20	-	-	-	-	-	-	-	-

Table 5.4: The Winters Exponential Smoothing Procedure Results

To forecast the seasonality of the level demand pattern for Product Type E we use the Winters' exponential smoothing method described in Chapter 4. As this procedure is potentially useful in aggregate, medium-range forecasting we use the periodic demand pattern instead of weekly patterns. The results of the Winters' exponential smoothing procedure, described in Chapter 4, are presented in Table 5.4. As only three years of sales history for this product is available the Winters' procedure for seasonal models can be significantly influenced by some incidental demands. The moving averages in this table are the averages over the yearly ten periods and are used as it can effectively handle changes in the underlying trend during the historical period (Silver, Pyke, & Peterson, 1998). This moving average calculates the average over the number of periods concerned. So in this specific situation the first moving average concerns the average over the first 10 periods. As the data concerns an even number of periods during the year we require two moving averages to find one centred moving average. The estimate of the F_t value is then calculated by dividing the actual demand for a specific period by the found centred moving average. The periods 6, 7, 8 and 9 which are not influenced by seasonality are valued as 1.00 for its validated F_t value. For the last period a validated index of 0.9 is given to indicate its seasonal influence. We use 0.90 as a factor as the estimates found of F_t are influenced too strong because of incidental deep falls in demand for these periods. The values for the Periods 1 to 5 are assumed to be valid because of its demonstrated seasonality. The normalisation index given in the table is the normalisation to set the current average of all periods, which equals 0.938…, back to one. Finally the average demand of 13 items per period resulted in the forecasted demand shown in the last column of Table 5.4. We do not use the updating procedure of this method of forecasting here as it is the first introduced forecast, which we cannot update yet. However, the updating procedure should be used once new data becomes available.

The periodic forecast found in Table 5.4 is translated to a weekly planning in quantities of ten to be useful as sales planning for Inventi. Hereby, we translate the periodic sales planning in a weekly planning based on the cumulative demand over the year shown in Table 5.5. To be able to deliver the first order in the complete range of time we plan the first order in the first week. An additional order is planned every time the cumulative demand value crosses a factor 10 which represents the fixed order quantity.

These are the end results of the sales planning for the upcoming year. As mentioned before, this forecast is leading up to the moment the specific customer delivers customer input for the sales planning. The customer input will be leading in the final sales planning as this customer input has historically seen been interpreted as accurate. As the employee input has already been implemented in the mathematical model this input is not explicitly used again. Nonetheless, the final sales planning out of the combination of the mathematical model and customer input will always be validated by Nedap employees.

Week (2013):	Weekly Demand:	Cumulative Demand:	Forecasted Demand:
1	2.5	2	10
2	2.5	5	
3	2.5	7	
4	2.5	10	10
5	2.5	12	
6	0.7	13	
7	0.7	14	
8	0.7	14	
9	0.7	15	
10	0.7	16	
11	2.2	18	
12	2.2	20	10
13	2.2	23	
14	2.2	25	
15	2.2	27	
16	4.4	32	10
17	4.4	36	
18	4.4	40	10
19	4.4	45	
20	4.4	49	
21	2.9	52	10
22	2.9	55	
23	2.9	58	
24	2.9	61	10
25	2.9	63	
26	2.9	66	
27	2.2	68	
28	2.2	71	10
29	2.2	73	
30	2.2	75	
31	2.2	77	
32	2.2	79	
33	2.6	82	10
34	2.6	85	
35	2.6	87	
36	2.6	90	10
37	2.6	92	
38	2.6	95	
39	2.6	98	
40	2.6	100	10
41	2.6	103	
42	2.6	105	
43	2.6	108	
44	2.6	111	10
45	2.6	113	
46	2.6	116	
47	2.6	118	
48	2.3	121	10
49	2.3	123	
50	2.3	125	
51	2.3	128	
52	2.3	130	

Table 5.5: Demand Forecast over 2013 for Product Type E

5.3.2 Aligning the Service and Inventory Management Process

Service management for this item is based on a make-to-order policy while it concerns a customer specific product. This means that Nedap is able to deliver the demanded products eight weeks after the moment of ordering if the demand is included in the sales planning. To hedge against deviations in order behaviour of the customer 5 items are standard kept in stock. This inventory is kept to be able to deliver earlier than planned or to cover product breakdowns. An agreement with the customer is made that he is obliged to take off these products in inventory, which decreases the risks for obsolescence significantly. Concluding, the current Nedap strategy seems eligible as it provides additional flexibility to the customer with no excessive amounts of inventory.

Additionally to this safety stock hedge for variability of demand for this product is available by its interchanging ability with Product Type F up to the last four weeks of production. This means if Product Type F is planned, this planning can still result in produced Product Type E products until its more than four weeks in production. This measure can only be applied in emergency situations as it confuses the order fulfilment process of Product Type F and the corresponding production process. Next to that, components of the specific product type need to be available at the moment of switching. For these reasons this exchange of Product Type E or F only actually happens in case of an emergency situation at the customer. The exchange ability is also valid for Product Type F.

5.3.3 Aligning the Supply Planning Process

Product Type E will be produced based on the make-to-order concept. The supply planning for the product is mainly based on the ordering behaviour of the customer. A safety stock level of this product is held for 5 items to hedge against demand variability. In case demand is required earlier than planned this inventory is used to satisfy the customers' desire for earlier distribution. The inventory is mainly used as an early shipment option and for that reason will be automatically replaced by the products in the pipeline. However, if this order considers an additional order the safety stock has to be replaced which can take up to 38 weeks. The 38 weeks are required as the required products will have to go through the complete order fulfilment process again. However, this replacement time can be shorter if components required for production are available or become available earlier. In general the production batch will be 10 for Product Type E items but in case this safety stock has to be replaced this production batch will be raised once up to 15 items as we have to add 5 additional safety stock items to the fixed order quantity. For Product Type F a production batch will always include the fixed order quantity of 15 items as the safety stock level is equal to 15 as well. For these items no specific production capacity limitations have to be included except the overall product group limitation introduced in the supply planning of Product Type C:

$$3 * (Order\ Quantity\ Product\ Group\ 1) + 1 * (Order\ Quantity\ Product\ Group\ 3) \leq 60 \quad (5.1)$$

For Product Group E and F the ability to exchange products is introduced in the service management part of this section. In the supply planning process of this product these special situations can be requested during the weekly meeting with Inventi. If exchange of product types is decided to be necessary and possible in the meeting, the supply planning for the substituted product type should be rescheduled.

5.4 Conclusions and Results

To complete the order fulfilment process for the pilot product groups we draw some final conclusions in this section. The chosen pilot product groups have different relevant product and market characteristics which make the alignment process example for all introduced pilot product types useful. These examples can be interpreted as general examples for the alignment process for the remaining products of Nedap UV. The process of configuring the order fulfilment processes and its parameters should be repeated several times during the year dependent on the product importance for Nedap UV. This repetition should be done because of changing product and market characteristics during their product life cycle. Frequently resetting the parameters in combination with process evaluation by a feedback loop over the process performance will result in more accurate order fulfilment processes. As the processes are dependent on each other, these updating frequencies should be equal for all processes per product type.

From the analysis in this chapter we conclude that the standardised product from Nedap UV out of Product Group 1 and 3 require the most changes. For these Product Types C and G we distinguished small and large orders. In the old situation products were offered to customers in general eight weeks after their moment of ordering. In the new situation the small items can be supplied within one week and the large orders can be supplied within the eight weeks current standard. For these improved service conditions Nedap UV requires lower inventory levels when aligning the products and processes as described in Chapter 4. For example, for Product Type C this means that 88% of the orders will be supplied seven weeks earlier while we reduce the safety stock level with 25%. This equals lower inventory levels and for that reason less inventory costs, while we improve the service conditions for the major part of the orders significantly. Based on the research of these two product groups we can conclude that Nedap UV’s former order fulfillment process, which was mostly based on experience, was not efficient. Aligning the product and market characteristics of the products to the order fulfillment processes results in less required inventory resources for improved service conditions for the customer.

Next to the improved operational processes, we expect significant improvements in the order handling workload as well. As customer service conditions improved significantly, complaints and order modifications from these customers will appear in a lower frequency. The smaller supply time window has a decreasing effect on the amount of requests for order information as the provided information will be more up to date. Besides, less order fulfilment complaints will come in as service conditions will be improved significantly. These effects and the improved transparency of the overall process results in less efforts on average to fulfil an order. The overall more efficient and effective way of working results in a decreased workload in which the UV employees are able to process more orders with the same efforts. Besides these Nedap UV results, the aligned order fulfilment process has a positive effect on Inventi as well. The aligned and more accurate sales planning process will result in a more accurate purchasing process for components at Inventi. Also the supply planning process will be more accurate because of the more accurate input information and the integrated capacity restrictions at Nedap UV. These effects will result in a decreased amount of supply planning modifications and efforts.

The exact effects regarding the performances of the aligned processes cannot be measured yet as historical delivery performance was not measured. Not being able to measure the actual effects in the order fulfilment process harms the credibility of this research as we are not able to prove the improvements. For that reason we do not end this research with providing examples of the order fulfilment process alignment. In the next chapter we introduce a set of key performance indicators for Nedap UV to improve the measurability and control over the aligned processes. We suggest implementing these key performance indicators before aligning and implementing the remaining product groups to be able to measure the alignment effects.

6. Order Fulfilment Process Performance Indicators

No performance of the former order fulfilment process is currently measured at Nedap UV. Step 8 of the Rohleder and Silver framework suggests starting to monitor the order fulfilment process performance. Besides, effects of the alignment of processes or other improvements cannot be measured as the current state of the system is not defined. We dedicated Section 2.3 towards performance management in the theoretical Chapter 2 to form the foundation of this chapter. We suggest Nedap UV to design a performance management system before continuing the alignment process for the remaining product types. With measuring the initial situation compared to the aligned order fulfilment process the effects of this alignment can be quantified. And if the effects of the alignment process become clear it will be easier to perceive company support for this alignment process. For that reason the last step in this research is the design of a set of indicators for the order fulfilment process performance management. Because of time restrictions we will not be able to introduce a complete performance management system. But this chapter will form the basis for the performance management system to be designed by Nedap UV. The set of indicators designed in this chapter provide the answer to the final research question: "*What indicators are required to monitor and control the Nedap UV order fulfilment process performance?*"

In Chapter 2 we introduced four indicators of the order fulfilment performance: process lead time, amount of order defects, service performance and stock performance. The process lead time and the amount of order defects are ignored in this research. The lead time indicator is ignored because of a fixed production lead time agreement between Nedap UV and Inventi of eight weeks. The necessity of these eight weeks is unclear and out of scope of this research. Inventi is responsible for the order defects as well and for that reason it is not a relevant performance indicator for Nedap UV either. The other two performance indicators mentioned in Chapter 2 do provide a relevant indication of the performance of the order fulfilment process at Nedap UV. For that reason we add *the delivery performance* and *inventory performance* as key performance indicators for the Nedap UV order fulfilment performance. These two indicators provide a quantitative insight into the performances of the service and inventory management process and the supply planning process. However, these two indicators do not provide any indication of the sales planning performance, for that reason we introduce another performance indicator which indicates *the reliability of the sales planning*. These three performance indicators will be described more detailed in the upcoming three sections.

6.1 Sales Planning Performance

By measuring the reliability of the sales planning process we can provide structural input for the feedback process in the sales planning framework. The first key performance indicator we introduce here concerns the reliability of the periodic sales planning for all product types up to a year in advance. As Nedap UV updates its periodic forecast during the year we suggest using a quarterly measure of this reliability. In this way we can visualise what effects the updated forecasts have without having to evaluate this forecast every period. In this way four moments of forecasting errors are measured, one year in advance and three, two and one quarter in advance of the specific period. For the forecast measure we use the mean square error, also referred to as MSE. This indicator compares the actual observed demands, $x_1, \ x_2, \ldots, x_n$ and the forecasts for y quarters ahead, $\hat{x}_{0,y}, \ \hat{x}_{1,1+y}, \ldots, \ \hat{x}_{n-y,n}$. Where $\hat{x}_{t,t+1}$ is the forecast made at the end of period t for period t+1. As we measure four different forecast moments during the year we have four different y values. The MSE value can be calculated by the following formula:

$$MSE = \frac{1}{n} * \sum_{t=1}^{n} (x_t - \hat{x}_{t-1,t})^2 \qquad (6.1)$$

We use this measure as it can be computed easily and provides comparable parameters with regard to the sales planning performance for all other product types. In the end we will have four indicators of the sales planning reliability of all products per period. A feedback loop in which the MSE results are analysed will provide input for the new sales planning of the product as planning errors will become evident. These errors have to be analysed every quarter during the year for trends and other deviations to learn from the identified deviations. These lessons and discovered trends should lead to a more accurate new sales planning constructed for the upcoming periods. Analysing the outcomes of this performance indicator will provide an indication of the origin of the error. This might be a customer input error, an employee input error or a mathematical model error. As including these inputs at the sales planning process is dependent on the actual information available, we aggregate the input factors to one reliability indicator:

- 1. Sales planning performance:
    - *(1.1) Mean Square Error over the sales planning and actual product type demand*
        - *(Year in advance, measure every quartile)*

6.2 Inventory Performance

Now we have aligned the inventory policy at Nedap UV with the pilot products we want to measure the performance of this inventory policy. Nedap is able to increase the delivery performance up to 100% if they fill the complete warehouse with UV products. But this inventory will decrease their liquidity and increase risks. For that reason we want to find a compromise in the order fulfilment process by aiming for good delivery performance combined with a low level of inventory. To be able to measure the inventory performance we introduce a set of performance indicators in this section.

First of all we measure the *on-hand stock level per product type*. By analysing these stock levels per product type we can evaluate the inventory performance by comparing this level to the average calculated on-hand stock levels in Chapter 5. This indicator will present the deviations from average stock levels and can therefore indicate the necessity of the product inventory level. The next inventory performance indicator we add is the *stock turnaround time per product type* as suggested by Johnson and Davis (1998). This indicator presents the value of the inventory per product type divided by the total turnover of the product type (Axsäter, 2006). The indicator provides an insight in the need for inventory of a specific product based on the historical sales. A long turnaround time on this measure will highlight products with relative high inventory levels compared to their historical sales. A long turnaround time might signify for that reason that current stock levels are unnecessary and sensitive for obsolescence risks. The last indicator for inventory performance measurement is the *total inventory value for the UV products in Euro's*. This indicator provides an overview of the total stock level developments over time. It functions as an input tool for inventory budgeting for the upcoming years as well, by analysing the stock value developments and its trends.

- 2. Inventory performance:
    - *(2.1) On-hand stock level per product type*
    - *(2.2) Stock turnaround time per product type (Stock level value/Yearly turnover)*
    - *(2.3) Total inventory value UV in Euro's*

6.3 Delivery Performance

As indicated in Chapter 4 customer focus is very important for Nedap UV. One of the main indicators of the quality of this customer focus is the delivery performance towards customers. To indicate the delivery performance of Nedap UV we introduce *the percentage of products shipped on time per product type*. In case the actual shipment date is before or on the initial agreed shipping date we consider an order to be on time. This indicator contrasts the actual shipping date against the initial promised shipping date. We use the initial promised shipping date as this date provides an accurate indication of initial promises to customers. Besides, it excludes late modifications of the desired shipping date which prevents incorrect presentation of this performance indicator as explained in Chapter 4. The distribution is handled by external parties on the responsibility of the customer, for that reason only the moment of shipping the products is indicative for the performance of Nedap. This KPI is measured per product type to obtain an indication of what products encounter delivery problems. Analysing this performance indicator helps identifying regular delivery problems, which should be identified to introduce measures to prevent these problems.

Only indicating what percentage of the products is delivered late is not enough to measure the performance of an order fulfilment process. Schneiderman (1996) suggested the inclusion of lateness categories of product deliveries for measuring delivery performances. We add *lateness of products* in performance measurement as not only the percentage of late deliveries is important but the degree of lateness as well. A product delivered late for over 100 days has different effects on customer satisfaction than 100 product delivered late for only a day. We measure lateness per day to perceive an indication on the degree of lateness of products. To every outgoing shipping note a lateness indicator will be assigned which presents the lateness in days. In case a product is supplied before the desired supply date this performance indicator will present negative values. We use the number of days per product as these figures can be aggregated to form for example categories of lateness. In this way the data can be aggregated to all lateness categories desired by Nedap UV, the performance indicator will for that reason be more flexible in the representation of its outcomes. The degree of lateness can indicate the severity of the delivery problems. Based on the outcomes of this performance indicator Nedap can initiate measures, for example increasing inventory levels in case of frequent late deliveries. These two key performance indicators are summed below:

- 3. Delivery performance:
  - *(3.1) Percentage of products delivered on time per product type*
    - Shipping notification date versus initial promised order distribution date
  - *(3.2) Lateness per supplied product in days*
    - Shipping notification date versus initial promised order distribution date

6.4 Performance Measurement Discussion

The six key performance indicators introduced in the three previous sections form the suggested set of indicators for the performance management system to be designed by Nedap UV. The performance indicators introduced present the performance per product type. If it turns out that information per product group is more informative the system is always able to measure at a higher aggregation level. The set of indicators we stated will be monitored by the business intelligence tool Qlikview for data analysis, dashboards and reports. This tool will be controlled by the operational manager and provides employees involved a good understanding of the current and past order fulfilment performances. To control and analyse these parameters a periodic meeting must be introduced. In this supply committee performance will be discussed and analysed, such as sales planning performance, stock performance and delivery performance. As data results must be stable of the time frame for tactical analysis of the performance we analyse the data in periods instead of smaller time frames.

As Lohman, Fortuin and Wouters (2004) stated; a performance measurement process will only work with a drive for continuous improvement. For that reason we want the involved employees to provide feedback on the performance indicators in periodic meetings to improve the aligned process continuously. This feedback process will also function as the validation step of performance management at Nedap UV. This meeting can be the start of a performance management system we suggest Nedap UV to implement based on the introduced performance indicators in this chapter. Furthermore, we comply with the effectiveness amount criteria stated by Chae (2009) to only focus on a small list of KPIs in a range from 5 to 10 indicators. The challenge for Nedap UV is now to make the order fulfilment performance measurement work. A start has been made as the first KPIs have been introduced in the Nedap UV business intelligence tool. Two examples of the visualisation of the introduced performance indicators of the Nedap UV dashboard are presented in Figures 6.1 and 6.2. Figure 6.1 presents the stock turnaround time performance over time. And Figure 6.2 presents the lateness of supplied products in seven categories. Now this section is completed we can state that we have fulfilled the last research question of this research: "*What indicators are required to monitor and control the order fulfilment process performance?*" To finalise this research we come up with the major conclusions drawn from this research and some recommendations towards Nedap UV in Chapter 7.

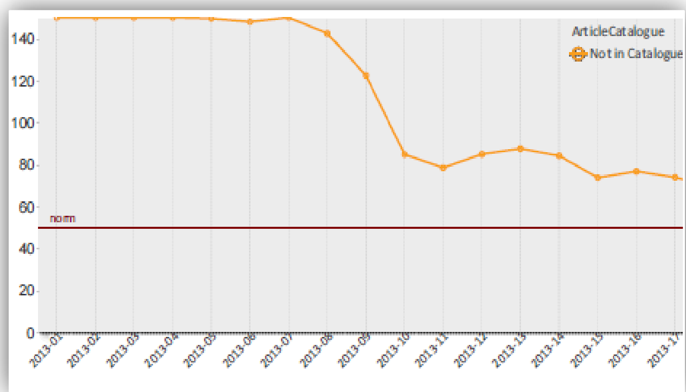

Figure 6.1: KPI 2.2: The Stock Turnaround Time for Product Type X

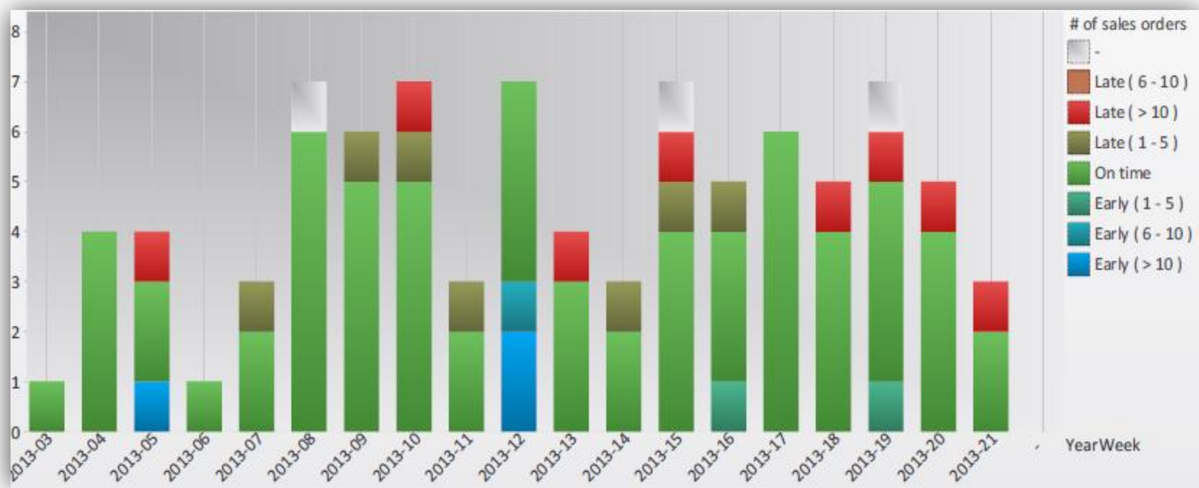

Figure 6.2: KPI 3.2: Quantity of Products per Lateness Category for Product Type X

7. Conclusions and Recommendations

The performance indicators introduced for the order fulfilment process finishes the individual chapters of this thesis. In this final chapter we draw the main conclusions and present Nedap the main recommendations of improvement options notified during this research. Section 8.1 presents the main conclusions and Section 8.2 presents the recommendations to Nedap UV.

7.1 Conclusions

The main problem identified at the start of this research at Nedap UV was an ineffective, inefficient and uncontrollable identified order fulfilment process. Order fulfilment is defined in this thesis as the complex process composed of several activities undertaken by different functional entities, starting with planning the future orders up to delivering the customer orders at the right time and the right place. A consequence of the underperforming order fulfilment process is a delivery performance which does not comply with the Nedap standards. This shortcoming in delivery performance should be prevented to keep up with the current market share and revenues in the innovative market Nedap UV is participating on. Another unwanted consequence of this underperforming process is the high workload for the operational manager to control the order fulfilment process. We approached this problem according to the business process improvement framework by Rohleder and Silver (1997). This resulted in the research results described below.

In Chapter 3 we identified three tactical order fulfilment processes at Nedap UV which affect the performance of the order fulfilment process significantly. These three processes are: sales planning, service and inventory management and supply planning. These processes are selected from the individual processes of the total order fulfilment processes as they have a significant effect on the process performance and are in control of the Nedap UV operational management team. Once these processes were clarified and described we selected the product and market characteristics that might influence these three order fulfilment processes. We aimed for an aligned order fulfilment process by introducing an alignment guide for the product and market characteristics in combination with the three order fulfilment processes. This aligning process aims to achieve the stated research goal*; a more effective, efficient and controllable order fulfilment process.*

In the next phase of this research we stated an example and validated the alignment guidance by implementing it on actual Nedap UV product groups. Due to time restrictions of this research we selected only two pilot product groups to align the order fulfilment process for. These product groups were selected based on three product characteristics, the product importance for Nedap UV, their potential demand growth and their demand variability. These characteristics were used to state an example for the product groups which were the most interesting for this research and which required the most complicated alignment processes. The selected two pilot product groups resulted in a comprehensive set of alignment examples. These pilots perform an exemplary role for the Nedap UV employees towards the independent execution of the alignment process of the remaining products. Experience and ownership are created by leaving the remaining products' alignment processes to the employees. This creates more commitment and awareness of the Nedap UV employees for the alignment process, required to achieve the desired goal.

Finally, a set of performance indicators is introduced to improve controllability over the order fulfilment process. These performance indicators monitor the performance of the three identified order fulfilment processes. These metrics monitor the aligned processes and provide Nedap UV the ability to control and adjust these processes for improvement. The set of indicators measure sales planning performance (1), inventory performance (2) and delivery performance (3) by this set of performance indicators:

- *(1.1) Mean Square Error over the sales planning and actual product type demand*
- *(2.1) On-hand stock level per product type*
- *(2.2) Stock turnaround time per product type*
- *(2.3) Total inventory value UV in Euro's*
- *(3.1) Percentage of products delivered on time per product type*
- *(3.2) Lateness per supplied product in days*

With this research we aimed for a more effective, efficient and controllable order fulfilment process. The effectiveness and efficiency cannot be exactly measured because of a lacking performance measurement system at Nedap UV currently. However, we expect the order fulfilment process to become more efficient and effective as the alignment of the process is now based on extensive research instead of employee experience. This expectation is based on a comparison between the actual situation and the research outcomes. For both aligned product groups inventory levels can be downgraded to achieve the desired service conditions. These desired service conditions are a significant improvement for the customer in terms of supply lead times and delivery reliability. For example, 88% of the orders of Product Type C can be delivered within 1 instead of 8 weeks while we reduce the safety stock with 25%. All of this within the targeted 97.5% of the product delivered at before the agreed delivery date. This comprises that we can improve the Nedap UV service conditions significantly with fewer resources in terms of inventory value. In comparison to the former service conditions we can conclude that our research outcome will lead to an improved effectiveness and efficiency of the order fulfilment process. With fewer resources, in terms of inventory levels, we achieve higher service levels for customers. Furthermore, although the exact historic delivery performance was not measured it is assumed by the employees involved to be structurally behind of the introduced service level goal of 97.5%.

One of the remaining unsolved problems so far is the order handling workload. With aligning the order fulfilment processes, procedures of the sales planning, service and inventory management and the supply planning have been standardised and clarified. This will result in more transparent and controllable functions in which operations are simplified. This standardisation and clarification of operations will result in less effort required on average to manage an order fulfilment. Besides, we expect the average order handling to consume less time. This is based on the decreasing amount of complaints and order conditions modification as orders are fulfilled within a smaller time window. The overall more efficient, effective and controlled way of working results in a decreased workload in which the UV employees are able to process more orders with equal efforts. Besides these Nedap UV results, the aligned order fulfilment process has a positive effect on Inventi as well. For example, the aligned sales planning process will result in fewer components in stock because of the improved accuracy of the sales planning.

In addition to the effectiveness and efficiency, the control over the process was a main goal of this research. This goal is achieved by introducing a set of performance indicators for the Nedap UV order fulfilment process. Implementing these performance indicators will provide insights for Nedap UV in deviations from goals. Analysis of these deviations can lead to main causes for a non-performing process. Identifying these causes is essential in the continuous improvement way of improving business processes Nedap wants to introduce.

The final result of this research is a guidance towards a more effective, efficient and controllable aligned order fulfilment process. This is confirmed by the implementation for the pilot products which have been proved to result in a more effective and efficient order fulfilment process. In this aligned order fulfilment process parameters and available information are used more cleverly. We conclude the research and its outcomes to be complete as all stated research questions are answered and all deliverables are achieved according to Chapter 2. Now it is up to Nedap UV to implement the research results. Next to this implementation process we provide Nedap UV some overall recommendations in the final 'recommendation' section of this research.

7.2 Recommendations

The last section of this research provides Nedap with the overall recommendations notified during this research. The basic recommendation to Nedap UV is to start implementing the aligned order fulfilment process described in this research. The first step to be taken is to start measuring the set of introduced performance indicators. The performance indicators should be implemented first to be able to form a baseline measure for the current order fulfilment performance. This baseline measure can show the effects of aligning the order fulfilment process. The results of the implementation can be used to perceive support and commitment for the alignment process for the remaining product types. Furthermore, we want to advise Nedap UV to not only use these performance indicators as measurements, but to build a performance management system of them. This performance management system should become a standard at the order fulfilment process to improve continuously by controlling and modifying current processes. It should for example consist of multiple feedback sessions out of which different initiatives to improve appear after target deviation analysis. The exact configuration of this performance management system is left to Nedap UV due to time limitations of this research, but the starting point of a set of performance indicators is provided in this research. This performance management system is required to be able to evaluate the improvement initiatives, and have been experienced as a shortcoming in this research to assure management support and commitment from employees involved.

In case this research has triggered Nedap UV to improve their order fulfilment process in a more extensive way than presented in this research we present some additional recommendations. One of these extensive recommendations for Nedap UV is to include more detail to the aligned processes. In the execution of this research multiple variable parameters are assumed to be fixed because of time limitations of this research. These parameters are varying for different processes and products and can for that reason be analysed more exactly. An example of such a fixed parameter is the throughput time of the production process at Inventi, which is assumed by Nedap UV to be eight weeks for all product types. To make the process alignment more exact it could be based on the actual variable parameters. Another aspect that could be researched in more detail is the production capacity restrictions of Inventi. In this research we only assume two major capacity restrictions which affect the final supply planning. Nedap UV should add all capacity restrictions at Inventi to make the planning more accurate. Furthermore, we want to advise Nedap UV to research the ability for using subassemblies of the products. In most product groups all product contain similar subassemblies. If a subassembly inventory would be introduced Nedap UV is expected to be more responsive to customers, with less required inventory value.

Besides going in to further detail of the order fulfilment process, Nedap UV can continue this business process improvement research with the remaining framework steps stated by Rohleder and Silver (1997). Time restrictions limited this research to only partial execution of the framework. Step 7, 9, 10, 11 and 13 of the introduced framework were ignored so far. These additional steps aim for a continuously improving business process for the specific improvement process. One of the additional steps is for example the evaluation of the set targets, this can only be executed in case the performance measurement is active at Nedap UV.

In addition to the execution of the framework steps remaining, the aligned process can be further optimised by linking discussed processes more explicitly to the ‘out of scope’ tactical order fulfilment processes. These processes comprise for example order fulfilment processes controlled by Inventi or other departments. The inclusion of these processes requires alignment of additional processes more explicitly, such as the purchasing and production processes. A new research will be required to align the remaining processes as these processes differ significantly from the targeted order fulfilment processes in this research. This improvement process can be further enhanced by more explicitly aligning the strategic and operational processes of order fulfilment. The inclusion of these remaining aggregation levels will make the overall process of order fulfilment more complete. In the end, a well streamlined order fulfilment process can only be achieved by cooperating and exchanging information with all other processes involved in the supply chain (Daft, 2007). On that account we advise Nedap UV to extend this initiated research to a more encompassing order fulfilment process.

We end this research with one main advice to Nedap: set focus to customer satisfaction. Customer satisfaction is essential for the innovative market Nedap is supplying, issues like delivery performance and service conditions are critical in this saturated market. A lost customer in a saturated market can be directly translated in lost turnover, which cannot be compensated easily as the market is saturated. Customer satisfaction is for that reason of key importance to Nedap UV.

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Appendices

This section provides all appendices, these research subjects of the appendices have not been relevant enough to insert in the main text of this thesis or include confidential information which should be hidden in the main text. The confidential information sections are indicated with an asterisk in their titles and will not be published in public versions of this report.

Appendix A: Nedap Business Units

As mentioned, Nedap is active around the world on different market segments. These segments are separated in the company in nine business units. The main focus and key issues from these business units are presented below:

- Agri

  Nedap Agri enables the automation of a high diversity in processes in and around the livestock farm. The technologies Nedap Agri delivers are mainly based on electronic animal identification. This unfolds in the control of feeding, milking and separating. Nedap supplies technological solutions that make animal care and monitoring of production and health conditions easier.

- AVI

  Nedap AVI (Automated Vehicle Identification) encompasses the recognition, identification and management of vehicles and drivers. The systems of Nedap AVI can be found all over the world and are implemented for example in rapid access to city centres, car parks, airports, gated communities and military complexes.

- Energy Systems

  Nedap Energy Systems developed the PowerRouter, a fully integrated energy management system to build a network for sustainable energy. This system provides a clear view in the generated and consumed energy every moment at all places. The system is also able to communicate with other energy systems to realise an efficient sustainable energy network.

- Healthcare

  Nedap Healthcare is a supplier in the automation of the entire care process. With an aging population and staff shortages the need for improved healthcare systems keeps growing. Nedap Healthcare develops all sorts of solutions for smart time and patient registration and the corresponding planning. Currently over 50,000 care professionals are working with this Nedap system.

- Library Solutions

  Nedap Library Solutions supports libraries in an innovative way to maintain and improve their relevance in the current age of information. Nedap offers a set of products to help libraries in their quest for efficiency and effectiveness. These products are for example able to recognise books and identify the person returning books. The Library Solutions products prevent waiting queues and loads of tedious work for library staff.

- Light Controls

  Nedap Light Control develops intelligent lamp drivers which control UV, HID and induction light bulbs for example. These drivers are developed to last longer, with decreased maintenance costs and minimised energy consumption. All of this adjusted to the needs of the customer. These drivers are for example used in UV water purification systems, big scale buildings lighting systems and explosive environments.

- PEP

  Nedap's PEP system is an automated hour registration system for flex workers. It communicates directly with the data processing web application PEPweb. This application displays information in a clear, accurate and orderly way. Furthermore it functions as an important source of information for company's management.

- Security Management

  Nedap Security Management business unit develops solutions to manage and control the safety of products and people around public places. The business unit developed the AEOS security platform. In this platform access control, visitor management, burglary detection, locker management, car park management and video surveillance are combined and integrated. Nedap's security system is innovative and is worldwide used and trusted by banks, governments, airports and refineries.

- Retail

  Nedap Retail helps retailers by providing innovative and smart products that contribute to the perceptions retailers want to create for their visitors. The products focus on a friendly shop experience for the customer. Nedap Retail is specialised in security for shops. Examples of these shops are chemists, fashion stores and supermarkets. The most familiar product is the business specific access gate which is able to identify the access of people and detect theft.

Appendix B: Light Controls Product Group Structure

- UV Products

Nedap Light Controls is the leading company in the world for lamp drivers in the Ultra Violet (UV) product market. UV light is an essential tool in the disinfection of water and other materials. For example it is used in the purification of wastewater, drinking water and ballast water, but UV light is also used in sterilising healthcare environments. A different functionality the UV drivers are used for is curing. Curing is the drying of a wide range of products in digital printing, coating and painting applications. Nedap UV distinguishes itself from its UV competitors by its wide range of specified products, which are in exact control of the lamp in an efficient energy consuming way.

Figure B.1 UV Lamp Driver

- QL Products

Nedap QL Induction Lighting is a proven smart technology with superior reliability for public areas and the retail industry. The product's low maintenance intensity characteristic, high reliability and long life time make QL lighting the ideal solution for hazardous and unattainable locations and applications. Another product characteristic that differentiates the product from its competitors is the natural white colour of light and its dimming function.

Figure B.2: QL Light Bulb & Driver

- Retail and Industry Products

The retail and industry product group supplies electronic ballast equipment and light management software for HID lamps. These R&I products are typically used when high levels of light over large areas are required and energy efficiency is desired. The products are for example used in large warehouses, sport arenas, parking lots and airports. The main competitive advantages of the Retail and Industry products are its increased light output and quality, its efficient long lamp life and the wireless control of the products.

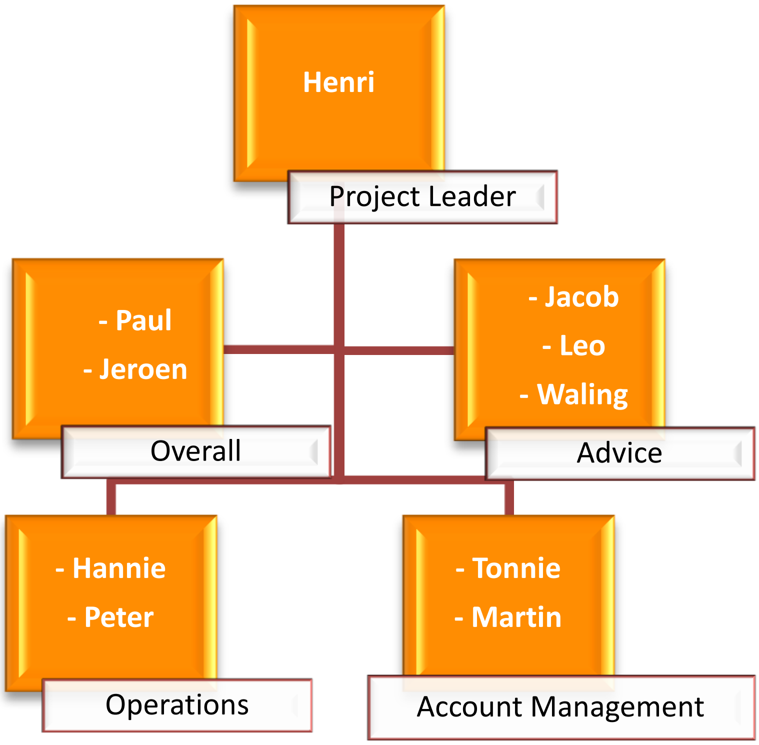
Figure B.3: R&I Lighting Application

- Explosion Proof Products

In high risk work environments explosion proof lighting is of vital importance. For example, the smallest spark on an oil platform can ignite a flame with disastrous consequences. To prevent these dangerous situations Nedap Light Controls supplies dedicated electronic lamp driver for hazardous areas. The drivers are known as reliable explosion proof lamp drivers which are able to test their own functionality.

Figure B.4 Applied Explosion Proof Products

Appendix C: Project Team Organisational Chart



Appendix D: Literature Research Method

We will firstly introduce the literature search method used throughout this research. In this research three methods of literature searching are used. The first method is finding articles on the internet by using multiple search engines, like Science Direct, Web of Science and Scopus. The key words of the subject are used as search terms in combination with some Boolean operators (i.e. AND and OR) to narrow the search results down. The amount of hits will be reduced by adding or deleting terms or using these operators. If this found amount of articles is below 100, we read the titles and select the most appropriate articles. After this step, we make a selection based on the abstracts of the articles before we start reading the complete articles.

The second resource we use to find relevant literature is the University of Twente. The university possesses a wide range of information is accessible. The continuation of handling the articles and books is the same as we described at the first method. The last method we use is cross reference searching. We use the citations in the articles found in the previous methods to find more relevant information about the specific subject. This method allows us to get more exact towards some research topics.

Appendix E: Empirical Research Method

The groundwork of this research method is led by conducting orientation interviews with the employees and staff as described in Kempen & Kiezer (2006). Due to the informal nature of these interviews, they only serve to find possible problems. The interviews are not used to collect actual input data or performance data. This data has to be selected out of a wide variety of databases. Validation of the data is done both by employees of Nedap who are involved with the activities measured and by the researcher. This is done because most employees know the processes well, but have no experience with reading the acquired data.

Appendix I: Smoothing Constants of the Winters Procedure

To find the special cases of the smoothing constants for the Holt procedure we introduce the following formulas:

$$\alpha_{HW} = [1 - (1 - \alpha)^2]$$

$$\beta_{HW} = \frac{(\alpha)^2}{1 - (1 - \alpha)^2}$$

In which α represents the general smoothing constant. The likely range of this α is 0.01 to 0.30 with a compromise value of 0.10 often being quite reasonable. (Silver, Pyke, & Peterson, 1998) Possible results are shown in the table below introduced in Silver, Pyke and Peterson (1998) along with the suggested values for γ_{HW}. For stability purposes the value of β_{HW} should be kept well below that of α_{HW} (McClain & Thomas, 1973).

TABLE 4.9 REASONABLE VALUES OF SMOOTHING CONSTANTS IN THE WINTERS PROCEDURE

	Underlying α Value	α_{HW}	β_{HW}	γ_{HW}
Upper end of range	0.30	0.51	0.176	0.50
Reasonable single value	0.10	0.19	0.053	0.10
Lower end of range	0.01	0.02	0.005	0.05

Appendix J: Normal Probability Distribution Table

TABLE B.1 *(Continued)*

k	$f_u(k)$	$p_{u\geq}(k)$	$G_u(k)$	$J_u(k)$	$G_u(-k)$	$J_u(-k)$	k
1.81	0.0775	0.03515	0.01392	0.009952	1.8239	4.2661	1.81
1.82	0.0761	0.03438	0.01357	0.009677	1.8336	4.3027	1.82
1.83	0.0748	0.03362	0.01323	0.009409	1.8432	4.3395	1.83
1.84	0.0734	0.03288	0.01290	0.009148	1.8529	4.3765	1.84
1.85	0.0721	0.03216	0.01257	0.008893	1.8626	4.4136	1.85
1.86	0.0707	0.03144	0.01226	0.008645	1.8723	4.4510	1.86
1.87	0.0694	0.03074	0.01195	0.008403	1.8819	4.4885	1.87
1.88	0.0681	0.03005	0.01164	0.008167	1.8916	4.5262	1.88
1.89	0.0669	0.02938	0.01134	0.007937	1.9013	4.5642	1.89
1.90	0.0656	0.02872	0.01105	0.007713	1.9111	4.6023	1.90
1.91	0.0644	0.02807	0.01077	0.007495	1.9208	4.6406	1.91
1.92	0.0632	0.02743	0.01049	0.007282	1.9305	4.6791	1.92
1.93	0.0620	0.02680	0.01022	0.007075	1.9402	4.7178	1.93
1.94	0.0608	0.02619	0.009957	0.006873	1.9500	4.7567	1.94
1.95	0.0596	0.02559	0.009698	0.006677	1.9597	4.7958	1.95
1.96	0.0584	0.02500	0.009445	0.006485	1.9694	4.8351	1.96
1.97	0.0573	0.02442	0.009198	0.006299	1.9792	4.8746	1.97
1.98	0.0562	0.02385	0.008957	0.006117	1.9890	4.9143	1.98
1.99	0.0551	0.02330	0.008721	0.005940	1.9987	4.9542	1.99
2.00	0.0540	0.02275	0.008491	0.005768	2.0085	4.9942	2.00
2.01	0.0529	0.02222	0.008266	0.005601	2.0183	5.0345	2.01
2.02	0.0519	0.02169	0.008046	0.005438	2.0280	5.0750	2.02
2.03	0.0508	0.02118	0.007832	0.005279	2.0378	5.1156	2.03
2.04	0.0498	0.02068	0.007623	0.005124	2.0476	5.1565	2.04
2.05	0.0488	0.02018	0.007418	0.004974	2.0574	5.1975	2.05
2.06	0.0478	0.01970	0.007219	0.004828	2.0672	5.2388	2.06
2.07	0.0468	0.01923	0.007024	0.004685	2.0770	5.2802	2.07
2.08	0.0459	0.01876	0.006835	0.004547	2.0868	5.3219	2.08
2.09	0.0449	0.01831	0.006649	0.004412	2.0966	5.3637	2.09
2.10	0.0440	0.01786	0.006468	0.004281	2.1065	5.4057	2.10

(Silver, Pyke, & Peterson, 1998)

Appendix L: Order Fulfilment Process Alignment of Product Group 3

This appendix covers the information for the three aligned product types of Product Group 3, which did not add enough value to be part of the main report.

L.1 Process Alignment for Product Type D and G

Aligning the Sales Planning Process

The sales planning process for Product Type D and G is based again on the designed sales planning framework of Figure 5.1. The customer specific Product Type D is comparable to the standard version of the product group; Product Type G. The two product types contain exactly the same components and only differ in the final configuration in the production process. For that reason we assume the product types together in this chapter. Exactly the process of combining two product types is what makes it interesting to also add Product Type D to this research. Product Type D is only ordered 1.5 times a year on average. All historic orders from the concerning customer have been in an order quantity of 5 items, which cover only 1.6% of the total sales of Product Type G. According to Chapter 3 this product type should for that reason be given only limited attention with regard to aligning the order fulfilment process. For that reason we integrate the order fulfilment processes of Product Type D in the process of Product Type G. Nedap UV agreed with the specific customer that orders can only be shipped on time if they are ordered at least eight weeks in advance of the desired shipment date.

Product type G is sold to 25 different customers over the last three years. This requires a different sales planning approach compared to the other considered products because of their differing product and market characteristics. Demand for this product is for example varying in order quantities as different customers have different desires. Furthermore, multiple different customers and markets have to be analysed to obtain a complete perspective of the market. Next to these characteristics, the standardised version covers a high sales rate, in a growing demand trend, with a growing amount of customers and is for that reason an important product in the Nedap product range. The importance of the product type indicates that much effort should be spent on a comprehensive sales planning, inventory and service management and supply planning to achieve the desired outcomes. To align the sales planning according to our designed sales planning framework we start with a mathematical sales model based on historical demand.

We check the presence of seasonal or trend behaviour in the historical sales data to find the required components for the mathematical sales model. Trend behaviour of the sales data seems logical as the product is categorised in the growing stage of the PLC in Section 2.2. Analysing the average sales over the last three years presents a growing trend in Figure L.1, by a growing average yearly demand. The account managers expect

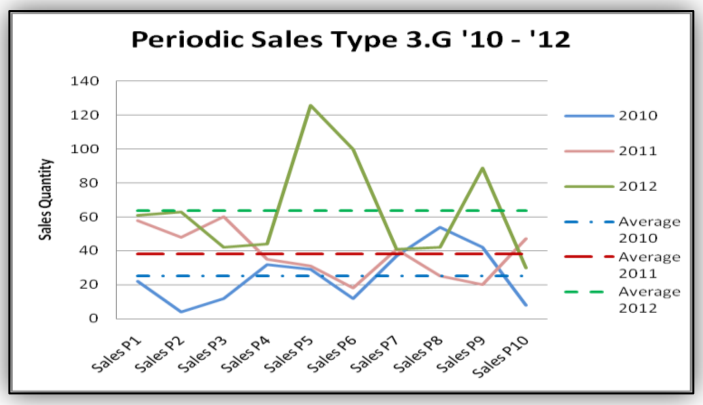


Figure L.1: Periodic Sales Product Type G over 2010 to 2012 the growth in demand to continue for the upcoming years. But the growth rate of 51% and 66% over the last two years is not expected to continue. Account managers expect the sales amount to grow 25%, and therefore expect the total sales amount over 2013 to be 800 items. This growth is expected because of the growing market for these products and special circumstances introduced in Appendix H. These findings imply the need for a trend component in the forecasting model of the sales planning. Figure L.1 presents many peaks and falls in demand over the three years when we consider seasonal patterns. To analyse these peaks and falls we introduce Table L.1, in this table the average sales per year and the actual sales for a certain period are contrasted. The red marked cells with negative values indicate the periods with a lower historical sales rate than average and the green marked cells with positive values indicate a higher historical demand than the yearly average. As no straight green or red periodic pattern appears it seems unlikely that a seasonal pattern exists. A seasonal pattern is not likely either in the product market as the product is used for multiple applications in several functional areas. We exclude seasonality therefore from our sales planning of Product Group G.

Period:	Average:	1	2	3	4	5	6	7	8	9	10
3-Year Sales:	127	141	115	114	111	186	130	119	121	151	85
Sales 2010:	25	-3	-21	-13	7	4	-13	12	29	17	-17
Sales 2011:	38	20	10	22	-3	-7	-20	3	-13	-18	9
Sales 2012:	64	-3	-1	-22	-20	62	36	-23	-22	25	-34

Table L.1: Demand Deviations from Average for Product Type G (2010-2012)

To setup a forecasting model with a level and trend component, we use the regression analysis methodology again. We use periodic forecasting here as weekly historical information will include too much variation to provide a stable sales planning at Inventi. We use Formulas 4.2 and 4.3 to come to the founded $\hat{a}$ value of 20.96… and the $\hat{b}$ value of 1.39…. The 'x_t^(a)'-column of Table 5.5 presents the results of the regression analysis calculations over the upcoming year, which includes Period 31 to 40. When we analyse these results against the actual yearly sales history we find the results presented in the first three rows of Table 5.6. From this table we conclude that the sales results in 2010 and 2011 have been depressing the sales forecast for 2012, because of a growing sales rate in these years. Comparing this forecast to the expected sales rate of 800 exposes an underestimation of the sales forecast of 2013. Based on this sales depressing figures and employee input, we decided the regression analysis to present too low forecast figures. To continue with a linear model, as we have introduced in Chapter 4, we fill the gap of the expectations in the regression analysis. Therefore we have to modify the trend parameter b^ of the model used for 2012 and 2013.

As the missing forecasted demand in 2012 is equal to 75 items we try to base the new b^ value based on these missing items in the sales planning. The third year covers Periods 21 up to 30, the sum of these periods that is included in regression analysis is 255. As a gap is found of 75 items over the sum of 255, we miss a demand trend of $\frac{75}{225} = 0.294\ldots$. This calculated value is used as an additional b^ factor,

Period:	Xt:	Xt^(a):	Xt^(b)
1	22	-	-
2	4	-	-
3	12	-	-
4	32	-	-
5	29	-	-
6	12	-	-
7	37	-	-
8	54	-	-
9	42	-	-
10	8	-	-
11	58	-	-
12	48	-	-
13	60	-	-
14	35	-	-
15	31	-	-
16	18	-	-
17	41	-	-
18	25	-	-
19	20	-	-
20	47	-	-
21	61	-	-
22	63	-	-
23	42	-	-
24	44	-	-
25	126	-	-
26	100	-	-
27	41	-	-
28	42	-	-
29	89	-	-
30	30	-	-
31	-	63.9	73.0
32	-	65.3	74.7
33	-	66.7	76.4
34	-	68.1	78.1
35	-	69.4	79.7
36	-	70.8	81.4
37	-	72.2	83.1
38	-	73.6	84.8
39	-	75.0	86.5
40	-	76.4	88.1

Table L.2: Regression Analysis Results of Product Type G which makes the new trend value b^ approximately 1.68 for the forecast calculations of 2012 and 2013. The calculations of the updated forecasts are presented in the fourth column of Table L.2. In the last two rows of Table L.3 we show the improved forecasted results for 2012 and 2013. The adaptation of the b^ value resulted in more accurate figures compared to the actual and estimated sales figures. This forecast is with that reason used as the mathematical model input for the sales planning of Product Type G.

Sales:	2010	2011	2012	2013
Actual:	252	383	638	800
Xt^(a)	286	424	563	701
Act-Xt^(a):	-34	-41	75	99
Xt^(b)	286	424	638	806
Act-Xt^(b):	-34	-41	0	-6

Table L.3: Evaluated Sales Forecast Results

As Inventi requires their incoming sales planning to be weekly for component purchasing we translate the found periodic forecasts in weekly forecasts. In Table L.4 the expected weekly sales figures for 2013 are presented. The weekly portion of the periodic forecasted demand and the next column smoothed the growth trend of the sales forecast, rounded in the next column to complete items. The sales planning constructed includes employee judgemental input in combination with a mathematical model. We integrate customer input to maximise the sales planning accuracy. Nedap asks Product Type G's main customers to provide a forecast of their upcoming demand. Nedap emphasises the importance of an accurate forecast to its customers for being delivered according to their desires. This attempt to convince the frequently ordering customers to handover a demand indication for the upcoming year is successful at some customers. In general the smaller customers do not understand this need or do not want to spend much effort in it. So, with constructing sales planning the available demand indications from customers should be integrated in the sales planning. When a customer forecast comes in it will be compared to the actual expected sales for that specific period. This employee judgement of the account manager indicates the accuracy of the constructed sales planning in Table L.4. In case the sales planning deviates significantly from incoming customer demand forecasts or orders the sales planning should be modified. In this

Week Number:	Portion of Periodic Forecast:	Smoothed Weekly Forecast:	Rounded Weekly Forecast:	Periodic Forecast:
1	14.60	14.50	14	
2	14.60	14.50	14	
3	14.60	14.60	15	73.02
4	14.60	14.70	15	
5	14.60	14.70	15	
6	14.94	14.80	15	
7	14.94	14.80	15	
8	14.94	14.90	15	74.70
9	14.94	15.00	15	
10	14.94	15.00	15	
11	15.28	15.10	15	
12	15.28	15.20	15	
13	15.28	15.30	15	76.38
14	15.28	15.40	15	
15	15.28	15.40	15	
16	15.61	15.50	16	
17	15.61	15.60	16	
18	15.61	15.60	16	78.06
19	15.61	15.70	16	
20	15.61	15.70	16	
21	13.29	13.10	13	
22	13.29	13.20	13	
23	13.29	13.30	13	
24	13.29	13.30	13	79.74
25	13.29	13.30	13	
26	13.29	13.40	13	
27	13.57	13.40	13	
28	13.57	13.50	14	
29	13.57	13.50	14	
30	13.57	13.60	14	81.42
31	13.57	13.70	14	
32	13.57	13.70	14	
33	16.62	16.50	16	
34	16.62	16.50	16	
35	16.62	16.60	17	83.09
36	16.62	16.70	17	
37	16.62	16.70	17	
38	16.95	16.80	17	
39	16.95	16.90	17	
40	16.95	17.00	17	84.77
41	16.95	17.00	17	
42	16.95	17.10	17	
43	17.29	17.10	17	
44	17.29	17.20	17	
45	17.29	17.30	17	86.45
46	17.29	17.40	17	
47	17.29	17.40	17	
48	17.63	17.50	17	
49	17.63	17.60	18	
50	17.63	17.60	18	88.13
51	17.63	17.70	18	
52	17.63	17.70	18	

Table L.4: Weekly Sales Planning Product Type G for 2013 modification the customer forecast is leading as it is assumed to include more market knowledge than Nedap has available. Again we restrict ourselves to this description as a practical example would violate confidentiality agreements with customers.

From the constructed sales planning we notice the growth factor for 2013 to be slightly higher in the regression analysis than the expected growth to 800 items on a yearly basis. This small additional quantity is accepted and used as the additional sales planning of Product Type D. This can be done as these two products are exchangeable up to the start of production. This last note finishes the sales planning for Product Type G and the integrated Product Type D.

Aligning the Service and Inventory Management Process

As presented in the sales planning of Product Type D it is produced on a make-to-order basis. While the demand for components is included in the sales planning of Product Type G this product type requires only its production throughput time before it can be shipped. This includes that Nedap will be able to deliver these products within the current eight weeks delivery period. As it is no important product in the product range of Nedap UV with only 1.5 orders a year we do not aim for a flexibility improvement regarding delivery conditions. Only in the unforeseen situation that both order quantity and frequency raises heavily this service policy should be reconsidered.

Product Type G is a regular ordered product with highly variable order quantities. Nedap does not want to be able to deliver all of these orders out of stock because of the high variable order quantities and the stock value it would entail. For that reason a separation in the product quantities and its accompanying service levels will be introduced in this service management section. We introduced a standard policy for Nedap to ship small order quantities within a week and large quantities within eight weeks. To confine the complexity of the overall service management policy we include an equal policy for Product Type G. To state the exact boundaries of which quantities should be delivered by what service conditions the historic sales are analysed and discussed. The historical demand sorted on order quantity and its frequency of ordering is presented in Table L.5.

Order Quantity:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Frequency:	17	20	4	11	5	8	1	6	1	12	1	3	1	0	6	1	1	2	0	0	0	0	0	1	1
Percentage:	17%	20%	4%	11%	5%	8%	1%	6%	1%	12%	1%	3%	1%	0%	6%	1%	1%	2%	0%	0%	0%	0%	0%	1%	1%
Cumulative (%):	17%	36%	40%	51%	56%	64%	65%	71%	72%	83%	84%	87%	88%	88%	94%	95%	96%	98%	98%	98%	98%	98%	98%	99%	100%

Table L.5: The Historical Order Quantity and Frequency Analysis of Product Type G

Based on this table it seems reasonable to place the threshold quantity between small and large orders at one, two, four, six, eight or ten items as these quantities cover significant order percentages. If we analyse these quantities more thoroughly we find that most infrequent and new customers do not order more than six items per order. Orders with at least six items originate from the five customers which take off most of these product type's items. As these customers do can handle the eight weeks lead time by holding their own inventory, there is not much added value to decreasing their lead-times for Nedap. However, for the smaller amounts of items a lead-time decrease could increase the competitive advantage of Nedap regarding new and small customers with a relative small increase in inventory. This analysis suggests taking six items as the boundary value. Discussing this boundary quantity with the operational manager and the account managers leads us to the conclusion that the six items as a threshold quantity is accountable. The amount of orders with a maximum of six as order quantity represent 64% of the orders which will be shipped within a week from now on. This 64% of orders represents 20 out of 25 customers which will be supplied within a week instead of within eight weeks. So for 80% of the Nedap customers the service conditions improve significantly with a decrease of seven weeks of shipment time.

In case demand orders are placed with an exceptional high demand over 25 items per order this cannot be handled within the large quantity order restrictions. These orders should be considered as projects which have to be included in the Nedap sales planning to be able to have components available at the start of production. While this exceptional quantity demand concerns long-term projects in general, special conditions should be agreed dependent on the demand request. For example portions of these orders can be supplied earlier depending on the current stock levels and availability of components. Remaining demand will have to be included in the sales planning to be able to satisfy other customers as well. This demand has to be discussed with the account managers, operational managers and the Inventi operations manager to come to a feasible solution both for Nedap and the customer. Nonetheless, these exceptional orders will not occur frequently as this never happened in the sales history so far.

To research the inventory policy regarding these service conditions we include the service level of 97.5%. Input for constructing an inventory policy is the expected demand found in the sales planning. With a trend being available we the first upcoming quarter expected sales as input for this model, the weekly average demand for the first quarter will for that reason be:

$$\hat{x} = \frac{\text{Expected Demand Q1 2013}}{\text{Amount of Weeks in Q1}} = \frac{73.02 + 74.70 + 45.60}{13} = 14.870 \ldots$$

As we introduced a separation between small and large demand we have to research what portion of this demand belongs to which order quantity category. Based on historical figures we conclude that 70.85% of the total demand is interpreted as large. The remaining 29.15% of historical demand is interpreted here as small demand and includes historically seen the quantity sold with orders smaller or equal to six items. As the average expected demand per week is different for both of these situations we separation the expected demand and standard deviations of these figures. This results in the expected demand calculations below for small and large orders per week:

$$\hat{x}_{\text{small}} = \frac{\text{Total } \hat{x}}{1/0.2915} = \frac{14.824 \ldots}{3.430 \ldots} = 4.334 \ldots \qquad \hat{x}_{\text{large}} = \frac{\text{Total } \hat{x}}{1/0.7085} = \frac{14.824 \ldots}{1.411 \ldots} = 10.536 \ldots$$

As the standard lead time of all products is eight weeks and the review period is one week, the expected demand during lead time and the review period for the small orders equals: (8 + 1) * 4.334… = 39.006… . For the large orders this total period for lead time and review period is different as Nedap want to deliver the products only within eight weeks instead of one week. This total nine weeks period should be subtracted by the seven weeks difference between these two shipment due dates as seven additional weeks are available to make the shipment. So the period we have to analyse now equals ((8 – 7) +1 =) 2 weeks. This makes the expected demand during lead time and review period for large items (2 * 10.536… =) 21.072… items.

Now the expected demand is clarified we start to calculate the variability of the historical demand of the last year. Again a shift in this analysis has to be made between small and large orders to calculate the relevant standard deviations of these products. As the calculations of this data are confidential and extensive we only present the final found standard deviations here:

$$\sigma_{small} = \sqrt{\frac{\sum_{i=1}^{n}(x_n - \bar{x})^2}{n-1}} = 3.7591 \dots \qquad \sigma_{large} = \sqrt{\frac{\sum_{i=1}^{n}(x_n - \bar{x})^2}{n-1}} = 12.4326 \dots \quad (4.13)$$

To translate these weekly standard deviations in standard deviations during the lead time L and review period R we present the calculations below:

$$\sigma_{L+R}^{small} = \sigma_9 = \sigma_{small} * \sqrt{L+R} = 3.7591 \dots * \left(\sqrt{(9}\right) = 11.2774 \dots \quad (4.14)$$

$$\sigma_{L+R}^{large} = \sigma_2 = \sigma_{large} * \sqrt{L+R} = 12.4326 \dots * \left(\sqrt{(2}\right) = 17.5823 \dots \quad (4.14)$$

Now the standard deviations are found we can calculate the required safety stock level by its standard formula. As the products for both types of orders are exactly the same we have to combine the standard deviations to calculate one combined safety stock level this product type. The standard deviations can be combined by the additive standard deviation formula for standard deviations: $(\sigma(X+Y))^2 = (\sigma(X))^2 + (\sigma(Y))^2$. (Welford, 1962) This formula applied to the current situation results in:

$$\sigma_{combined}^2 = (\sigma_{L+R}^{large})^2 + (\sigma_{L+R}^{small})^2 = (11.2774 \dots)^2 + (17.5823 \dots)^2$$
$$= 127.1809 \dots + 309.1402 \dots = 436.32126699$$

$$\sigma_{combined} = \sqrt{\sigma_{combined}^2} = \sqrt{436.3212 \dots} = 20.8883 \dots$$

The next step according to Chapter 3 is calculating the required safety factor by Formula 4.9:

$$P_2 = 1 - \frac{\sigma_{R+L} * G_u\left(\frac{\sigma_{R+L}}{\sigma_L} * k + \frac{\widehat{x_R}}{\sigma_L}\right)}{\hat{x}_R} \quad (4.12)$$

To fill this formula we use the service level defined in Chapter 4, this value equals 0.975 and represents the P_2 parameter. The σ_{R+L} parameter calculation have been shown above and equal 20.888... . The σ_L parameter can be calculated based on the found value for σ_{R+L}:

$$\sigma_L = \sigma_8 = \frac{\sigma_{R+L}}{\sqrt{L+R}} * \sqrt{L} = \frac{20.8883 \dots}{(\sqrt{9})} * (\sqrt{8}) = 19.6936 \dots$$

Now the all required parameters to calculate the k value are available we start filling Formula 4.12:

$$0.975 = 1 - \frac{20.888 \dots * G_u\left(\frac{20.888 \dots}{19.693 \dots} * k + \frac{14.870 \dots}{19.693 \dots}\right)}{14.870 \dots} \rightarrow 0.0250 = 1.404 \dots * G_u(1.060 \dots * k + 0.755 \dots)$$
$$\dots \rightarrow 0.0177.. = G_u(1.060 * k + 0.755 \dots)$$

From the normal probability distribution given in Appendix I, we can find the x value of $G_u(x)$ for 0.0177... to be 1.712. This leads to the following formula for finding parameter k:

$$1.712 = (1.060 \dots * k + 0.755 \dots) \rightarrow 0.956 \dots = (1.060 \dots * k) \rightarrow k = \frac{0.956 \dots}{1.060 \dots} = 0.902 \dots$$

Now we found the safety factor we can start calculating the safety stock required for the service level of 0.975. Using Formula 4.11 for the safety stock calculations results in:

$$SS = k\sigma_{R+L} = 0.902 \dots * 20.8883 \dots = 18.845 \dots \quad (4.11)$$

This safety stock value can cover the variances for small and large demand of the customers during lead time and the review period. As Nedap handles only complete units we have to round this value.

As the value is close to 19 items we use this quantity as safety stock level to pursue the set service level goal of 97.5% for Product Type G. To calculate the average on-hand stock we have to add the average weekly incoming stock to the safety stock level. In the current situation for Product Type G, this includes:

$$Average\ On\ Hand\ Stock = SS + 0.5 * \frac{Q1\ Demand}{Weeks\ in\ Q1} = 18.845 + \frac{193.32}{26} = 26.280 \ldots \quad (4.15)$$

The risk of obsolescence of the inventory for this product type's items is low because of the wide customer range of 25 customers last year. And the fact that most components of this product are exchangeable to the other product types in this product group reduces the consequences of obsolescence. The average stock turns of this inventory will probably be 806/26.280... = 30.669... a year. This means the average stock will be in for only 12 days on average. With the expected market growth and market share we assume this average stock turn time to be accountable.

Aligning the Supply Planning Process

The supply planning for Product Type D should be handled with care as the sales planning is included at Product Type G. The product type can be planned in its own version at the start of the production process. As the customer needs to place its orders more than eight weeks in advance the supply planning can be based on the order behaviour of this customer. As no further changes can be implied in this production process by the customer for this product the exact amount ordered will be produced.

For Product Type G the supply planning situation is based on the sales planning and service and inventory management outcomes. As the safety stock for this product type is known the order-up-to level for the supply planning in the (R,s,S) policy can be calculated. This level S should be sufficient to cover all demand until the arrival of the next replenishment order. The S level can be calculated by adding the demand during lead time and the review period to the calculated safety stock. This results in the following calculations, which are in line with the findings of the service and inventory management process alignment:

$$S = k * \sigma_{combined} + \hat{x}_{L+R}^{small} + \hat{x}_{L+R}^{large} = 19 + 39.006 \ldots + 21.072 \ldots = 79.078 \ldots \quad (4.13)$$

The order-up-to level S is rounded down as this value is near to 79 final products. Based on this level S Nedap should place its orders in the weekly meeting with Inventi and should order up to 79 items minus its current inventory position to pursue the service level of 97.5%. Also for this product type we should include the capacity restriction 5.1 introduced at the supply planning of Product Group 1.

In general the ERP system automated the availability of components at the moment of production at Inventi. Once the products are produced according to the supply planning of Nedap they arrive one week before the shipment date into the distribution centre of Inventi. From the distribution centre the products will be shipped on the requested shipping date to finish the order processing process.

L.2 Process Alignment for Product Type F

Aligning the Sales Planning Process

The sales of Product Type F are comparable to the sales planning situation for Product Type E. The product is customer specific, the customer provides accurate forecasts and the products are ordered in fixed quantities. In 2012 twenty order moments for this product appeared with an average order quantity of 14. However, orders are agreed to come in fixed order quantities of 15. The orders deviating from this fixed order quantity are orders that were required earlier than ordered and have been distributed in portions of the original order. Customer W provides generally accurate forecasts for the upcoming twelve months which are updated monthly. While this customer owns more specific market information and has more market knowledge we assume the customer forecast to be more accurate than a self-made forecast. The accuracy and frequency of customer forecasting for this product type resulted in the decision to use the customer forecast as the Nedap sales planning. This forecast is excluded from this report as it would infringe confidentiality agreements with customer W.

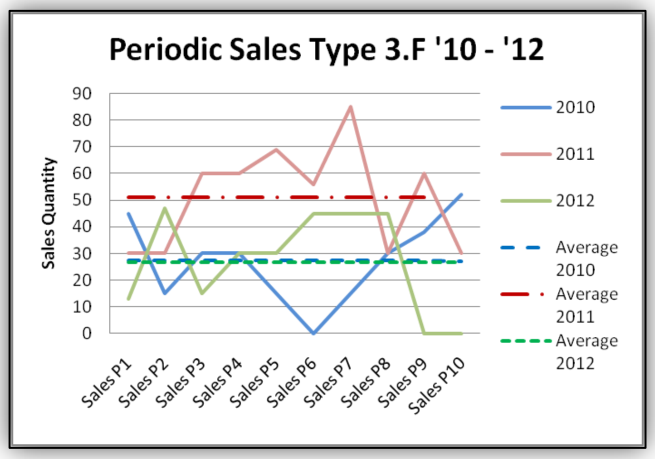


Figure L.2: Historical Periodic Sales Product Type E

To exclude missed demand patterns by the customer we take a closer look at the historical sales pattern. In Figure L.2 we visualise the sales from the last three years. From this figure we conclude that the sales level increased steeply in 2011 with respect to 2010. Average sales in 2010 were 28 products and in 2011 51. This steep sales increase ended in 2012 when sales dropped to the average sales level of 2010. This decreasing sales perspective is expected to continue according to the Nedap's account managers. The total sales level is expected to decrease from 270 to 195 items on a yearly basis. As this decreasing sales level also flows out of the customer forecast we expect this decrease in sales to continue. However, this decreasing sales rate is included in the customer forecast for that reason no modifications to the customer forecasts have to be made. As no obvious seasonal pattern appears in the historical sales from Figure L.2 we do not include these patterns either. There are some incidental demand peaks and falls in the historical sales but these peaks do not follow a certain pattern throughout the historical years of sales. Concluding, the customer forecasts are accurate and frequently updated and for that reason there is no need at Nedap to modify this forecast for a decent sales planning. Neither do we advise Nedap to put much effort in it as the demand rate is decreasing heavily. This could suggest the product type to be on the end of its life cycle at which it will become less important for Nedap its total product range.

Aligning the Service and Inventory Management Process

Also this product type is a customer specific version in this product group. Customer W provides Nedap with orders for more than half a year in advance. This order behaviour enables Nedap to start the order fulfilment process only once orders are in. But these early orders make it hard for the customer to exactly plan its desired shipping date, which therefore is changed regularly. Nedap agreed with the customer to keep a safety stock of 15 of these items to cover the modifications of the desired shipping date. Next to this held safety stock the customer holds a certain inventory level itself. The inventory held by the customer increases the predictability of the demand as a first level of demand variance will be hedged for. As the small demand variations are hedged for the hold inventory at Nedap functions as a safety stock for shipping date variability and unexpected demand peaks. As this stock level can hedge for one complete order we consider this stock level to be accountable for only 13 order moments a year. We consider the safety stock to be accountable with regard to the risk for obsolescence. First of all the customer is obliged to take off all products which have crossed the production start threshold. Furthermore Nedap is an important supplier for the customer as it provides multiple customers specific product types for this customer. This will decrease the risk of changing Nedap as a supplier. Even in case of a bankruptcy most of the subassemblies of the products are reusable in the other product types in this product group. So, there is no cause for concern with regard to obsolescence risks even though the demand rate for this product type is decreasing. As Nedap considers the customer satisfaction to be more important than the inventory costs involved, we accept the additional costs of this stock level.

Aligning the Supply Planning Process

Also Product Type F will be produced based on the make-to-order concept. The supply planning for this product type is mainly based on the ordering behaviour of the customer. For the customer a safety stock is held for hedging against demand variability. This safety stock will only be supplied for the full 15 items as the customer holds an inventory itself for small demand varieties. In case demand is requested earlier than planned this inventory is used to satisfy these customers desire for earlier distribution. The inventory is mainly used as an early shipment option and for that reason will be automatically replaced by the products in the pipeline. However, if this order considers an additional order the safety stock has to be replaced which can take up to 38 weeks. 38 Weeks are required as the required products will have to go through the complete order fulfilment process again. However, this replacement time might be shorter if required components for production are available or become available earlier. For Product Type F a production batch will always include the fixed order quantity of 15 items as the safety stock level is equal to 15 as well. For these items no specific production capacity limitations have to be included except the overall product group limitation 5.1 introduced in the supply planning of Product Group 1. For Product Groups F the ability to exchange products is introduced in the service management part of this section. In the supply planning process of this product these special situations can be requested during the weekly meeting with Inventi. If it is decided that this exchange of product types is necessary and possible the supply planning for the substituted product type should be rescheduled.