MASTER

Business Process Redesign of the Order Management Process Improvement at a High-Tech Manufacturing Company

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Award date:
2022

Department of Industrial Engineering & Innovation Sciences
Operations, Planning, Accounting and Control Group

Business Process Redesign of the Order Management Process Improvement at a High-Tech Manufacturing Company

Master Thesis

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Eindhoven, November 29, 2022

Abstract

Growing demand is stressing supply chain management. The order management process could particularly restrain the supply chain from being scalable and resistant to supply growth. This requires a mature order management structure that performs efficiently and time effectively. However, there is no general approach how to achieving maturity in order management. The ideal order management structure depends on the environment. This report provides insights into the approach and possible order management structures to achieve a higher potential.

First, the supply chain and its challenges are studied. Addressing the order management process would have the most impact since this process highly influences the supply chain management burden. Secondly, business process redesign is applied to test redesigned order management processes and changes in the supply chain. A selection of twelve promising redesigns is quantitatively and qualitatively tested and compared. Besides, the consequences of implementing these redesigns are investigated, which can be used by the company to determine whether the improvement of the redesign is worth the investment. Based on the study, we can conclude that the redesigns that are considered to be most beneficial based on the performances highly depend on the company and supply chain characteristics. The most important characteristics of the studied supply chain are, dealing with two different planning domains, having an MTS environment based on MRP-logic, and manually controlling components in-house that are consumed by the supplier. The redesigns based on the heuristics integration and specialist-generalist seem most beneficial in terms of the cost and time perspective. Combining the redesign flexible assignment with task automation and the redesign flexible assignment with specialist-generalist can also be beneficial.

Management Summary

Introduction

This research is conducted at Malvern Panalytical, a company that develops and produces scientific X-ray instruments in material characterization. In these instruments, Malvern Panalytical uses several different detectors that are developed in-house. This research focuses on one of the detectors, namely the silicon drift detector called the Panalytical Own Drift Detector (PODD). This detector accurately detects, measures, and converts X-rays that are translated into human-interpretable information. The PODD is distinguished into four types and a fifth type will be added in the near future. Figure 1 shows the supply chain of these PODD types that consist of multiple suppliers that produce half-manufactures or supply buy-parts, which are all controlled by Malvern Panalytical. Malvern Panalytical is considered as the supply chain leader of this supply chain due to its economic power and the fact it initiated the partnerships and collaborations (Mentzer et al., 2001). The current way of managing this supply chain is not as scalable as desired due to complexities and capacity limitations. The ability to scale is necessary because growth in production volumes is forecasted starting in 2024. Therefore, this study aims to answer the following main research question: *What is the improved PODD supply chain management structure to cope with complexity and to scale up production volumes at Malvern Panalytical?*

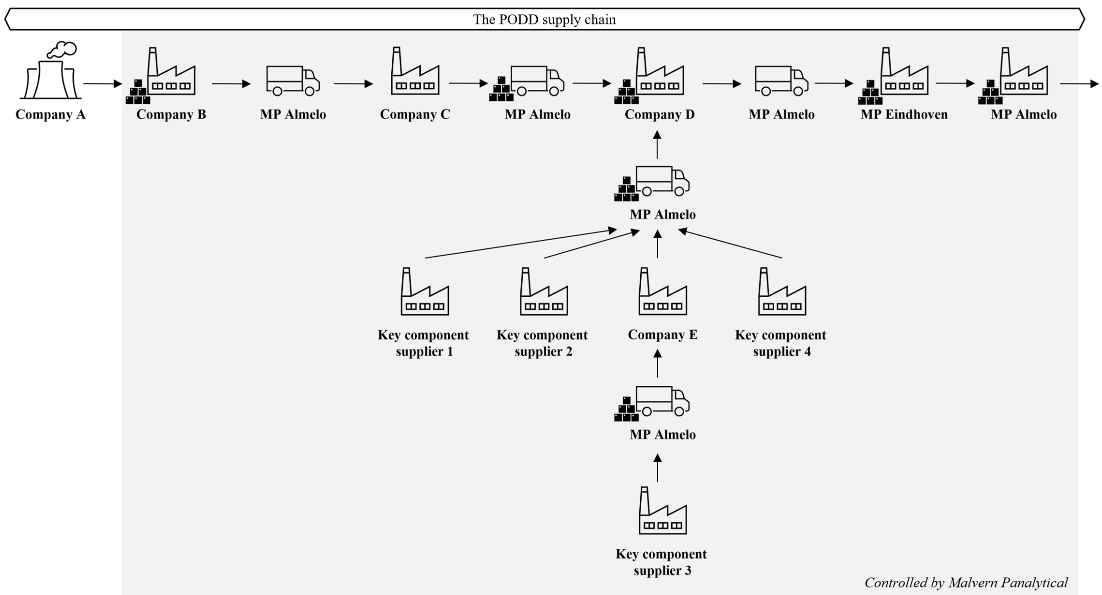

Figure 1: The high level overview of the PODD supply chain

Current supply chain and challenges

To answer the main research question, first, the supply chain is mapped and the management structure is discussed. Figure 1 shows a high-level representation of the PODD supply chain, including the relationships between the multiple-tier suppliers and Malvern Panalytical. The causes that ensure that the supply chain is not as scalable as desired are analyzed. For this research, the selected problem must be within the span of control for Malvern Panalytical. Besides, the balance between feasibility and relevance is considered to address the most impactful challenges to improve the supply chain management structure. From this analysis, it is diagnosed that the most impactful challenges lie within the order management process from the first-tier supplier until the in-house drift detector production. The first challenge is caused by the fact that the inventory at the first-tier supplier of the four key components is manually tracked and managed. The other challenge is caused by the fact that Malvern Panalytical has two different planning domains in The Netherlands, namely for Almelo and Eindhoven. A half-manufacture of the PODD is produced in Eindhoven. Subsequently, the production of the PODD is concluded in Almelo. Thus, planning activities are decentralized since in both domains activities are required to perform for the order management of the PODD. To conclude, both most impactful challenges are causing a time-consuming management within the PODD supply chain, which is not desirable concerning increasing demand in production volumes.

Improvement of the order management process

The as-is situation of the order management process contains many complications due to how the supply chain management is structured. Accordingly, the company desires to improve this process. A comprehensive approach to improve the order management process is not found. Therefore, an approach is developed to structure the improvement of this process, which is shown in Figure 2. The approach is mainly based on research about Business Process Redesign (BPR) of (Reijers, 2003; Reijers & Mansar, 2005; Mansar & Reijers, 2007; Jansen-Vullers et al., 2008). BPR provides 29 best practice heuristics that can be used as a guideline to structure a redesign process. The BPR heuristics are applied to the PODD supply chain in two different ways, namely (1) by changing the order management process and (2) by changing the supply chain structure, resulting in changes in the order management process. Six heuristics are selected and applied on the PODD order management process. Three of the heuristics can be applied in several variants, concluding ten different initial redesigns. The redesign heuristics applied are, integration, flexible assignment, specialist-generalist, buffering, task automation, and outsourcing. Additionally, the developed approach allows to include and test combinations between redesigns, which was suggested for further research by Jansen-Vullers et al. (2008). Thus, two redesign combinations out of 40 possibilities are selected, which concludes twelve redesign options in this research. The redesigns are tested and benchmarked with the original situation using quantitative results on (1) the yearly costs of man-hours spent to execute order management activities and (2) the percentage of time spent per year by a resource on order management activities versus the working hours available in a year. Furthermore, the satisfaction of three key resources is questioned about the allocated tasks in the original situation and redesigned situations. Lastly, requirements to implement each of the redesigns are given.

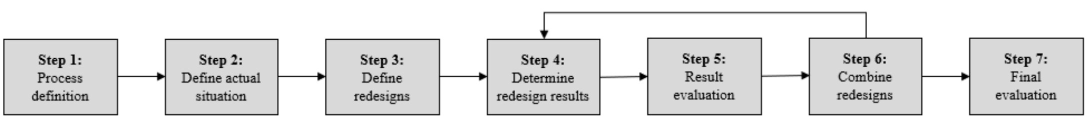

Figure 2: Approach to identify the most beneficial redesign possibilities of a business process

Conclusion

Malvern Panalytical strives for an order management process (i.e., part of the supply chain management structure) with the lowest order management costs and the lowest involvement of the resources Supply Chain Engineer and Strategic Buyer. Based on these preferences and the results found, the following redesigns are most beneficial: (1) two variations of the integration redesign, (2) the specialist-generalist redesign, (3) the combination of the flexible assignment and task automation redesign, and (4) the combination of the flexible assignment and specialist-generalist redesign. Malvern Panalytical should further investigate the provided lists of requirements to implement these redesigns based on the implementation costs, time, and risks. Additionally, potential effects on other performances that are not included in this research need to be discussed. Redesigning the order management process is associated with making trade-offs. Therefore, further investigating the redesigns is necessary before a determined decision can be made.

Limitations of this research are suggested as directions for further research. First, the main limitation is that the predicted impacts are based on data estimated by experts. The estimations are, for example, based on the performances of experienced employees and on regular situations (i.e., exceptions are mostly not included). Second, assumptions and simplifications are made to perform the analysis. Waiting times are excluded, feedback loops in order management are simplified, and it is assumed that buy parts are always in stock. Lastly, a limitation of this research is that the findings cannot be generalized. The studied order management process has very specific characteristics. Thus, other processes at Malvern Panalytical and processes of other companies can only benefit from this analysis if the supply chain management structure has similar characteristics. This also holds for the selection of the performance measures since these are context dependent. The most important characteristics are, dealing with two different planning domains, having a MTS environment based on MRP-logic, and manually controlling components in-house that are consumed by the supplier.

Preface

This Master thesis is submitted as the final step in completing my master's degree in Operations Management Logistics at the Eindhoven University of Technology (TU/e). This research has been performed at Malvern Panalytical. It was supervised by Zümbül Atan and Melvin Drent from the TU/e and Ludo Verhoeven from Malvern Panalytical.

First of all, I would like to thank Zümbül Atan for her guidance and support as my first supervisor of the research. She always provided me with interesting insights because of her knowledge in the field of supply chain management and motivated me with her enthusiasm about the topic. Moreover, I would like to thank my second supervisor Melvin Drent for his guidance and support. I believe that his suggestions and feedback increased the quality of my thesis.

Secondly, I would like to thank my company supervisor Ludo Verhoeven. With his guidance, I learned about the company and one of the most complex supply chains the company is involved with. Ludo gave me the feeling that I was part of the team and that the work I was doing has great value for the company. Moreover, I would like to thank the other colleagues at Malvern Panalytical for supporting me and making my days at the office enjoyable. Especially, I would like to thank Philippe Bronckers for giving me the opportunity to perform my Master thesis at the company.

Finally, I would like to express my gratitude for the support of my family, boyfriend, and friends during the months of my thesis and entire studies in Eindhoven. My time as a student was amazing with you, I would not have wanted it any other way.

Maud Vorstenbosch

Glossary

BOM Bill Of Materials.

BPMN Business Process Model and Notation.

BPR Business Process Redesign.

BPS Business Problem-Solving.

CA Company A.

CB Company B.

CC Company C.

CD Company D.

CE Company E.

EOQ Economic Order Quantity.

ERP Enterprise Resource Planning.

FCFS First Come First Served.

IOQ Incremental Order Quantity.

MOQ Minimum Order Quantity.

MP Malvern Panaltycial.

MRP Material Requirement Planning.

MTS Make To Stock.

PFD Process Flow Diagram.

PODD Panalytical Own Drift Detector.

SDD Silicon Drift Detector.

WIP Work In Progress.

XRF X-Ray Fluorescence.

Contents

Chapter 1

Introduction

The aim of this chapter is to introduce the research that is conducted at Malvern Panalytical. First, Section 1.1 introduces the research context by introducing the company, drift detector technology, and drift detector supply chain. Next, Section 1.2 explains the problem within this supply chain. Section 1.3 includes the research design, which consists of the research questions, the methodology, and the scope. The research motivation based on literature is given in Section 1.4. This chapter will conclude with a reading guide for this thesis in Section 1.5.

1.1 Research context

First, the description of the company is given in Subsection 1.1.1. Subsequently, Subsection 1.1.2 describes the technology and configurations of the detector of the supply chain that is the topic of this research, which is explained in Subsection 1.1.3.

1.1.1 Company description

This research is conducted at the Supply Chain department of Malvern Panalytical. Malvern Panalytical is a Spectris plc company that develops and produces scientific instruments and services in the field of material characterization and employs more than 2,300 people worldwide. In 2017, Malvern Panalytical Ltd is formed by the fusion of the companies Malvern Instruments and a Philips split-off called PANalytical (Philips Analytical). Malvern Instruments is a UK-based company specialized in designing and manufacturing systems that measure the size, shape, and charge of particles. The instruments of PANalytical provide elemental and structural information on a wide variety of materials. Malvern Panalyticals instruments are used by customers to understand and improve productivity and quality. The instruments are used for both scientific research and industrial applications to analyze primary materials, advanced materials, pharmaceuticals, and food.

1.1.2 Detector technology

Figure 1.1 shows an X-ray source that radiates incident angle X-rays on a material sample. The sample reflects X-rays that are received by a detector, which is an instrument that converts the X-ray signals from photons into electronic signals. These electronic signals are translated into the energy of each detected X-ray, which equals the physical characteristic of an element. These characteristics are translated and displayed in a diagram generated by software. From this diagram, the identification of the elements of the sample material can be concluded. Malvern Panalytical uses several different detectors in their scientific instruments. All of these detectors are Malvern Panalytical's intellectual property and are developing rapidly to remain competitive in the market. This research focuses on one of these detectors, namely the Panalytical Own Drift Detector (PODD). The PODD is a Silicon Drift Detector (SDD). SDDs detect, measure, and convert X-rays that are subsequently translated in outcomes that are more accurate and reliable than from alternative detectors. Currently, most PODDs are installed in X-Ray Fluorescence (XRF) analyzing instruments that perform simple element identification. The PODD is a unique selling point for this XRF analyzer because of its high-quality performance.

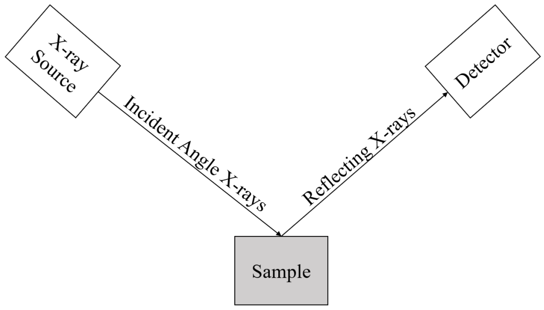

Figure 1.1: The general functioning of X-ray technology (adapted from Malvern Panalytical)

Currently, there are four configurations of the PODD and one configuration will be introduced in the near future. The product hierarchy is shown in Figure 1.2. For confidentiality reasons, the product characteristics are anonymized. Three of the currently used configurations contain a sensor chip of type I and one configuration contains a type II sensor chip. In addition to the different chips, the PODDs are distinguished by the difference of the materials of two components, which are a window and a collimator. Thus, we distinguish between chip type I or II, collimator type A or B, and window type 1 or 2. The PODD types are differentiated in this research since the in-house production process slightly differs depending on the chip used. This research will focus on all five PODD types.

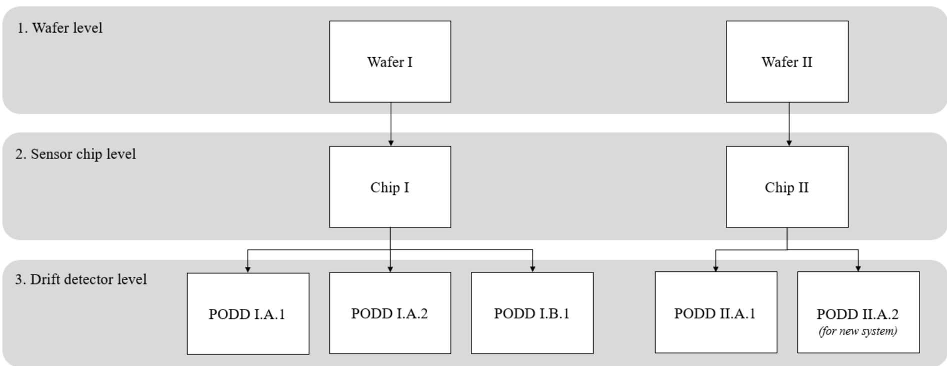

Figure 1.2: Product hierarchy of the PODD (I or II = chip type, A or B = collimator type, and 1 or 2 = window type)

1.1.3 The supply chain at Malvern Panalytical

In Figure 1.3 a high-level overview of the PODD supply chain is visualized showing the relationships between suppliers and Malvern Panalytical. Malvern Panalytical produces the PODDs in collaboration with multiple suppliers that are localized in various places in Europe. The suppliers are anonymized for confidential reasons (i.e., Company A to E) and almost all controlled by Malvern Panalytical. After the production, the PODDs are assembled in the X-ray instruments or used as spare parts. The detectors are produced following the Make To Stock (MTS) principle, thus the customer order decoupling point is between the drift detectors are finished and before the assembly in the X-ray instruments. The PODD supply chain is complex since it consists of one raw material and four half-manufacture suppliers, four key components suppliers, and many general component suppliers, sometimes over long time horizons (Gao et al., 2018). Malvern Panalytical can be considered as the supply chain leader of this supply chain due to their economic power and the fact that they initiated the partnerships and collaborations (Mentzer et al., 2001).

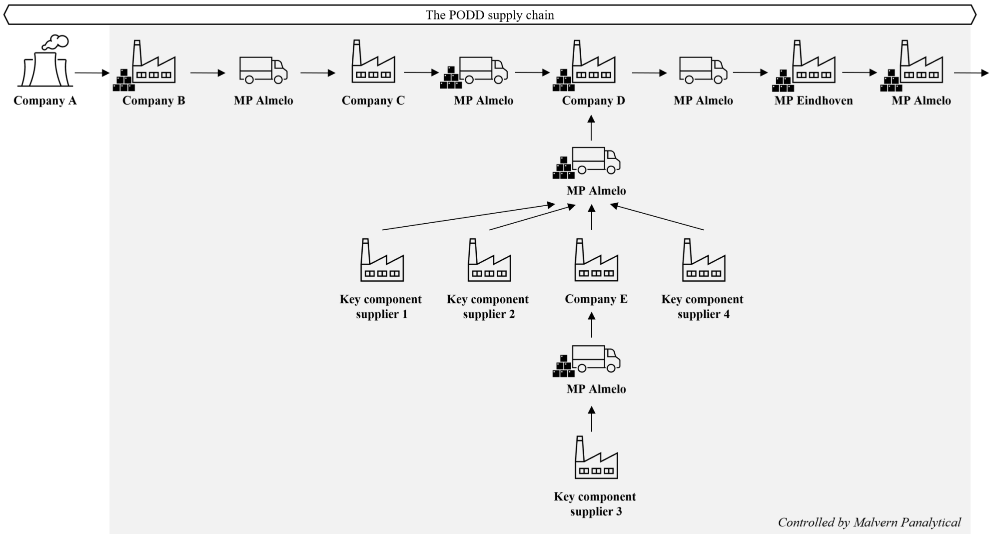

Figure 1.3: High level overview of the PODD supply chain management structure

1.2 Research problem

Currently, Malvern Panalytical faces some complexities in the PODD supply chain. The company expected that existing challenges are mainly a result of the urge that Malvern Panalytical wants to control the entire supply chain (i.e., steering the supplier of the supplier of the supplier). The supply chain has been developed this way in the past eight years because Malvern Panalytical desired to have control over the process to guarantee quality and supply. As mentioned before, guaranteeing quality and supply is important because this drift detector is their unique selling point. The current way of controlling the PODD supply chain is manageable so far, although managing is time-consuming since it requests many manual tasks and communication.

The current way of managing is not desirably scalable since there are many time consuming tasks. Scalability is required since significant demand growth for two of the PODD types is forecasted starting from 2024. The cause of the significant growth is the introduction of the by Malvern Panalytical developed new desktop instrument, hereafter called 'new instrument'. Usually, the systems in which the PODD is currently assembled have one detector. However, depending on what the client needs to measure with the instrument, the new instrument will contain either one or four detectors. Having four detectors in one system significantly increases the demand for detectors. Moreover, it is expected that the sales volumes of one of the current systems will decrease because the new instrument would be a more accurate and innovative replacement. All these expectations are incorporated in the forecasts made by Malvern Panalytical. These forecasts include PODDs for the current instruments, the new instrument, strategic stock, and spare/service parts. As an indication of the impact of the growth in demand, in 2024 the sales are expected to be doubled in comparison with the past years and even tripled in 2028 due to the introduction of the new system.

Explicit numbers are confidential and therefore not shared. Additionally, it is expected that the current PODD supply chain cannot supply enough PODDs to meet the expected future demand due to the currently implemented way of managing. Malvern Panalytical does not measure the performances of the whole PODD supply chain. Thus, we can not rely on fact-based information. Therefore, the expectation is further explored in Subsection 1.2.1.

Based on introduction meetings and several interviews with the company supervisor and various PODD supply chain stakeholders, an initial cause-and-effect diagram was developed as shown in Figure A.1 in Appendix A. The main problems in this figure on the left-hand side are a complex supply chain (management) and the expectation that the supply chain is not scalable in terms of production volumes. Thus, we distinguish in two types of capacity, namely the management capacity and production capacity. The cause-and-effect diagram summarizes the causes of these problems, which are displayed on the right side of the diagram. This diagram should be used to get a better idea of the problem, but not as a guideline since it is established during the first research phase.

1.2.1 Problem validation

The problem is validated before defining the problem statement. The fact that the PODD supply chain majorly faces real problems regarding the management burden (i.e., management capacity) because of the various complexities has been validated through multiple interviews. Problems that are considered to be real problems are worthwhile as a subject of a business problem-solving project (Van Aken et al., 2007). Therefore, the future production capacity problem needs to be verified as being a perception or real problem since this problem is an expectation of stakeholders and has not been evidenced yet. To investigate this, additional interviews are conducted with experts about the capacities of the suppliers and internal production processes of the PODD. In this section, information is given about these capacities and a conclusion is given about the problem type.

According to Cachon & Terwiesch (2013), each process or activity has a capacity, which implies the amount the process or activity can supply. This is opposed to the throughput of an activity or process. Throughput, also called flow rate, is the amount the activity or process produces. The capacity of the process equals the minimum amount of the activity capacities (Cachon & Terwiesch, 2013). External interrupting events, such as breakdowns, do not influence the capacity but the throughput (Cachon & Terwiesch, 2013). Therefore, the throughput can be determined as the minimum of the availability of its input, the demand, or the capacity. To roughly validate the problem quantitatively, it is chosen to first investigate the process step capacities. The capacity of each process was determined using information from the expert interviews. Within this supply chain, cross-docking has no capacity restrictions and therefore the capacity is not applicable. The capacity of all stock points are also neglected since no problem is expected with stocking the work in progress or (semi-) finished goods. However, stock capacity can not be excessive because of inventory costs.

The Strategic Buyer is interviewed about the supplier capacities. There are no supply capacity problems expected at any of the suppliers. New agreements regarding expansions are necessary for Company D (CD), which could be easily arranged. For all other suppliers, the capacities are no problem because the Minimum Order Quantitys (MOQs) required by the suppliers are relatively high in comparison with the number of units needed. Malvern Panalytical orders small volumes in comparison with other customers of the suppliers. Regarding the internal production at Malvern Panalytical, a process engineer is interviewed to investigate the processes in Eindhoven and a production employee is interviewed for the part in Almelo. Both in Almelo and Eindhoven, visits took place for observation purposes. Only for two process steps in-house at Malvern Panalytical, the capacities were questioned considering the growth in demand. It is found that the machine of one process step at MP Eindhoven and one machine at MP Almelo have capacity problems starting from 2027 and 2024 respectively. The machine at MP Eindhoven needs approximately 9% more capacity in 2027 in terms of percentages of the current capacity and 13% more in 2028. Thus, one additional machine is necessary at MP Eindhoven. The machine at MP Almelo needs approximately 37% more capacity in 2024 in terms of percentages of the current capacity, 55% more in 2025, 83% more in 2026. Thus, one additional machine is necessary from 2024 to 2026 at MP Almelo. Starting from 2027, approximately 108% more capacity than the current capacity is necessary and 115% for 2028. Therefore, another additional machine is necessary to perform this process at MP Almelo.

To conclude, the expectation of having capacity problems in the future is verified and therefore is a real problem. However, the capacity problems will only exist internally at Malvern Panalytical. The production capacity for one process step at MP Eindhoven and one process step at MP Almelo will become insufficient to meet the future demand. The validation section only focused on supply and manufacturing capacity. The expectation is that the supply and manufacturing capacity issues could be easily improved by expanding. However, the challenges caused by the complexity of managing this supply chain require more investigation to improve.

1.2.2 Problem statement

The problem definition is summarized in the following problem statement:

The current PODD supply chain management is complex (e.g., time-consuming and not completely automated) because Malvern Panalytical manages the supply chain multiple tiers deep. In addition, the current management structure is expected to be insufficiently scalable due to capacity limitations. Therefore, this will become a problem to meet the increased demand that is forecasted starting from 2024.

1.3 Research design

The research design of this thesis consists of research questions, a methodology, and a scope. First, the main research question and seven supportive questions are formulated in Subsection 1.3.1. Second, the methodology used to perform this research is described in Subsection 1.3.2. Lastly, the scope is given in Subsection 1.3.3.

1.3.1 Research questions

The objective of this research is translated into the following main research question:

What is the improved PODD supply chain management structure to cope with complexity and to scale up production volumes at Malvern Panalytical?

To structure this research and to investigate all aspects of the main research question, seven sub-questions are formulated:

RQ.1 *What does the current PODD supply chain management structure look like?*

RQ.2 *What are current and potential challenges in the PODD supply chain management structure considering the complexity and scalability?*

RQ.3 *Which of the identified challenges are most impactful?*

RQ.4 *What performance measures can be selected to evaluate the most impactful challenges?*

RQ.5 *Based on these measures, what are the performances of the supply chain with the current demand and forecasted future demand?*

RQ.6 *What organizational changes are necessary for the PODD supply chain to cope with the most impactful problems and to improve the performances?*

RQ.7 *How shall the changes be implemented within the current infrastructure?*

1.3.2 Methodology

Business Problem-Solving (BPS) is typically solved using the regulative cycle of Van Strien (1997) (Van Aken et al., 2007). This cycle is shown in grey in Figure 1.4 and consists of the problem mess, problem definition, analysis and diagnosis, plan of action, intervention, and evaluation. The plan of action concludes the body of this Master thesis project. The steps of intervention and evaluation of the regulative cycle belong to the actual implementation of the solution design, which is out of scope of this project. Therefore, an explanation follows from the problem mess until the plan of action phase. The regulative cycle starts with the problem mess, which is a set of problems of a company including the initial problem statement. The problem definition step follows from the problem mess and should include the project plan and approach for the subsequent step covering the analysis, diagnosis, and design (Van Aken et al., 2007). The problem is defined in the previous section and the approach is explained in Chapter 4. The approaches are based on a separate literature review. A literature review provides a range of solution concepts to solve the problem of which one should be chosen and adapted to the problem and its context (Van Aken et al., 2007). The analysis and diagnosis step is the analytical part of the project in which quantitative and qualitative research methods can be used (Van Aken et al., 2007). The goal of this step is to gather context and problem-specific knowledge. Following with the plan of action step that covers the solution design for the problem. Since this is the last step that will be performed in this thesis, a conclusion will be given afterward.

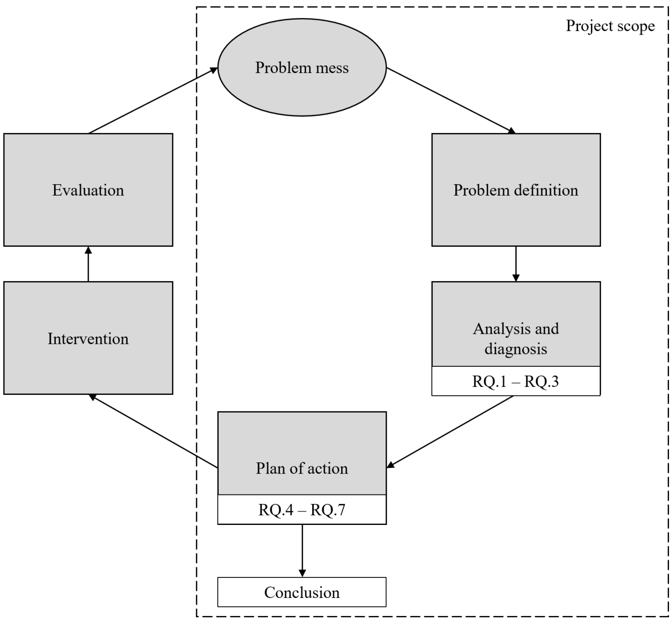

Figure 1.4: Adapted regulative cycle of Van Strien (1997) retrieved from Van Aken et al. (2007)

The research questions as proposed in Subsection 1.3.1 are related to the first three steps from the regulative cycle as shown in Figure 1.4. This figure shows the research setup that will be performed in this Master thesis project. RQ.1 to RQ.3 cover a field study, of which the third question will provide the final diagnosis. Based on this diagnosis, the direction to continue within the plan of action phase will be chosen. The plan of action consists of RQ.4 up to and including RQ.7. The fourth question requires research based on literature about performance measuring and the fifth question will provide insight into the current performance. The sixth and seventh question will discuss potential changes and their implementation. After performing these steps, we will provide conclusions on the main research question, company recommendations, and limitations of the research.

Figure 1.5 shows the conceptual project design for the diagnosis in a BPS project. This concept consists of three elements: the subject of the analysis, a set of theoretical perspectives to study the problem, and the deliverables of the project (Van Aken et al., 2007). These elements are represented by the right side, left side, and bottom of the model in Figure 1.5 respectively. In this project, several theoretical topics will be studied and applied to improve the PODD supply chain management structure, which is the subject of this project. Theoretical topics that are interesting and valuable to perform the field study and describe the as-is situation are supply chain management structures and performance measurements within supply chain management. The performance measurements will serve as a base for comparison when evaluating possible improvements. Regarding the plan of action phase, theoretical topics are studied to support the exploration of possible improvements. We decided to study the theory of BPR as a framework to support the plan of action phase. BPR is explained in Chapter 4. The deliverables are a result of the regulative circle. For the analysis and diagnosis phase, the deliverables are insights into the current situation regarding the drift detector supply chain, the management structure, and the challenges in terms of complexity and scalability. Additionally, performance measures are selected and given for the current and future situation to evaluate two of the most impactful challenges in this supply chain. For the plan of action phase, the deliverables consist of a list of potential changes to address the most impactful challenges, quantitative and qualitative evaluations of the benefits and downsides of these changes, and implementation suggestions to improve the supply chain management structure.

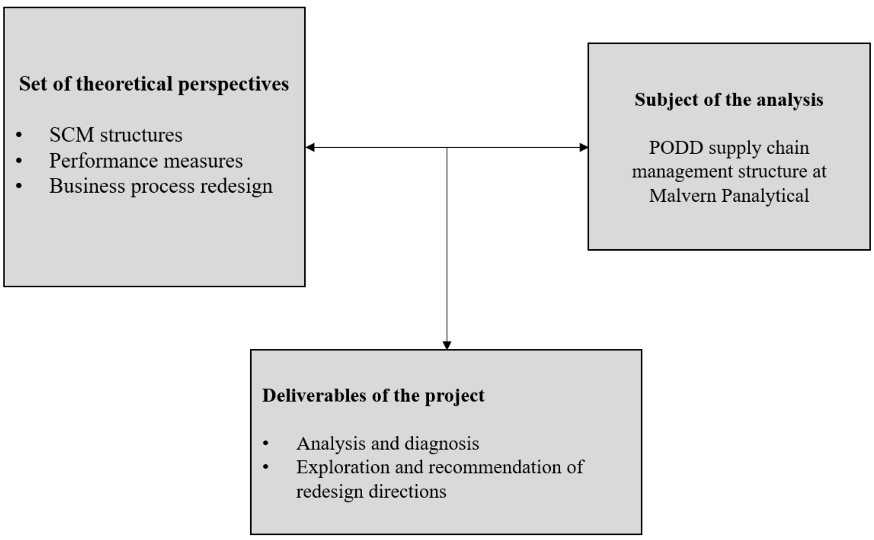

Figure 1.5: Conceptual Project Design retrieved from Van Aken et al. (2007)

1.3.3 Scope

The project scope includes the supply chain of the PODD at Malvern Panalytical, i.e. from raw material to a final drift detector as discussed in Subsection 1.1.3. Thus, the supply chain of the instruments in which the drift detector is assembled is out of scope of this research. However, the demand for the PODD depends on, among other things, the forecasted demand for these instruments. The forecast of instruments and services including the PODD is hereby within scope. Within supply chain planning a distinction is made between three types of supply chain planning, namely the operational, tactical, and strategic supply chain planning Huang et al. (2003). Below, the definitions of the planning types are given and the scope is explained.

- The operational planning includes short-term decisions that focus on order replenishment and shipment (Hugos, 2018). The structure of the operational planning of the internal production at MP Almelo and Eindhoven is in scope for this project. The production planning and execution of work orders are out of scope.
- The tactical planning of the supply chain deals with the processes of procurement, processing, and distributing the products (Santoso et al., 2005). Most problems related to the management burden are within the tactical planning of the supply chain. The structure of the tactical planning must be revised to address the complex issues by considering reorganizing the tactical processes. Note that even though transportation between suppliers and Malvern Panalytical is out of scope, the process of how cross-docking (i.e. distribution) between the plants of Malvern Panalytical is organized within scope.
- The strategic planning of the supply chain partly involves the configuration of the network (Santoso et al., 2005). Since we are considering reorganizing the supply chain management structure strategic planning is in scope as well.

1.4 Research motivation based on literature

Much research is conducted on supply chain and supply chain management. To understand the basics, for example, we studied general research about supply chain management (Mentzer et al., 2001; Hugos, 2018). While we also studied papers with more specific topics such as supply chain dynamics, configurations, and strategies (Huang et al., 2003; Ernst & Kamrad, 2000; Lee, 2002; Fisher, 1997). This research will first focus on the supply chain and supply chain management structure in general. Afterward, the focus shifts to the order management process, which we consider as an element of the supply chain management structure.

Order management is a process that transfers information about orders from the customer through the whole supply chain consisting of retailers, distributors, manufacturers, and service providers (Hugos, 2018). Thus, order management can be related to the information supply chain flow, which is an element of the conceptual model of supply chain management of Mentzer et al. (2001). Additionally, order management influences and is related to multiple traditional business activities. In the past, order management was performed using paper documents and phone calls. However, most order management tasks are integrated with information systems these days. In the case of a supplier-company relationship, the company releases a purchase order to request parts from the supplier. The supplier fulfills this order directly from stock (i.e., make-to-stock) or starts production and fulfills afterward (i.e., make-to-order). Mostly at suppliers, purchase orders are translated into a picking order, packing order, and invoice. Suppose the supplier needs to source raw materials or half-manufactured products from other suppliers. In that case, the original customer purchase order turns into a purchase order from the supplier to a second-tier supplier. The second-tier supplier repeats the fulfillment steps of the first supplier. This process repeats for each supplier in the chain, implying that the longer the supply chain in terms of suppliers, the more orders will be generated. Due to changing demands and complexity in supply chains order management is a process that also evolves (Jain & Benyoucef, 2008). Hugos (2018) noted four basic principles of order management. 1) Enter the order data once, the system should transfer the relevant order data to other systems and supply chain participants to create purchase and picking orders. 2) Order handling automation for routine orders by minimizing manual interventions. 3) Make order status visible to customers and service agents from order entry to delivery. 4) Use integrated order management systems that synchronize in a timely and accurate way with other related systems (e.g., to update inventory status, calculate delivery schedules, and generate invoices) to maintain data integrity. These principles are thus very basic and not covering all challenges of the PODD order management process.

To our knowledge, little research is conducted on improving the execution of the order management process. Therefore, we decided to use the BPR approach, which is applied to a wide variety of business processes in various industries Reijers (2003); Reijers & Mansar (2005); Mansar & Reijers (2007). Among them is the manufacturing sector and service sector, including for example administrative processes. No explicit research is found about the application of BPR in order management processes. However, order management processes have similarities with administrative processes, which are for example used by Reijers (2003) in combination with BPR. The BPR approach would serve as a relevant scientific foundation to redesign the supply chain management structure at Malvern Panalytical. The BPR contains best practices that are categorized based on the framework of (Reijers & Mansar, 2005). Each category can relate to one or more elements from the supply chain management model of Mentzer et al. (2001). Therefore, we expect that BPR is a relevant method to use within this Master thesis project. The studies on the best practices of Reijers & Mansar (2005) and Mansar & Reijers (2007) will be used in the Master thesis to select suitable redesign heuristics for the PODD order management process. The best practices presented in the paper are mostly gathered from experiences in large companies or consulting firms engaged in BPR projects. Although many best practices exist, a lack of adequate (quantitative) support is identified in practice. While in literature, the best practices are mainly quantitatively evaluated using the devil's quadrangle by considering four dimensions (Reijers & Mansar, 2005). Brand & Van der Kolk (1995) distinguishes the four dimensions cost, time, quality, and flexibility. This research will contribute by providing (1) an approach to test the BPR heuristics in practice both qualitatively and quantitatively and (2) with a case study of BPR heuristics in order management.

1.5 Thesis outline

This section explains the outline of this thesis. The current chapter outlined the research context, problem, and design. In Chapter 2 we describe the current situation of the PODD supply chain. Subsequently, in Chapter 3 we explain the challenges within this supply chain and select the most important ones to continue this research with. In Chapter 4, we first select the performance measures as a base for comparison and we determine the current performances. Second, the redesign approach is introduced. Third, we provide the potential redesigns and results including implementation suggestions. Finally, we conclude this report in Chapter 5.

Chapter 2

Current supply chain

This chapter aims to answer *RQ.1: What does the current PODD supply chain management structure look like?*. First, the approach used to visualize the PODD supply chain is explained in Section 2.1. Second, the current PODD supply chain is explained in Section 2.2. Third, Section 2.3 explains how the order management within this supply chain is structured.

Before the supply chain is explained, the definition of a supply chain is given. In literature, there are various definitions of the supply chain. The definition of Christopher (1992), as found in the widely used research of Mentzer et al. (2001), is chosen for the purpose of this section. Christopher (1992) defines a supply chain as a network of organizations that are involved, through upstream (i.e., supply) and downstream (i.e., distribution) linkages, in the different processes and activities that add value in the form of products and services delivered to the ultimate customer. The organizations involved could be raw material and component producers, product assemblers, wholesalers, retailer merchants, and transportation companies (Mentzer et al., 2001). From the perspective of the PODD supply chain, the ultimate customer is Malvern Panalytical or its customers. Malvern Panalytical demands the PODDs to be assembled in their scientific instruments and the customers demand PODDs as service parts. The aggregated demand of Malvern Panalytical and the customers is from now on called the PODD demand.

2.1 Process flow diagram

A Process Flow Diagram (PFD) is a graphical approach that describes the process and supports structuring collected information (Cachon & Terwiesch, 2013). Figure 2.1 shows the original PFD elements on the left-hand side, which are start/end, activity, stock-point, and flow. Activities are represented by a rectangle and are carried out by resources that have a maximum capacity (i.e. maximum throughput per time unit). An activity adds value to the chain and thus has to be fulfilled before continuing to the next step. Since multiple suppliers can carry out an activity, we adapted the PFD by adding the company to an activity or stock point with a dotted rectangle. Activities can conclude with semi-finished products, therefore we decided to indicate a newly assembled semi-finished product in the PFD with a rectangle underneath the activity. Some of the products are purchased, this is represented by a clear oval. The three added elements are shown on the right-hand side of Figure 2.1. Both half-manufactures and buy-parts can be stocked. Stock points are visualized using a triangle. Stock that is planned to have is modeled, however, Work In Progress (WIP) is not visualized but could still exist between activities. The flow between activities and/or stock points is indicated by arrows. Multiple flow unit types could flow through the process, this is indicated with a number on the arrow. This is used in PFDs to represent the different product types in the different levels as shown in Figure 1.2. Note that one product type is produced at a time, the flow number indicates the ability to process different kinds of products, which is called mix flexibility (Jansen-Vullers et al., 2008).

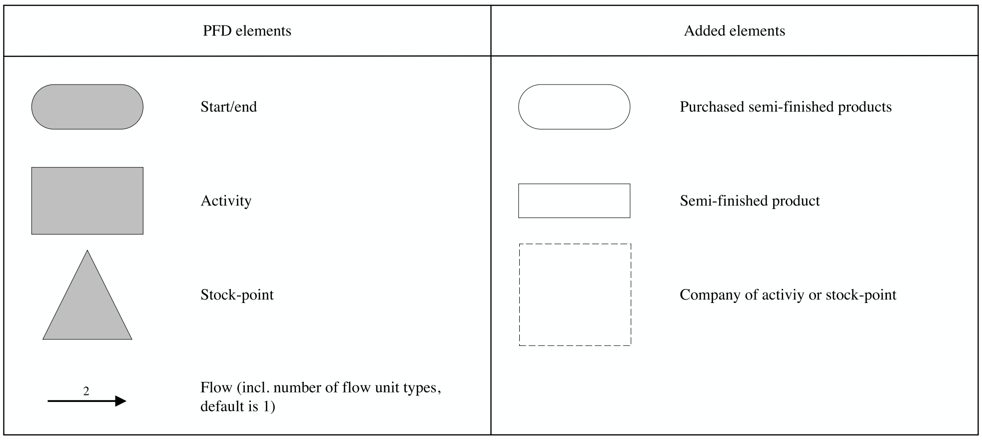

Figure 2.1: Legend of the PFD

2.2 Detailed supply chain

The product hierarchy, shown in Figure 1.2, can be seen as the high-level perspective of the PODD supply chain. Only the four currently produced PODDs are included in this section since the PODD II.A.2 is not in production yet. The supply chain is explained in three parts using PFDs as introduced in Section 2.1. The three parts follow from the product hierarchy logic, thus the three parts explain the production of (1) the wafers, (2) the sensor chips, and (3) the drift detectors. Subsection 2.2.1 explains the first part of the supply chain, in which the wafer is produced by external suppliers. Subsection 2.2.2 explains the second part, in which the two different sensor chip types are produced. In Subsection 2.2.3 the supply chain is concluded with the third part, in which the production of the four different configurations of the PODD is described. Within the last part, an additional circular process exists for reusable packaging to transport half-manufactures. This circular process is explained in Subsection 2.2.4.

2.2.1 First part PODD supply chain

The first part of the PODD supply chain is shown in Figure 2.2 and starts with the production of ingot at Company A (CA). Subsequently, CA utilizes its in-house produced ingot for the production of process wafers. A process wafer can be considered as the first state of a wafer. CA operates with an Incremental Order Quantity (IOQ) of 12 plain wafers. Implying that these wafers can be ordered in multiples of 12. Because of this IOQ, the minimum quantity that must be ordered is sufficient for many years of sensor chip production for the PODD. After the production step at CA, the wafers are transformed by Company B (CB) into SDD wafers. All wafer shipments within this supply chain are carried out in batches of six units to spread and minimize potential risks during transport. In general, transport is outsourced to a third-party logistics provider. This is arranged by the sending party and paid by Malvern Panalytical. At CB, the SDD wafer is produced using a mask designed by Malvern Panalytical. This mask design consists of only type II chips or multiple sizes combined, namely, type I and II, and two other sizes of chips. The two other chip sizes are used for research and development purposes. Recently, Malvern Panalytical decided to develop a new mask with only type I chips in the near future. The introduction of this mask is desired because there already is sufficient type II chip stock and it's easier for the production process. Thus, it is decided to use the type I-only and type II-only masks in near future. CB delivers the desired quality but at the expense of a time-consuming process. After the SDD wafers are produced, testing is done to inspect whether the production process meets the requirements. The test does not give any indication about the quality of an individual chip, this information will be provided later in the process. When the SDD wafer production and testing at CB are finished, the wafers are transported via MP Almelo to Company C (CC) (i.e. cross-docking). According to Van Belle et al. (2012) cross-docking is a logistics strategy where goods are unloaded from inbound vehicles and directly or almost directly loaded into outbound vehicles, minimizing in-between storage. The cross-docking strategy seems to be increased in many industries because of its various advantages, such as cost reduction and decreasing lead times (Van Belle et al., 2012). Again, transportation is done in batches of six wafers. At CC, the SDD wafers are tested with small needles using a wafer prober. The goal of this test, called probing, is to estimate the number of usable sensor chips that can be produced at a later stage in the supply chain. This concludes the first part of the supply chain, which is the final stage of a wafer that is used for chip production in the second part.

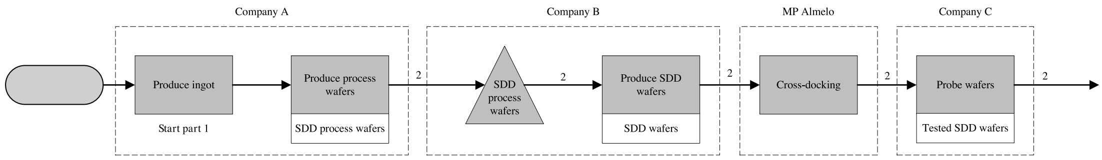

Figure 2.2: PFD part 1 of the PODD supply chain

2.2.2 Second part PODD supply chain

The second part of the supply chain is shown in Figure 2.3 and starts with the probed wafers. These wafers are stocked in nitrogen cabinets in multiple locations at MP Almelo to spread risks (e.g. in case of fire). The wafers are stocked in the nitrogen cabinets until a work order is placed, which will be explained in Section 2.3. After being stocked, one or more wafers are transported to the main plant of CD. CD transports the wafers to their other plant. At this plant the protective foil on the tested SDD wafer is removed. This process is called detaping. After detaping, the wafers are diced into sensor chips at CD's main plant. The number of chips produced from one wafer depends on the used mask design. For example, one wafer with only type II chips can be diced into 165 sensor chips. After dicing, the sensor chips are inspected, sorted, and stocked sequentially at the CD main plant. The sorting is based on the probing test result (failed or passed) and on the type I and type II chip variants. The stock at the main plant of CD is the temporary strategic stock of sensor chips as explained before. This stock is sufficient for about one to one and a half years of supply of the PODD with the current demand.

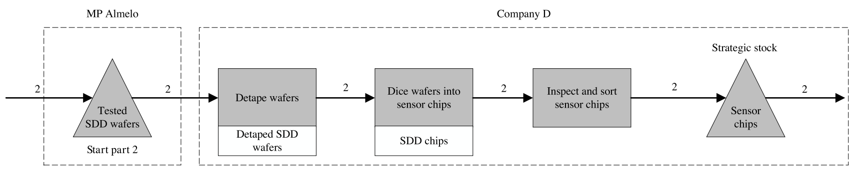

Figure 2.3: PFD part 2 of the PODD supply chain

2.2.3 Third part PODD supply chain

In parallel with the chip production, the other key components that are purchased at external parties are supplied to CD to be assembled with the sensor chip. This parallel is shown in Figure 2.4. The first externally supplied key component is purchased at a supplier and is stocked at MP Almelo. Afterward, four key components, namely a collimator, cube, peltier, and NTC resistance, are purchased at different suppliers and also stocked at MP Almelo. The header is sent to and used by Company E (CE) to supply the peltier. In comparison to the wafers, the four key components are purchased more frequently, which is desired to minimize inventory costs and possibly due to shorter lead times and smaller required order quantities. At a certain moment, the components are transported to the place of assembly, which is at CD. In addition to the key components, there also are other externally supplied components used to produce a PODD. Malvern Panalytical purchases various generic components, such as circuit boards, cables, glue, and screws. These components are necessary for the last few production steps at MP Almelo and Eindhoven. Besides, another part used for PODD production, ceramic, is not purchased by Malvern Panaltycial but directly by the supplier that assembles the ceramic part. Thus, CD purchases ceramic parts themselves, and therefore these parts are directly transported to their main plant for the assembly (also called assy) of the header stack. Since Malvern Panalytical is not responsible for the procurement of a ceramic part, it is excluded from the PFD.

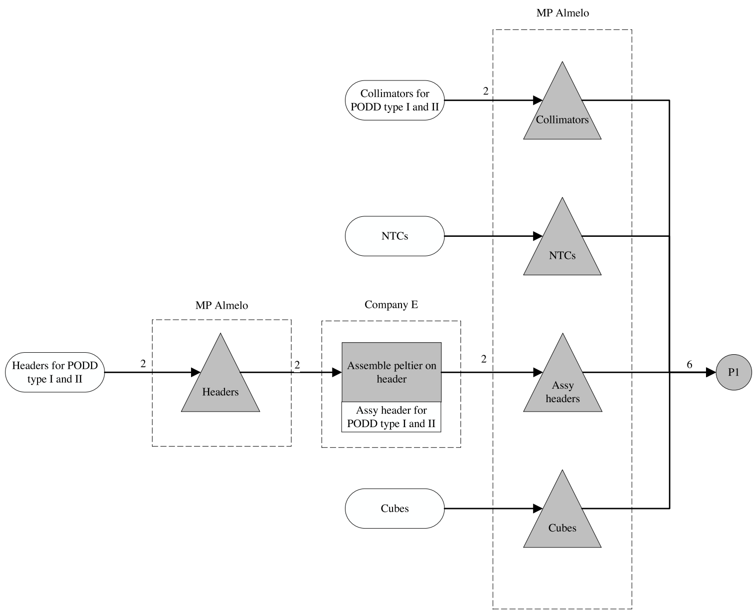

Figure 2.4: Parallel Process Flow Diagrams

The parallel stream comes together with the main process at CD to form the third and last part of the PODD supply chain. The third part is shown in Figure 2.5, in which P1 represents the parallel flow presented in Figure 2.4. At CD, the header stack is assembled from the four key components, ceramic, and a sensor chip. The assembly process starts when Malvern Panalytical places an order. The assy header stacks are produced by CD in three different types, namely a general variant for all the PODDs with the type A collimator and a specific one for the PODD with the type I chip and type B collimator (i.e., PODD I.B.1). After assembly, the header stacks are tested and if passed transported to MP Almelo to be shipped immediately to MP Eindhoven (i.e. cross-docking). In parallel, the caps for the PODD I.A.2 that are ordered by a purchaser at MP Almelo are transported via MP Almelo (i.e. cross-docking) by a third-party logistics carrier to MP Eindhoven. The production of this cap is outsourced since a fragile material is involved and can not be processed by Malvern Panalytical. If these caps are not necessary yet for production, the caps are stored in a cabinet at the production facility at MP Eindhoven. However, for this research, the cap for the PODD I.A.2 is left out of scope since this is a last-time buy item. At MP Eindhoven, the cap itself is assembled and subsequently assembled on the header, this resulting product is called the PODD. The assembly of the caps needs to be performed at MP Eindhoven since a material is involved that has health risks if it damages (i.e. scratches or breaks) during production. The cleanroom level at MP Eindhoven meets the conditions for working with this material, which is not the case at MP Almelo. After assembly, the PODD is tested and if passed the PODDs are transported via a third-party logistics provider to MP Almelo. The last step of the supply chain occurs at MP Almelo, which consists of the final assembly and testing of the detector. The PODD is assembled with various other components, such as a printed circuit board and wires. This assembly step takes approximately seven to ten minutes according to the interviewed operator and concludes the production of the drift detector. The drift detector is denoted in the PFDs by DD. The final test is performed using an X-ray, of which one test instrument is available. First, a pre-test of ten minutes is performed. If this test is passed, the complete test is started manually. If the test is failed, the operator needs to solve the software-specified problem, which is often done in several minutes. The main test takes 2.5 hours, therefore only three detectors can be tested during one working day. The test result implies whether the final detector works or not. If the main test has failed, the software displays what type of rework is necessary and another pre-test and the complete test are performed. At this stage, rework could be either fast or time-consuming. If the operator does not understand the problem, the development department will investigate the problem. The PODD supply chain is concluded after a passed test.

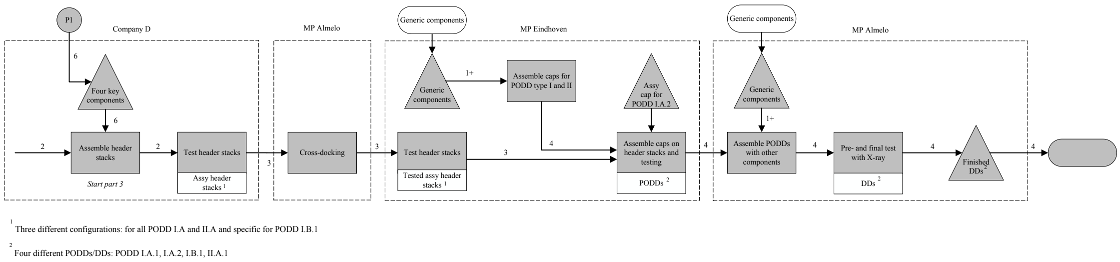

Figure 2.5: PFD part 3 of the PODD supply chain

Combining the three parts as described in Subsection 2.2.1 to Subsection 2.2.3, we can conclude the PODD supply chain with the PFDs in Figure 2.4 and Figure 2.6. This supply chain is a network supply chain since it combines divergent (distribution) and convergent (assembly) structures (Huang et al., 2003).

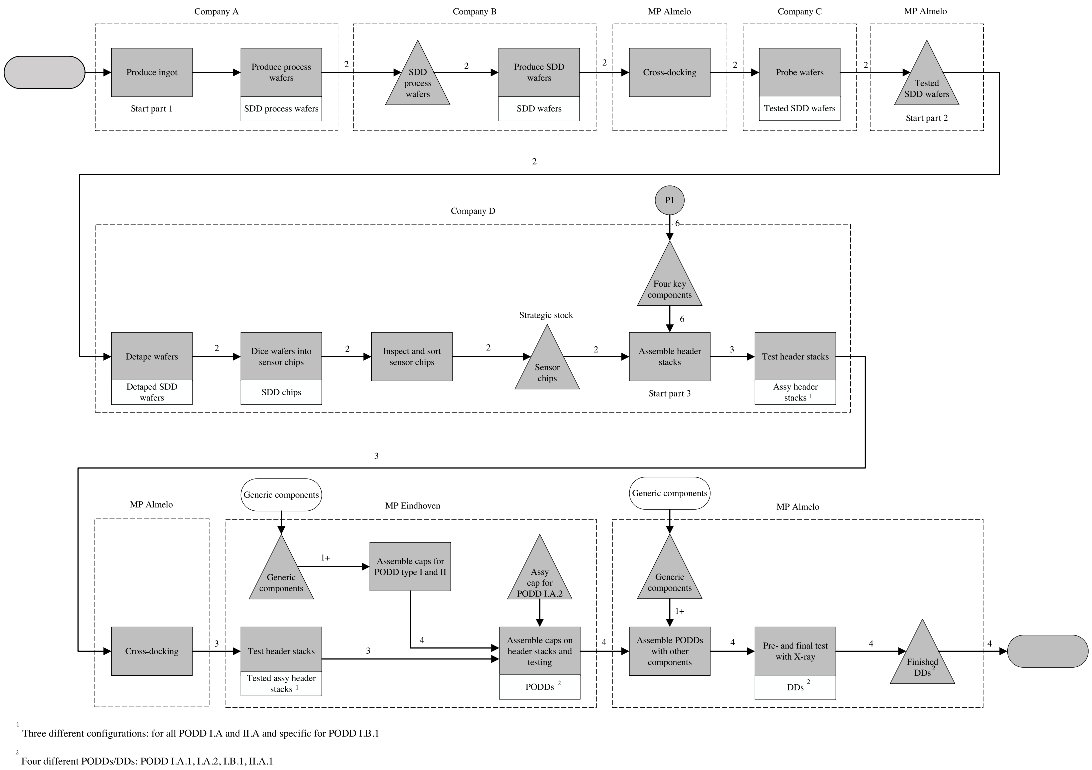

Figure 2.6: PFD of the PODD supply chain

2.2.4 Return packaging

The packaging used to safely transport the half-manufactures follow a circular cycle, meaning that the packaging needs to be returned for reusing purposes. The process of returning the packaging is a manual process and is shown in Figure 2.7. First, the empty packaging is filled by CD with assy header stacks and sent to MP Almelo to be cross-docked to MP Eindhoven. Since assy header stacks exist in two sizes, namely with the type I and type II chip, the return packaging also exists in two types. After production at MP Eindhoven, the PODDs are sent by the Supply Chain Engineer to MP Almelo to produce the final drift detectors. Subsequently, the empty packaging return to CD, which completes the circle. The order to send the package is given manually by the Supply Chain Engineer at MP Eindhoven via mail. This mail is sent directly to the warehouse employee that needs to send the packaging to CD.

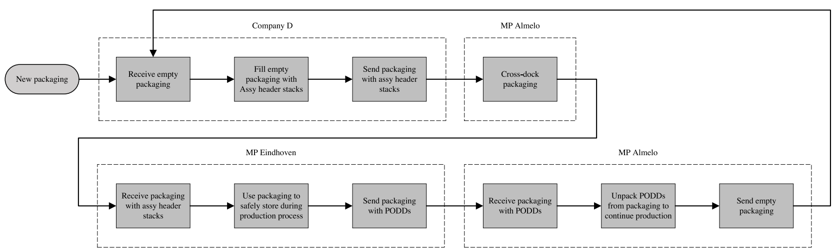

Figure 2.7: Circular PFD for the return packaging

2.3 Managing the supply chain

The majority of the PODD supply chain is steered by Malvern Panalytical. The replenishment policy is based on Material Requirement Planning (MRP)-logic, which takes into account input parameters such as the forecasted demand, Bill Of Materials (BOM), lead time, safety stock, safety time, and work in progress. Managing the first and second part of the supply chain is an exceptional process in comparison with other replenishment processes within Malvern Panalytical because it depends upon strategic decisions. Therefore, order suggestions of MRP are not immediately followed but evaluated by a team. The first supplier in the PODD supply chain, which is CA, is not managed by Malvern Panalytical, but by the subsequent supplier in the supply chain. Thus, the purchasing of process wafers at CA is executed by CB. Note that CB has to cope with the IOQ of 12 process wafers as required by CA. Malvern Panalytical has an agreement with CB that they must have stocked 50 process wafers from three different batches of ingot, produced by CA. Therefore, most of the time 24 wafers are ordered. The three batches are process wafers produced from the old, current, and new ingot. The wafers of the current ingot are the largest batch. This strategy is necessary since the quality of ingot slightly deviates from each batch, by maintaining batches there is time created to validate the batch of wafers from the new ingot. The validating process is time-consuming and complex since the new batch needs to be manually prioritized and tracked in the production process. As explained earlier, the quality of the ingot only can be validated with an X-ray experiment, which is executed in the last step of the supply chain at MP Almelo. If the test passes, Malvern Panalytical continues production with this new batch based on the First Come First Served (FCFS) principle. If the test fails, action is necessary (i.e. ordering a new batch of wafers with a new ingot). However, the tests never failed yet. Although the purchasing of the process wafers is executed by CB, Malvern Panalytical still partly steers the supply chain starting at CA. Malvern Panalytical has a level of control by requiring CB to purchase at CA and by being in contact with CA for information about the ingot batches.

The third part of the supply chain, as shown in the PFD in Figure 2.6, is controlled by Malvern Panalytical (i.e., from CB) by mostly directly following up triggers generated by MRP. Managing the key components in parallel flow P1, orders at CD, the cross-dock between CD and MP Eindhoven, and production at MP Almelo are incorporated within the MP Almelo domain planning. Only the key component management is not included within the MRP logic. The production at MP Eindhoven is incorporated within the planning of the Eindhoven domain. Thus, different departments at both MP Almelo and Eindhoven are involved in managing the process (e.g., creating work, shipment, and purchasing orders).

Chapter 3

Supply chain challenges

This chapter aims to answer *RQ.2: What are current and potential challenges in the PODD supply chain management structure considering the complexity and scalability?* and *RQ.3: Which of the identified challenges are most impactful?*. First, Section 3.1 explains how the diagnosis is performed. Second, in Section 3.2, the challenges within the PODD supply chain are studied. Afterward, in Section 3.3, we evaluate the importance of the challenges and select the most important ones to continue this research on.

3.1 Diagnosis approach

Supply chains are frequently complex and valuable when they consist of multiple suppliers, consumers, and service providers spread across several organizations or functions, sometimes over long time horizons (Gao et al., 2018). The PODD supply chain has a long end-to-end lead time and includes multiple suppliers, external manufacturers, and service providers to support producing, assembling, testing, and transporting the materials necessary to produce the drift detectors. As a result, it is not surprising that the PODD supply chain is valuable but also comes with complexities. These complexities, also called challenges or problems in this section, are mapped via various expert interviews. Experts from various disciplines are interviewed to obtain a complete understanding of all the problem characteristics. We interviewed two physics experts, three supply chain experts, and one purchasing expert, to gain insights into the supply chain from different perspectives. During these interviews, the situation with the current demand and growing future demand are questioned and discussed. To gather more information about the internal operational processes, one production and one process expert are interviewed at MP Eindhoven. In addition, one production and one warehouse operator from Almelo were interviewed. Where possible, operational activities were also observed at MP.

After the interviews, we visually displayed the challenges and all interrelations in an initial cause-and-effect diagram, which is shown in Appendix A. The initial diagram is used in follow-up interviews to validate the problems and interrelations in an iterative manner. After several validation interviews, we end up with a comprehensive and reliable cause-and-effect tree as shown in Figure 3.1. We decided to use the informal cause-and-effect diagram of Van Aken et al. (2007) since they found that this method provides more freedom to relate causes and effects and their chronology. In the diagram, causes of a certain effect can be found. Causes appear on the left-hand side of an arrow and the effect on the right-hand side. The final cause-and-effect tree is used to discuss the impact of all the challenges with the experts.

We decided to select one or more problems to further focus this research on within the plan of action phase. The approach used for the selection procedure is based on a theory of Van Aken et al. (2007) and based on various expert interviews within Malvern Panalytical. Within the selection procedure, it is important to consider the following statement of Van Aken et al. (2007): "Selecting a business problem at the extreme right-hand side of the cause-and-effect tree normally increases the relevance of the study but decreases its feasibility". In other words, studying the problem most the right-hand side, which is 'supply chain not (desirably) scalable', is most relevant but less feasible according to this statement. We decided to select business problems with a more left-hand side orientation since we consider the feasibility of the study of high importance. For feasibility, we also take into account that the chosen problem is within the span of control of Malvern Panalytical. We consider a problem within the span of control when Malvern Panalytical is able to address the problem or challenge. For some problems, Malvern Panalytical cannot handle the root of a problem but can only react to a problem. In other words, Malvern Panalytical cannot avoid or tackle some problems and instead needs to cope with them.

3.2 Challenges in the PODD supply chain

Figure 3.1 shows the final cause-and-effect diagram. The final effect, which is not being able to desirably scale the supply chain operations, matches the problem of the thesis. Time-consuming management burden is the major cause of not being able to desirably scale the supply chain operations. Too much time is required from employees due to manual tasks (i.e. high demand of human resources) to run the process. The other cause of not being able to scale the supply chain operations is the limited production capacities at Malvern Panalytical in the future. All the causes, effects, and interrelations of Figure 3.1 are briefly explained below.

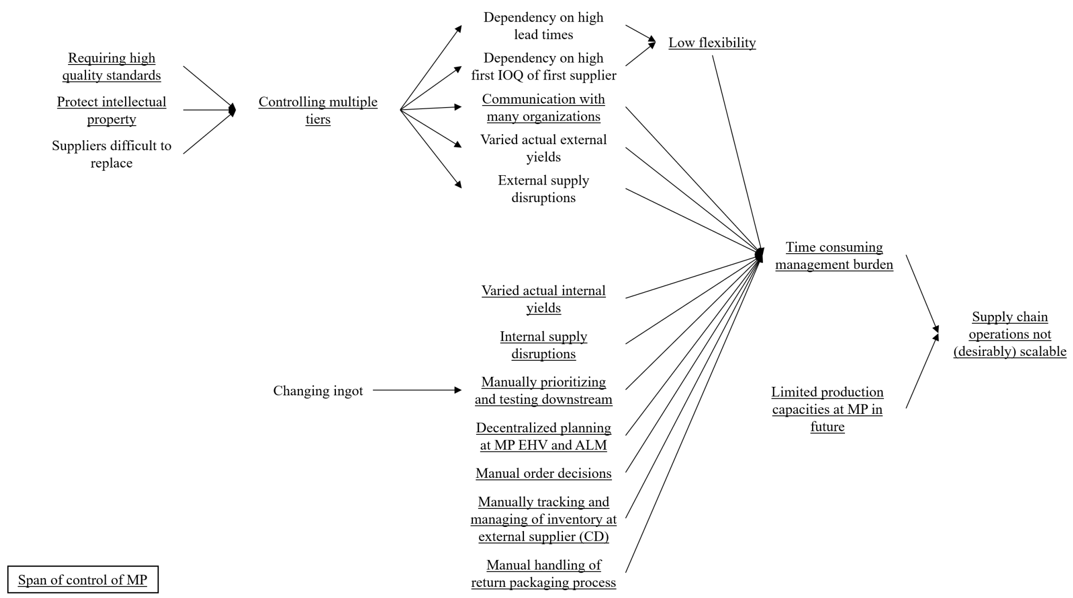

Figure 3.1: Cause-and-effect diagram

3.2.1 Controlling multiple tiers

Currently, Malvern Panalytical faces challenges in the PODD supply chain. In the first and second parts of the supply chain, these challenges are mainly a result of the fact that the entire supply chain is controlled by Malvern Panalytical (i.e. controlling starting from the supplier of the supplier of the supplier). This deviates from the traditional way of order management, where a supplier only steers its direct supplier (Hugos, 2018). The supply chain is created this way because

Malvern Panalytical requires high-quality standards, wants to protect its intellectual property, and suppliers are difficult to replace. The company has control over these aspects by managing the whole chain. However, this has some undesired consequences and challenges that are explained below.

Dependency on high lead times

Since the whole supply chain is controlled by Malvern Panalytical, the order and replenishment planning is entirely managed by Malvern Panalytical. Meaning that Malvern Panalytical has to make order decisions far in advance. These high lead times decrease the flexibility of the supply chain because quickly reacting to fluctuating demand is not possible. However, being responsive and flexible to demand is desired for the agile supply chain (Lee, 2002). The company copes with these high lead times by having safety stocks through the process as indicated in Section 2.2. Holding stock of partially completed products (i.e. WIP) increases the flexibility of the supply chain since the lead time to finish the final product is much shorter than when starting with the raw material. However, high lead times still decrease flexibility for making order decisions in general, especially in combination with the high IOQ of the first supplier and the rapidly developing technology. Strategic decision-making is required because of low flexibility in the first part of the PODD supply chain.

Dependency on high first supplier IOQ

Second, managing multiple tiers in the supply chain also causes Malvern Panalytical needs to cope with the IOQ of the first supplier. The IOQ of the first supplier in the supply chain equals the need for wafers for approximately five to six years with the current demand. As mentioned, the wafers need to be ordered far in advance since the lead time is relatively high. The high IOQ at the start of the supply chain decreases the flexibility of the supply chain since Malvern Panalytical cannot determine the preferred order quantity such as the Economic Order Quantity (EOQ). Therefore, the order decision of the wafers is a strategic decision in which the potential changes of the mask design or other evaluations regarding the chip design need to be considered. This is the main reason why Malvern Panalytical needs to control the supply chain. Since the purchasing price of the wafers is not in proportion to the prices of the production/services provided by the succeeding suppliers. They do not have the economic power to handle the procurement of the wafers themselves. Hence this responsibility lies with Malvern Panalytical because of their economic power (i.e. supply chain leader characteristic (Mentzer et al., 2001)).

Communication with many organizations

Due to organizing the whole chain from raw material to final drift detectors, various organizations are involved. Malvern Panalytical needs to communicate with all these organizations since they are the supply chain leader. This communication is time-consuming since it is mainly personal communication via phone or e-mail.

Varying actual internal and external yields

Final products or half-manufactures can be rejected after several process steps within the supply chain. The rejected products influence the yield. For both internal and external yield, an estimated value is used for planning purposes that is based on historical data. Thus, the ordering suggestions created by MRP considers this calculated yield. For example, when nine products are needed and the calculated yield of that product is 0.90 Malvern Panalytical needs to order ten products in total. In reality, it will be most likely that one product will be rejected in a batch, but it can vary. Thus, the estimated yield can vary, which we are referring to as the varying actual yield.

Since both external processes at suppliers and internal processes at Malvern Panalytical copes with yield, we distinguish between external and internal yield. First, Malvern Panalytical has to deal with the external yield of its suppliers as a result of controlling the whole chain. The actual external yield often deviates from the value that is used for planning the orders, increasing uncertainty in supply. The uncertainty in supply has some long-term causes that are undesired. Namely, stock-outs if the actual yield is lower than the calculated yield or accumulation of stock if the actual yield is higher than the calculated yield. Especially when the actual yield is lower than the preset value, the correcting and responding tasks are more time-consuming. The internal yields are within the production facilities of MP Almelo and Eindhoven. Similar to the external yield, the actual internal yield often fluctuates and therefore increases uncertainty in supply and results in more time-consuming follow-up tasks.

3.2.2 Internal and external supply disruptions

Supply disruptions can occur for both buy parts (i.e. external), half-manufactured products at suppliers (i.e. external), and half-manufactured products at Malvern Panalytical (i.e. internal). These disruptions can cause delays in the production of PODDs. Supply disruptions are, for example, not delivering on time or delivering fewer products than demanded. Malvern Panalytical also faces challenges with suppliers of some of the key PODD components that can cause supply disruptions. The supply of the cube and peltier is insecure in the future. First, the supplier of the cube is recently acquired by a competitor of Malvern Panalytical, which is not an immediate problem. However, it could become one if that company decides not to collaborate with its competitor (i.e. Malvern Panalytical) anymore. For more certainty of supply in the near future, Malvern Panalytical has consignment stock in their warehouse at MP Almelo. Consignment stock is by the supplier (i.e. supplier of the cube) owned inventory that is stored at the customer (i.e. Malvern Panalytical) until it is consumed (Corbett, 2001). Second, there are two suppliers for the peltier. However, Malvern Panalytical decided to temporarily not cooperate with these companies anymore for confidential reasons, resulting in high uncertainty for the supply of the peltier for the PODD. Therefore, Malvern Panalytical is currently searching for a new peltier supplier.

3.2.3 Manually prioritizing and testing downstream

Another challenge within the supply chain is that the ingot changes per batch. Therefore, the quality of the every ingot batch needs to be verified before continuing production with this ingot. The production of a sensor chip for the new ingot batch needs to be prioritized over the previously used ingot for testing purposes. The prioritization needs to be performed at multiple suppliers, which also results in a time-consuming management burden because this needs to be communicated to each supplier by the Detector Physicist. After communication, the batch number needs to be tracked and evaluated at MP Almelo after the X-ray test.

3.2.4 Decentralized planning at MP Almelo and Eindhoven

Multiple employees are responsible for the planning of purchasing, manufacturing, and distributing orders. A separate planning domain in the Enterprise Resource Planning (ERP) is used for both Eindhoven and Almelo, which need to be consistent. The planning concerning the PODD at MP Almelo is managed by the Supply Chain Engineer and in Eindhoven it is managed by the Planner. The planning is made based on MRP logic and is created about half a year in advance. If a change needs to be made in the planning of one domain, the planning of the other domain needs to be adapted too. To explain this more concretely, the following example is given: if the actual number of PODDs produced changes at MP Eindhoven because of e.g. the yield, the result is that the number of PODDs that will be transported from Eindhoven to Almelo needs to be manually adapted in the shipment planning. This increases the management burden for the employees involved in the ordering, production, and shipment planning at both locations.

3.2.5 Manual order decisions

Planning for ordering in the first two parts of the supply chain is not automated in the ERP system. Although the orders within the first two parts of the PODD supply chain are incorporated in the ERP, it is impossible to directly rely on triggers generated by the MRP. This is a result of the strategic and human decision-making that is necessary. As a result, ordering decisions are partly based on these triggers but mainly made by the PODD team. These decisions are often made after multiple meetings, which increases the management burden. This is a difference from the more automated planning used at Malvern Panalytical, which in almost all cases, directly follows up the triggers generated by the ERP.

3.2.6 Manually tracking and managing inventory at Company D

As mentioned, a part of the stock of the four key components is physically located at CD. The planning to refill these stocks is not automated. The responsible employee tracks the inventory level at CD manually based on information in the ERP that indirectly shows the stock level at CD. Thus, stock levels at CD are not transparent or easily accessible for Malvern Panalytical. Physically counting the components is not easily accessible and requested to be performed once a year. If the inventory is not sufficient to produce the orders for a certain period, the employee manually determines the number of components shipped to the suppliers and requests a warehouse employee at MP Almelo to send them. The number of components shipped can vary between each component type due to a varying BOM. For example, the NTC and cube are used in every assembly, however, the collimator and peltier have a different type for PODD type I or type II. While the stock levels at CD are checked manually, the stock levels of the buy-parts (i.e. collimator type I and type II, NTC, header for PODD type I and type II, and cube) that are stocked at MP Almelo are controlled by MRP. The stock level at MP Almelo of the assy header type I and type II also is monitored manually. Summarized, maintaining sufficient inventory for the four key components at CD and for the assy headers at MP Almelo is a time-consuming process where multiple employees are involved. Thus, this significantly increases the management burden of the PODD supply chain.

3.2.7 Manual handling of return packaging process

Another process that is not automated that results in problems and increased management burden is the cyclic process of return packaging. This cyclic process often fails to result in a shortage of reusable packaging. Then, for example, the production department at MP Eindhoven has to wait for the return of packaging when the packaging is not sent on time from MP Almelo to CD to be refilled and send via MP Almelo to Eindhoven. In some cases, the return packaging was even lost somewhere in the process. The purchasing process of the packaging is not automated, since nothing about the return packaging is included in the ERP system. Besides, ordering new return packaging is avoided as much as possible since it is a custom-made product that is very expensive.

3.2.8 Limited production capacity at MP in future

Currently, production and supply capacity is not yet a problem in this supply chain. However, future capacity problems are expected because of the growth in production and therefore investigated in various interviews. Since the supply chain consists of multiple organizations and two different internal production locations, three interviews are conducted to cover the whole supply chain. First, the Strategic Buyer of the PODD supply chain is interviewed about the suppliers. In this interview, it is found that the suppliers in the first part of the supply chain (i.e. CA until CC) will have more than enough capacity. Since the IOQ is relatively high in this part in comparison to the demand it will not become a problem. The process steps executed by CD need to be expanded in the future. CD is able to expand these capacities so it would not be a bottleneck. For the suppliers of the four key components, it also will not be a problem. Again, the minimum quantities to order are high relative to the number of units needed. Malvern Panalytical orders small volumes in comparison with other customers of the suppliers. An Operator and Process Engineer are interviewed regarding the capacities at MP Almelo and Eindhoven respectively. It is found that at both locations one machine will become a bottleneck in future facing the growth in production.

3.3 Challenge selection

This section first explains each problem from Figure 3.1 to what extent the problem can be addressed within the span of control of Malvern Panalytical. Afterwards, the remaining problems are evaluated on the business impact and a selection is made accordingly considering the feasibility versus the relevance.

3.3.1 Challenges out of control

As explained in Section 3.1 we first filter the problems that are out of control for Malvern Panalytical. As visible in Figure 3.1, six problems are not within their span of control. First, *'suppliers difficult to replace'* is out of control and is a condition they have to deal with. The relationship with the supplier or partnership must remain because there is little to no substitution of some suppliers. This means that Malvern Panalytical cannot address the root of the problem, however, they can react to the problem by for example having the supplier as a strategic partner or maintaining the relationship with the supplier. Nothing is mentioned about difficulties with maintaining the relationship with suppliers or partnerships. Therefore, we assume that this is not a problem. Thus, the problem 'suppliers difficult to replace' will therefore not be selected. Second, *'dependency on high lead times'* is out of control for Malvern Panalytical since these are hard conditions of the suppliers and cannot be easily shortened. Malvern Panalytical is already reacting to the high lead times by planning orders in advance and having intermediate stocks, such that they can improve the flexibility of the supply chain and the ability to deliver orders from stock. Third, the problem *'dependency on high IOQ of first supplier'* is out of control because the IOQ is a hard requirement of the first supplier. Implying that the supply chain needs to deal with this condition. As mentioned, the high IOQ results in order sizes that satisfy several years of demand. However, since the demand for the PODD will significantly increase, the period that the order size will satisfy is going to decrease. Therefore, the need to cope with this problem will become less important because the gap will become smaller. Since we cannot change the IOQ and the problem will already automatically become smaller, it is decided not to further investigate on this matter. Second, *'varied actual external yields'* are out of control because this depends on the production processes at the external suppliers. Changing these production processes is not within the span of control of Malvern Panalytical, so it is only possible to cope with varying yields. Fifth, the challenge regarding *'external supply disruptions'* is out of control because these disruptions occur at the supplier. Malvern Panalytical has to react to disruptions and does not have the ability to prevent them because this is out of its control. Lastly, *'changing ingot'* is out of control for Malvern Panalytical since this is a characteristic of the production process of ingot at CA. Malvern Panalytical can react to this problem by performing an X-ray test at the end of the production process of the PODD. It could be questioned whether this test can be performed earlier within the supply chain in order to have the test results available earlier. The remaining problems as shown in Figure 3.2 are problems considered to be within the span of control for Malvern Panalytical.

3.3.2 Challenges within span of control

After the problems are categorized as being in or out of control for Malvern Panalytical, the selection procedure continued based on the problems within the control of Malvern Panalytical. The selection is done by discussing all the problems using the cause-and-effect diagram as guidance with various experts that are stakeholders of the PODD supply chain. The outcomes of

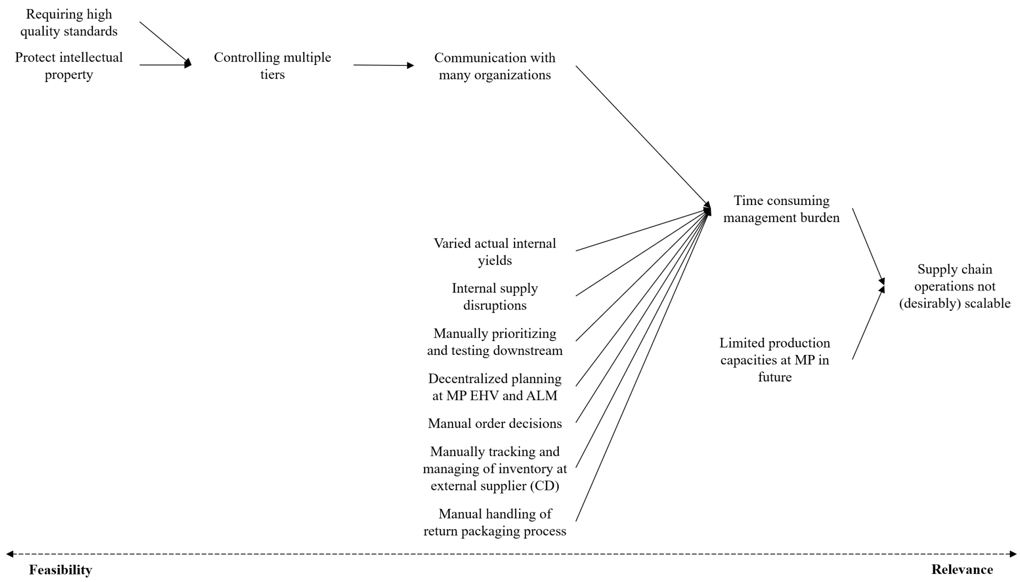

Figure 3.2: Cause-and-effect diagram of the problems within the span of control

the interviews are summarized below. First of all, *'requiring high quality standards'* and *'protect intellectual property'* are not selected since these topics are not within the field of supply chain management. Since the scope of this project focuses on the tactical and strategic level, the problems of *'varied actual internal yields'* and *'internal supply disruptions'* are also not selected since this is related to the operational level. The *'limited production capacities at MP in future'* is decided to be a problem requesting a pragmatic solution, which is not fulfilling the expectations of a Master thesis project for Malvern Panalytical. Besides, this problem does not belong to the supply chain management structure, thus it will not fit this research. However, it is appointed because it will be a bottleneck for the scalability of this supply chain. In all interviews, it is found that the problem that the *'supply chain is not (desirably) scalable'* is majorly caused by the fact that the PODD supply chain has a *'time-consuming management burden'*. Thus, it is most relevant for Malvern Panalytical to address this problem and its causes. The six remaining problems that cause this are *'controlling multiple tiers'*, *'manually prioritizing and testing downstream'*, *'decentralized planning at MP EHV and ALM'*, *'manual order decisions'*, *'manual tracking and managing of inventory at external supplier (CD)'*, and *'manual handling of return packaging process'*. All these problems are time-consuming in terms of man-hours since the tasks are majorly performed manually. Therefore, it is studied which problems have the most impact on reducing the management burden. We decided that all remaining problems are relevant to Malvern Panalytical and also desirably feasible since these problems are left-hand-sided. *'Manually prioritizing and testing downstream'* occurs every time a batch of the new ingot is introduced, which is only once in a few years. Thus, addressing this problem will not decrease the management burden regularly and is therefore not selected for this project. The problem regarding *'manual order decisions'* requires human interaction since strategic decisions must be made. Strategic decisions are necessary in the first part of the PODD supply chain since innovations and changes need to be incorporated in the mask design of the wafer. Also the sensor chips require strategic decisions because of the strategic stock that is located on this level. We end with three problems that are considered to have the most impact in reducing the management burden; *'communication with many organizations'*, *'decentralized planning at MP EHV and ALM'*, *'manually tracking and managing of inventory at external supplier (CD)'*, and *'manual handling of return packing process'*.

We decided to select the problems *'decentralized planning at MP EHV and ALM'* and *'manually tracking and managing of inventory at external supplier (CD)'* for further plan of action. The first reason is that these tasks majorly influence the management burden for the responsible employees. Second, the supply chain is initially designed this way many years ago for various reasons. However, several things in the supply chain environment are changed over the years that make the initial reasoning (partly) irrelevant. Regarding *'decentralized planning at MP EHV and ALM'*, it was mentioned that the processes are divided over the plants at MP Almelo and Eindhoven. This was in alignment with the strategy of Malvern Panalytical because the process steps best suited the specializations of these different plants. The company already considered to start a project to change this. However, no detailed research is done yet. Therefore, it is relevant to select this challenge for this research. In one of the interviews, most of the initial reasons to control the process of *'manually tracking and managing inventory at the external supplier (CD)'* in-house were explained. As well as the changes that have been endured that make it no longer necessary to manage it in-house. Third, these problems will face different challenges and requirements that need to be studied in comparison with other identified problems. Therefore, combining these two problems can lead to multiple solution directions. Lastly, the two selected problems both belong to the order management process. Thus, there is potential that the problems could be addressed simultaneously within one solution.

To conclude, the decision is made to focus on the supply chain management structure related to the *'decentralized planning at MP EHV and ALM'* and *'manually tracking and managing of inventory at external supplier (CD)'*. These problems are incorporated in part 3 of the PFD as shown in Figure 2.5. The process related to the first problem starts at MP Almelo with the cross-docking process until the final drift detectors are stocked at MP Almelo as shown in Figure 2.6. Figure 2.4 shows the parallel process, which is related to the second selected challenge. Note that, the procurement of the general components that are used in production at MP Almelo and Eindhoven are out of scope while improving the order management process flow. We made this decision since this process is a regular purchasing process performed by strategic and operational buyers where no challenges are expected in the span of control of this project.

Chapter 4

Improvement of the order management process

This section aims to answer the research questions from the plan of action phase (i.e., *RQ.4*, *RQ.5*, *RQ.6*, and *RQ.7*). First, Section 4.1 explains the concept of Business Process redesign. Second, the approach to reconsider the supply chain management structure is explained in Section 4.2. The main goal of restructuring is to lower the management burden of the order management process. By executing the approach, the research questions are answered. Section 4.3 provides an analysis of the current order management process. This answers *RQ.4: What performance measures can be selected to evaluate the most impactful challenges?* and *RQ.5: Based on these measures, what are the performances of the supply chain with the current demand and forecasted future demand?*. The performances of the current situation are used to benchmark the redesigned situations. Section 4.4 to Section 4.7 answer *RQ.6: What organizational changes are necessary for the PODD supply chain to cope with the most impactful problems and to improve the performances?* and *RQ.7: How shall the changes be implemented within the current infrastructure?*. Answering is done by selecting BPR heuristics and evaluate if the supply chain management structure can be improved with these redesigns. For each redesign, the consequences for implementation are listed.

4.1 Business process redesign

The range of solution concepts to improve the order management process is studied with the support of the BPR framework and its best practices. The framework that is selected can be used as a guideline to structure a BPR initiative by supporting the investigation of all necessary directions before applying a redesign (Reijers & Mansar, 2005). The framework is shown in Figure 4.1 and consists of seven components, namely customers, products, business process operation, business process behavior, organization, information, technology, and external environment. We found that each BPR component is related to one or more components from the supply chain management model of Mentzer et al. (2001). Therefore, we conclude that the BPR framework can support with improving the supply chain management structure. This section further explains the best practice heuristics in Subsection 4.1.1 and an evaluation of the performances as found in literature in Subsection 4.1.2.

4.1.1 Redesign heuristics

Within BPR, 29 best practice business cases are included as shown in Table C.1 in Appendix C. The best practices, also called redesign heuristics, can be applied to improve business performance by adapting an existing business process. The evolutionary approach (i.e., adapting the existing process) is the most used approach to develop an improved business process instead of the revolutionary approach (i.e., designing a process from scratch) (Reijers & Mansar, 2005; Jansen-Vullers

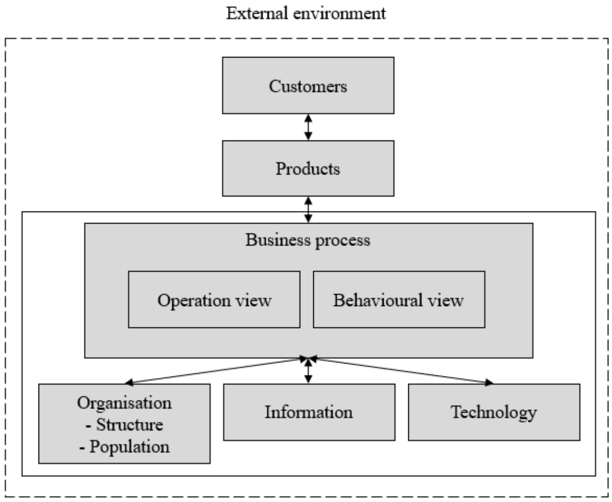

Figure 4.1: BPR framework adapted from (Reijers & Mansar, 2005)

et al., 2008). The best practices presented in the paper are mostly gathered from experiences in large companies or consulting firms engaged in BPR projects. Although many best practices exist, a lack of adequate (quantitative) support is identified in practice. While in literature, the best practices are mainly quantitatively evaluated using the devil's quadrangle by considering four dimensions (Reijers & Mansar, 2005). Brand & Van der Kolk (1995) distinguishes the four dimensions cost, time, quality, and flexibility.

The best practices are categorized based on the seven components of the BPR framework. However, an existing process is required for redesigning. Therefore, there is no best practice category distinguished for products while it is addressed in the framework. This concludes six categories for the best practice heuristics. Table 4.1 shows each category and its focus. These categories are not exclusive since one best practice could be focused on several categories. The best practices for each of the categories are given in Table C.1 in Appendix C. The best practices can be applied in various types of industries, among them the manufacturing sector and service sector (including administrative processes). We think that the order management process is comparable with administrative processes since both consist of procedures in which decisions are made that are carried out by human to control a process. Therefore, the challenges found within the PODD supply chain could benefit from the BPR heuristics.

Table 4.1: Best practices categories concerning the BPR framework of Reijers & Mansar (2005)

Category	**Focus**
Customer	Customer contact
Business process operation	Workflow implementation
Business process behavior	Timing of workflow execution
Organization	Allocation, type, and number of resources
Information	Information (may) used and (may) created
Technology	Technology (may) used
External environment	Collaboration and communication with third parties

The study of Mansar & Reijers (2007) continues with the framework and 29 best practices of Reijers & Mansar (2005) (i.e., their own research). The purpose of the follow-up research is to find indications for the actual application and qualitative impact validation of the best practices in real-world BPR implementations. They selected the top ten best practices based on popularity in two case studies performed by other researchers and used their literature review by reviewing the number of cites of a best practice. The top ten best practices are task elimination, task composition, integral technology, empower, order assignment, resequence, specialist-generalist, integration, parallelism, and numerical involvement. With the support of an online survey, the application and impact in practice of these ten best practices is tested and validated. The survey was conducted in the early 2000s and had 25 respondents with, on average, 15 years of experience from different industries in The Netherlands and the United Kingdom. In Table C.1 in Appendix C, the top ten is marked with a number, indicating the ranking of the best practice in the top ten. The top ten best practices are from the framework components customer, business process operation and behavior, organization structure and population, and technology. In other words, the categories of information and external environment are excluded from the top ten.

4.1.2 Redesign heuristics performances

The devil's quadrangle with the four dimensions distinguished by Brand & Van der Kolk (1995) is widely used in studies about BPR. In the best case situation, the redesign of a business process decreases necessary time and cost and increases quality and flexibility (Reijers & Mansar, 2005). However, improving a dimension could lead to the deterioration of another dimension, which can be even worse than in the existing business process. That is why this model is called the devil's quadrangle, by creating awareness of trade-offs due to redesign. For example, the parallelism heuristic results in theory in a reduced process duration (i.e., time). However, implementation is very expensive due to the investment in new technology that is required to perform tasks simultaneously (Mansar & Reijers, 2007). As discussed in the previous section, Mansar & Reijers (2007) benchmarked real-world performance outcomes of ten heuristics on the theoretical results of Reijers (2003). Surprisingly, many of the best practice results deviate while comparing the survey feedback and theoretical estimation. Deviating survey results appear to be more positive than the theoretical findings. The explanation of the differences between the theoretical and survey results mainly is the fact that participants were referring to different examples of BPR applications since each best practice can be applied in several contexts. This implies that there still is a lack of knowledge in how, when, and where to apply a best practice heuristic. Therefore, we can conclude that any of the 29 BPR heuristics should be considered regardless of the results that have previously been found in either theoretical or practical results.

4.2 Approach for business process redesign

Although Reijers & Mansar (2005) developed a framework to structure BPR best practices, the previously mentioned studies do not provide explicit quantification of the best practices. Jansen-Vullers et al. (2008) identified that there still is a deficiency of a comprehensive approach to quantitatively evaluate the effectiveness of best practices. There only exists a small number of performance dimensions and a few aspects for each dimension. Therefore, their study aims to quantify the impact of redesign heuristics by focusing on business process performances. After considering six performance measurement systems, five dimensions of performance are selected. Namely, time, cost, external quality, internal quality, and flexibility. All dimensions are presented in the devil's quadrangle of Brand & Van der Kolk (1995), which is also used in the studies of Reijers & Mansar (2005) and Mansar & Reijers (2007). The quantification approach developed by Jansen-Vullers et al. (2008) consists of eight steps, namely (1) project definition, (2) defining and modeling the current situation, (3) model validation, (4) defining and modeling the redesigned situation, (5) experimental design, (6) Execution of simulation runs, (7) output analysis, and (8) conclusion. A similar approach was already applied by Reijers (2003). Three of the best practices identified by Reijers & Mansar (2005) were used while testing the quantification approach, namely parallelism, knockout, and triage. Unexpected and counter-intuitive outcomes on the dimensions of the devil's quadrangle were found compared to the qualitative evaluation results of prior studies

(Jansen-Vullers et al., 2008). A potential explanation of this finding is that there is a difference in the level of detail of these studies since these qualitative results were based on expectations and rules of thumb (Jansen-Vullers et al., 2008). The quantification approach seems very beneficial, although it also has some practical implications resulting in a deviating approach that is necessary for this research. This is decided based on three reasons found in practical implications identified by Jansen-Vullers et al. (2008). First, the simulations used seem infeasible for the order management process because the process and its redesigns are much more complex than the one in the paper. Jansen-Vullers et al. (2008) already mentioned that simulating was very time-consuming and many simulation runs were required. While they tested only three redesigns on a flexible process of just six sequential activities. Second, they did not succeed to include the quality aspect within their simulation, while for our research the internal quality is selected to include. Thus, we need an alternative way to include internal quality. Third, the approach is only tested on very straightforward redesigns and with only one best practice at a time. However, testing combinations of two or more redesigns is preferred in practice (Jansen-Vullers et al., 2008).

We can conclude that executing the existing quantitative approach of Jansen-Vullers et al. (2008) does not totally match this research and business case. Accordingly, we developed an approach that fits our research. The approach is a mixed approach by combining both quantitative and qualitative aspects. First, we chose to quantify the performances using mathematical calculations, instead of a simulation that is validated through mathematical calculations as in the research of Jansen-Vullers et al. (2008). We decided that estimated results based on ERP order data, forecasts on order demand, and estimated deterministic values are sufficient to make a comparison between redesigns and the current situation. Second, there are a lot of consequences and trade-offs to implement a redesign in practice that cannot be easily quantified. Therefore, we added the identification of those qualitative results that also needs to be considered while comparing redesigns. Additionally, we added the possibility to define and evaluate combinations of redesigns as suggested by Jansen-Vullers et al. (2008). Figure 4.2 shows the adapted approach and its seven steps are briefly explained below. The execution of the approach is explained in the remaining of this chapter.

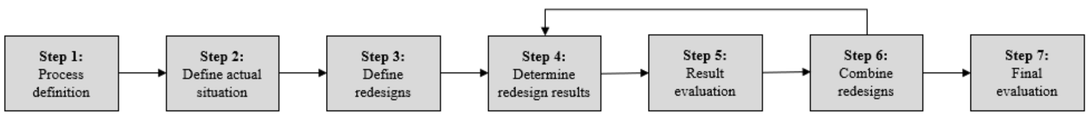

Figure 4.2: Approach to identify the most beneficial redesign possibilities of a business process

Step 1: Process definition. The first step is to collect evidence to accept the hypothesis that redesign is necessary, the subsequent steps will follow after accepting the hypothesis. This step is already comprehensively executed in the prior chapters. The evidence is summarized based on the arguments to redesign a workflow that is dysfunctional (e.g., high ratio of controls and iterations or many procedures for exception handling), the importance of workflows (e.g., critical success factors for the company), and redesign feasibility (e.g., when expected costs become less) (Reijers, 2003). First, the order management of the PODD supply chain is dysfunctional since many tasks need to be performed manually and visibility is lacking due to decentralization. Second, the importance of the workflow will highly increase because of the significant growth in future demand. Lastly, the redesign feasibility can be expressed as the expectation that the time-consuming management will decrease.

Step 2: Defining and modeling the current situation. The current situation can be defined based on five sub-steps.

Step 2.1: Map current process. First, the current order management process is mapped by creating models that help to understand and visualize the process. We modeled the supply chain with PFDs as explained in Chapter 2. The order management process is modeled using Business Process Model and Notation (BPMN) diagrams. With BPMN, all successive and parallel manual tasks and occurrences of the order management process can be modeled and allocated to the responsible employee (i.e. task owner) showing task relations.

Step 2.2: Model validation. The PFD and BPMN diagrams are validated with interviews with PODD supply chain stakeholders and the diagrams are adapted until they represent reality.

Step 2.3: Select performance measures. The performance measures are selected to compare the current and redesigned situations. The selection will be done based on literature, knowledge gained during the project, and data availability.

Step 2.4: Data collection. The necessary information and data is collected via interviews and the ERP to determine the performances set in step 2.3.

Step 2.5: Determine performances of current situation. The performances of the current situation are determined based on the collected data from step 2.4 and performance measures set in step 2.3.

Step 3: Defining the redesigned situations. The redesigned situations are developed following two sub-steps.

Step 3.1: Identify and model redesign possibilities. Potential redesigns for the PODD supply chain can be accomplished in two ways, namely directly and indirectly. With directly, we imply that the order management process (i.e., BPMN diagrams) needs to be changed. With indirectly, we mean that the supply chain (i.e., the PFD)) needs to be changed, which affects the order management process. Thus, for direct redesigns, we change the BPMN diagrams and for indirect redesigns, we change both the PFD and BPMN diagrams. The selection of possible redesigns will be done with the support of the framework of Reijers & Mansar (2005). As mentioned in Section 4.1, the framework can be used as a guideline to structure a BPR initiative by supporting the investigation of all necessary directions. Thus, all 29 redesign heuristics are discussed with experts to decide whether they can be directly or indirectly applied. Additionally, the experts were questioned about other redesign possibilities to ensure that we have a complete set of redesigns.

Step 3.2: Indicate implementation requirements. To be able to implement the redesigns, changes in the current supply chain and supply chain management structure are required. The implementation requirements are important trade-offs.

Step 3.3: Validate the redesigns. Iteratively validate the PFD and BPMN diagrams with experts and adapt the diagrams until the redesigns represent the expected situation.

Step 4: Determine performances and collect qualitative results of the redesigns. The results consist of quantitative (i.e., performances) and qualitative results and are determined in three sub-steps.

Step 4.1: We conducted interviews to question employee satisfaction with the current situation and the redesigned situations. The interviewees are the three key-users of the order management process.

Step 4.2: The performances defined in step 2.3 can be determined for all the redesigned situations based on the collected data from step 2.4 and the redesigned BPMN diagrams from step 3.

Step 5: Result evaluation. Evaluate findings of both the qualitative and quantitative results from step 4. Thus, provide an evaluation of the performances for each redesign and findings on employee satisfaction.

Step 6: Combining of redesigns. Combinations of redesigns need to be tested to obtain a more complete set of redesign possibilities, as suggested for further research by Jansen-Vullers et al. (2008). Investigate which redesigns from step 3 can be combined using the output analysis from step 5. These redesign combinations should be tested following step 4 and step 5.

Step 7: Final evaluation. After performing the prior steps, conclusions can be drawn based on the evaluation of step 5 for both the initial redesigns and the redesign combinations. Additionally to the performance analysis, changes that are necessary to implement a certain redesign are listed. These implementation consequences are valuable for the company to be able to make an informed decision about which redesign(s) can be considered for further investigation before actually implementing them.

4.3 Step 2: Defining and modeling the current situation

This chapter continues with step 2 since step 1 is already executed in the prior chapter. In this section, the execution of sub-step 2.1 until 2.5 is explained.

4.3.1 Step 2.1: Map current process

To understand the current process, both the supply chain and order management processes are mapped. The supply chain is mapped in Section 2.2 using PFDs in Figure 2.4 andFigure 2.6. The BPMN diagrams of the as-is order management process are shown in Figure 4.3, Figure 4.4, and Figure 4.5. As mentioned, we only focus on the third part of the order management process, in which the material purchasing and work orders of the assy header stacks until the final detectors are managed. For completeness, the order management process of Part 1 and 2 are included in Appendix B.

The BPMN diagrams show that five resources are involved in the order management process of part 3, namely the Supply Chain Engineer, Strategic Buyer, Planner, Warehouse Operator at MP Almelo, and Warehouse Operator at MP Eindhoven. The BPMN diagrams show the interactions between the resources and the responsibilities of the resources. All parts together consists of 39 tasks, of which the Supply Chain Engineer is responsible for the majority of the tasks (i.e., 22 out of 39 tasks). The Supply Chain Engineer is responsible for external and internal work orders and inventory control of the MP Almelo domain. The Strategic Buyer is responsible for external purchase orders of the MP Almelo domain. The Planner of MP Eindhoven is responsible for internal work orders of the MP Eindhoven domain. Lastly, each domain has its own warehouse operators. From the BPMN diagrams, it can be seen that in both domains work orders can be released. In part 3.1 and 3.2 in Figure 4.3 and Figure 4.4, work orders to external suppliers are released. As shown in these diagrams, several routine administrative tasks follow. While in the Eindhoven domain, work orders that are released are internal work orders and do not follow these administrative tasks. These administrative tasks are automatically performed by the ERP system in the Eindhoven domain.

The following modeling choices are made regarding the BPMN diagrams:

- **BPMN setup:** The order management process of part 3 is visualized in three different BPMN diagrams based on three different parts within the order management process. Namely, part 3.1: Order management process of the key components, part 3.2: Order management process of the assy header stacks at CD, and part 3.3: Order management process of the PODDs and drift detectors internally at Malvern Panalytical. The latter has two separate BPMN diagrams within one diagram as further explained in the next item. Thus, we end up with four different process models since these processes can be performed in parallel and can start at different moments. Additionally, the processes are dependent on each other. The components ordered in part 3.1 are necessary to produce the assy header stack ordered in part 3.2. The assy header stack is necessary to produce the PODD in part 3.3. Finally, the PODD is necessary to produce the drift detector in part 3.3.

- **BPMN start:** The starting points of the BPMN diagrams immediately follows a trigger of the ERP system based on the MRP-logic. Each ERP trigger is assigned to a specific employee, who is executing the start of the process. The employee periodically reviews the ERP to check if there are any notifications. Note that all semi-finished products from Figure 2.6 have an ERP trigger. However, the trigger for tested assy header stacks is not modeled because the actual trigger to release this work order is when the warehouse operator from MP Eindhoven verbally notifies the receiving of the assy header stacks. Finally, the number of times the four processes are executed also depends on the number of ERP triggers. This model choice will support the determination of performances in the next step.

- **Component availability feedback loop:** The availability of the BOM is checked before a work order can be released. This check is necessary because the components/half-manufactured products are at the location as WIP only, thus there is no planned stock of the half-manufacture required to continue production. Resulting in feedback loops in case the half-manufactured products are not available yet because of e.g. a delay in supply. Thus, feedback loops are included in both internal order management of the PODD and drift detector to investigate the status of assy header stacks and PODDs respectively. In case of an unavailable item, the waiting icons display which steps of the prior order management process still need to be executed. In practice, these feedback loops can occur repetitively, but for simplicity reasons, we assume that a feedback loop can occur only once for each work order. Additional tasks need to be executed in case the work order can not be released immediately. For example, the feedback loop after the ERP trigger for PODDs consists of up to six additional tasks. Note that if all six activities of this feedback loop need to be performed, the total time spent on order management will highly increase since it is found that the task times to perform the activities in the feedback loops are much higher than the activities to check the BOM availability, release the work order, and create a shipment order. This also holds for the feedback loop after the ERP trigger to order drift detectors. We conclude that the impact on the performances is immediately noticeable after going through a feedback loop once.

- **Assume 100% availability of buy-parts:** The buy-parts within the PODD supply chain are the four key components and the general components. Since order management of the general components at MP Almelo and Eindhoven are out of scope, we assume that general components are always in stock. For the key components, the feedback loop as explained above is not necessary for the current situation. We can assume that there are always sufficient key components available at MP Almelo, which is a reasonable assumption since there is a relatively high inventory for these components. Thus, all general and key components are available at MP. Therefore, we assume a 100% availability for this analysis and neglect potential supply disruptions. The assy header stack that is produced at CE is not a buy-part but we made the same assumption for this part.

- **Excluded waiting times in diagrams:** We focus on decreasing the management burden of the order management process. Therefore, we decided to exclude the waiting times which the order management processes depends on. For example, the time necessary to produce and ship products. We show them in the BPMN models for completeness but we will not take them into account in the calculations.

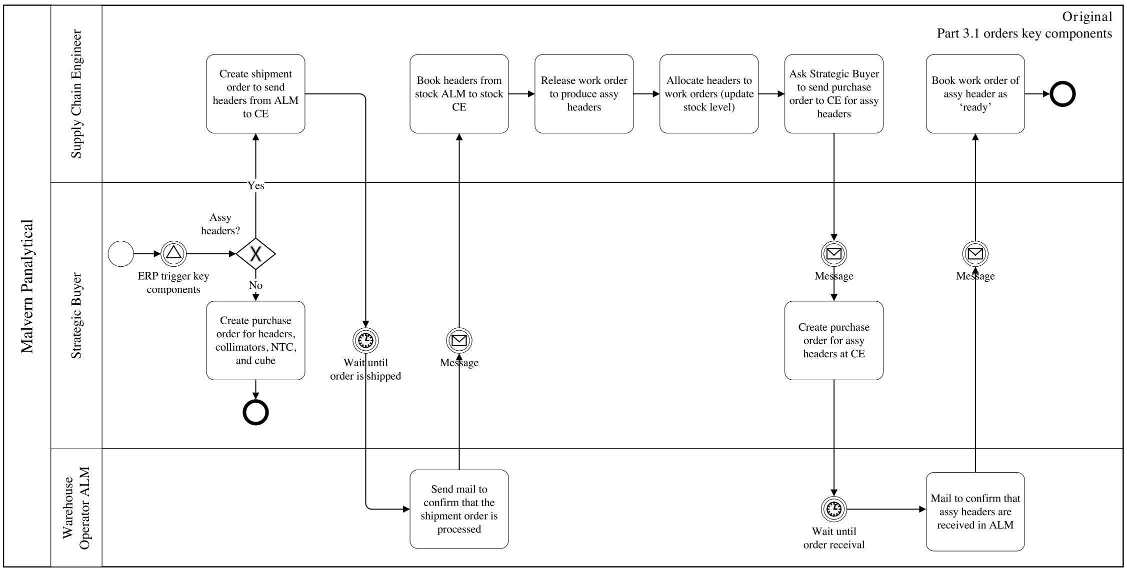

Figure 4.3: BPMN part 3.1: Order management process of the key components (P1 in PFD)

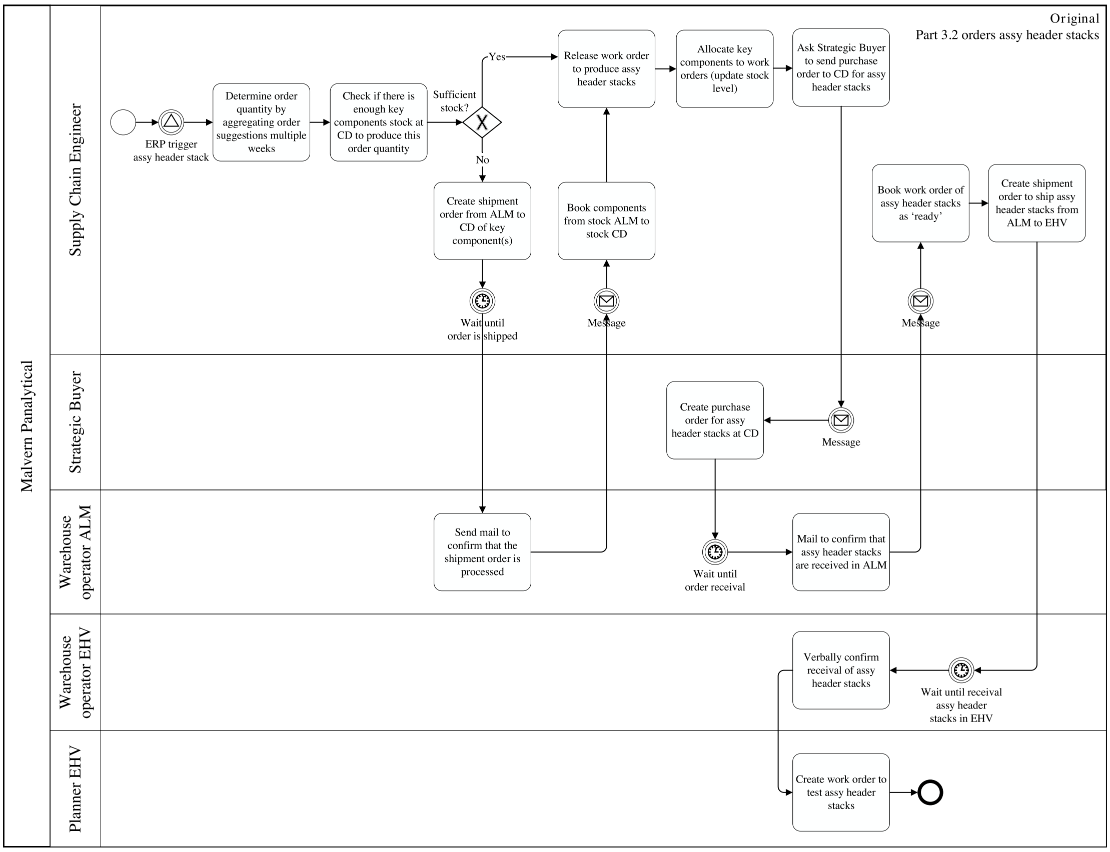

Figure 4.4: BPMN part 3.2: Order management process of assy header stacks at CD

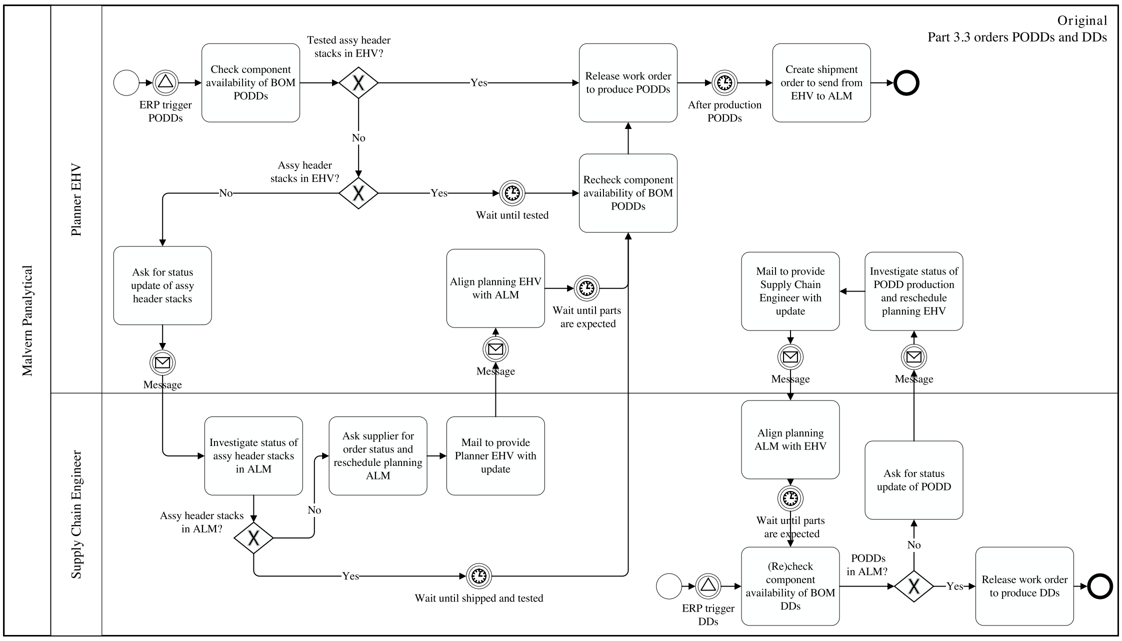

Figure 4.5: BPMN part 3.3: Order management process of the PODDs and drift detectors (DDs) internally at Malvern Panalytical

4.3.2 Step 2.2: Model validation

Before continuing with the subsequent steps the models are validated by experts at Malvern Panalytical. Both the PFD and BPMN diagrams are iteratively improved until we decided that the models accurately represent reality. The PFD is discussed with five stakeholders and the BPMN diagrams with three stakeholders.

4.3.3 Step 2.3: Performance measure selection

To compare the current situation and the redesigned situation we need performance measures. A single measurement ignores important interactions between supply chain characteristics and critical aspects of organizational strategic goals Mentzer et al. (2001). We are coping with the characteristics of the PODD supply chain and the organizational strategic goal that we want to lower the management burden of its order management process. Therefore, it is important to select more than one performance measurement and not only the time aspect that directly is related to the management burden. Strategic goals of an organization focus on the measurement of resources, output, and flexibility (Beamon, 1999). Beamon (1999) found that resource and output measures are widely applied within the supply chain. Flexibility is less frequently applied, while there are numerous benefits to having a flexible supply chain. A flexible supply chain as referred by Beamon (1999) is comparable to the agile supply chain strategy which most fits the PODD (Lee, 2002). The framework of Beamon (1999) incorporates all three measurement types of strategic goals, with the objective to inclusively measure the overall performances of a supply chain. Because the measurement types of resources, output, and flexibility are interconnected, Beamon (1999) states that the supply chain performance measurement system must include at least one measure from each.

Focusing on the order management process, we want to improve the management burden by minimizing the time spent on related activities. We have to consider that an improvement in time measure, can negatively or positively affect the result of other performances. Therefore, to inclusively measure performances we need to select more than one measure as stated by Beamon (1999). By selecting more than one measure, we can present trade-offs that have to be made. Three measures are selected and are shown in Table 4.2. The frameworks of Beamon (1999) and Brand & Van der Kolk (1995) can be compared regarding the included categories and the goal to show potential trade-offs. The selected measures are within the resources and output categories of Beamon (1999), which are overlapping with the cost, time, and quality elements of the devil's quadrangle Brand & Van der Kolk (1995). We further continue with the time, cost and quality dimension from Brand & Van der Kolk (1995). Although the flexibility category is included in both frameworks, we did not selected a measure in this category. As confirmed by the literature, it is difficult to quantitatively measure flexibility Beamon (1999). The PODD supply chain faces some inflexible characteristics due to the high IOQs of suppliers and batch sizes, however, it tends to be rather flexible. Flexibility types as defined by Jansen-Vullers et al. (2008) are used for evaluation. First, the PODD supply chain has mix flexibility, which is the ability to processing different kinds of products (i.e., four different PODD types and the flexibility to add a fifth one). Second, the production operators provide labor flexibility, which is the ability to perform different tasks. The operators at Malvern Panalytical are able to execute multiple different tasks for the PODD production and production of other products. This also holds for the warehouse operators. Additionally, the order management is flexible by the fact that we can assign tasks of the Planner to the Supply Chain Engineer and vice versa. The purchasing tasks can be performed by a Strategic Buyer or Operational Buyer, this depends on e.g. the importance of the components. Lastly, there is process modification flexibility, which is the ability to modify the process. Due to process modification flexibility, we are able to redesign the current supply chain and its order management process in several ways, which will be further explained in Section 4.4. Although measuring flexibility is excluded, we should maintain the mix flexibility of the supply chain, while utilizing labor flexibility and process modification flexibility.

Selecting performance measures

The order management process is one of the primary operations that connect companies within a supply chain (Hugos, 2018). Order management is a subset of supply chain management and is related to many traditional business activities via the information flow Mentzer et al. (2001). Thus, we are focused on a specific part of supply chain management. This implies that the performance measures we aim to select differ from performance measures to measure the supply chain performances as a whole (e.g., lead and throughput time, running costs, inventory costs). Considering the context characteristics of the order management process and the goal for the redesign, we selected two measures as a base for comparison. The first is within the time category, which is the percentage time spent on the order management process by a specific resource per year. This measure is selected because of the objective to reduce the workload within the order management of the PODD for both the Strategic Buyer and Supply Chain Engineer. Second, we select the administrative costs of part 3 of the order management process. We decided to calculate cost per year for the actual and redesigned situations. This measure is based on the time spend per resource but is more informative than just the time spent since the resources involved are within different wage scales. As a result, we will be able to evaluate the impact of yearly growth in demand on the actual and redesigned situations for both measures. How both performance formulas are constructed is explained in Section 4.3.3. Lastly, employee satisfaction is included in this study to evaluate the (internal) quality. This concludes the three used dimensions to evaluate the performances with two quantitative and one qualitative measure.

Measuring selected performances

Before we are able to determine the quantitative performances, we define the formulas used. In general, the duration and frequency of an activity are required to calculate the total duration spent on that activity. In the order management process, the number of work orders that need to be processed at a time highly influences the duration of the activity. Therefore, we distinguish

Table 4.2: Selected performance measures

Category	Measure	Notation	Explanation
Time	Percentage resource time spent per year	$P_y(r)$	Percentage of time spent per year by a resource on order management activities versus working hours available in a year
Cost	Administrative costs	C_y	Yearly costs of man-hours spent to execute order management activities
Quality (internal)	Employee satisfaction	-	The satisfaction of the employees with assigned order management tasks

between the setup time $SU_t(a,r)$ and time to process one work order $WO_t(a,r)$ for each activity a performed by resource r. Multiplying $SU_t(a,r)$ by $SU_f(a,r)$ gives the total time spent per year to set up activity a by resource r. Where $SU_f(a,r)$ is the frequency a setup is performed per year. Similar for the work orders, where multiplying $WO_t(a,r)$ with $WO_f(a,r)$ gives the total time spent to proceed all work orders for activity a. Note that $SU_f(a,r) \leq WO_f(a,r)$ because there always has to be a work order before a setup takes place. The occurrence in relation to the initial number of setups and work orders for all activities is determined based on the occurrence of the X-OR splits in the BPMN diagram.

The frequency of setups and work orders that will be proceeded in an activity per year depends on the occurrence of that activity. The occurrence of that activity is the multiplication of the initial number of setups and work orders per year with the percentage of a workflow that occurs. Each ERP trigger in all BPMN diagrams comes with its own number of setups and work orders that varies per year. How we determine these numbers is further explained in Subsection 4.3.4. The occurrence of activity is 100% by default except when activities follow an X-OR split in the BPMN diagram. The splits are always partitioned into two options, which are either yes or no. The probability going in each direction is between 1% and 99% and sums up to 100%. Note that in some cases the flows come together, resulting in the summation of the frequencies of setups and work orders. For example, the activity to release a work order to produce PODDs in Figure 4.5. This activity immediately occurs after there are tested assy header stacks available in Eindhoven (i.e. yes after the X-OR split). However, this activity will also be performed after following the workflow when there are no tested assy header stacks available in Eindhoven (i.e. no after the X-OR split). In the end, the occurrence of this task is 100% in relation to the initial number of setups and work orders for the PODD implying that we need to calculate the frequency of setups and work orders for each activity based on the workflow and initial ERP input. The task to (re)check the component availability of the BOM of drift detectors can even occur more than 100% in comparison to the initial number of setup and work orders. This phenomenon occurs when there are no PODDs available in Almelo while checking the component availability.

Using the yearly setup and work order frequency per activity, we are able to calculate the time (in hours) spent $T_y(r)$ on order management activities in part 3 by a resource per year. The formula for time spent on order management activities of part 3 is shown in Equation 4.1. $T_y(r)$ is calculated for each design (i.e., original situation and redesigns) as an input to calculate the performances as explained below. Table 4.3 introduces the variables used in the equations.

$$T_y(r) = \sum_{\forall a \in A} (SU_t(a,r) \cdot SU_f(a,r) + WO_t(a,r) \cdot WO_f(a,r)) \text{ for } r \in R \tag{4.1}$$

Using the yearly time spent $T_y(r)$ on activities allocated to each resource, we can calculate performances that are relevant to benchmark the actual situation and redesigns. First, the percentage $P_y(r)$ of time spent by resource r based on the working hours available per year is calculated for each resource using Equation 4.2. The working hours available per year is set to 1720 hours for a full-time employee in The Netherlands (van Sociale Zaken en Werkgelegenheid, 2018).

Table 4.3: List of variables used in performance measure formulas

Variable	Explanation
a	Activity
A	Set of activities in BPMN part 3.1, 3.2, and 3.3
c	Costs per hour
f	Frequency
r	Resource
R	Set of resources: SCE[1], SB[2], PEHV[3], WALM[4], and WEHV[5]
t	Time in hours
SU	Setup
WO	Work order
y	Year

[1] Supply Chain Engineer, [2] Strategic Buyer, [3] Planner Eindhoven, [4] Warehouse operator Almelo, [5] Warehouse operator Eindhoven

$$P_y(r) = \frac{T_y(r)}{1720} \cdot 100\% \text{ for } r \in R \tag{4.2}$$

Second, the yearly time spent $T_y(r)$ on activities by a resource is used to calculate the total yearly costs C_y spent on order management for each design. Distinguishing the hours spent by each resource is made since the employees can be roughly categorized into three different hourly wage scales. The total yearly costs spent on the administrative tasks of part 3 in the order management process are calculated following Equation 4.3.

$$C_y = \sum_{\forall r \in R} T_y(r) \cdot c(r) \tag{4.3}$$

Lastly, we interviewed the key resources involved in the actual and redesigned order management process. The goal of this interview is to question their (expected) satisfaction with all different situations. The key resources are the Supply Chain Engineer, Planner, and Strategic Buyer. The satisfaction of the resources with the allocated tasks of the current situation and of the redesigns is questioned.

4.3.4 Step 2.4: Data collection

Data is collected via various sources to determine performances of the current situation with both historical and future demand and for the redesigned situations. There are three sources used, namely (1) the ERP system, (2) existing forecast, and (3) expert knowledge. Mainly, the data that we need depends on the performance measures selected in the previous step. Thus, we need data in order to calculate $P_y(r)$ and C_y, which are both dependent on the $T_y(r)$. The data necessary to calculate $T_y(r)$ is based on all three sources.

First, we collected historical order release data in the ERP system. This data consists of order information of all key components, assy header stacks, PODDs, and drift detectors. The data is collected from January 2019 to September 2022. In the columns of the data set information is given about each work order. Thus, the work orders are listed in the rows. The data was prepared by only deleting a few rows that contained orders that were rejected by the incoming quality control. This is decided because we consider the regular order management process and rejected orders require exceptional tasks. Besides, rejected orders are exceptional, thus deleting them would not largely affect the analysis. Especially because we test the current situation and all redesigns based on the same data set. No other data cleaning or preparation steps were necessary. Before the order release frequencies can be determined, different data sets need to be combined. Different product types ordered at the same supplier or at the same time internally need to be merged. Merging is necessary since these different product types belong to the same setup of activity because of the mix flexibility. After merging, counting the number of work orders (i.e. rows) belonging to a specific year provides the frequency of work orders released WO_f in that year. Accordingly, the yearly setup frequency SU_f was determined by counting every unique date when an order was released in a year. As mentioned, data was collected until September 2022. Since there is no seasonality within releasing orders we decided to extrapolate SU_f and WO_f for 2022. An aggregated overview of the ERP data is shown in Figure 4.6.

Second, the existing forecasts for the drift detector demand from 2023 until 2028 is explained. We assume that these forecasts made by experts are accurate. In 2023, the forecasted production volumes are similar to previous years. However, significant growth in production volume is forecasted starting in 2024 due to the introduction of the new system. A distinction is made between the forecasted production of assy header stacks, PODDs, and drift detectors. The yield loss is included in these forecasts. Figure 4.7 shows the forecasted production volumes that are converted into the number of batches, assuming that the batch sizes stay constant. This conversion is made since the number of batches required equals the work order frequency WO_f, which is relevant for this research. SU_f is not forecasted, thus this is determined for every year in the future in the consolidation of an expert by reasoning how MRP will react. The frequency of 2023 is set similarly to 2022 and the frequencies of the subsequent years are slightly increased based on prior years and at most once a week (i.e., a maximum of 52 setups per year). No forecasts are available regarding the key components. Therefore, it is assumed in consolation with one of the experts that the setup frequency will not change and only the number of work orders slightly increases every year. The SU_f would not deviate in the future due to the high IOQ of the suppliers.

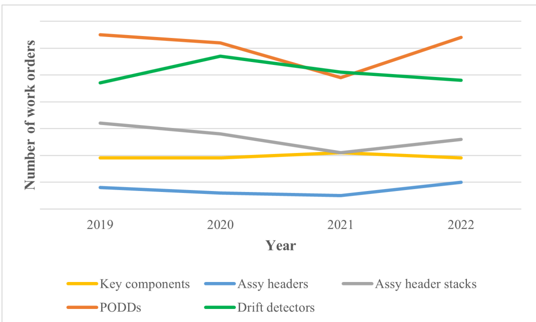

Figure 4.6: Released work orders

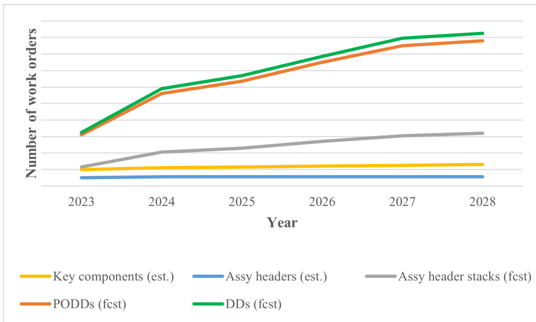

Figure 4.7: Forecasted work orders

Third, some data is based on expert knowledge, which is the estimated hourly wage, average activity time, and estimated occurrences. We assume that the knowledge of the expert was sufficient to obtain realistic and reliable values. The five involved resources are categorized in three wage scales, resulting in $c(SCE) = c(SB) > c(PEHV) > c(WALM) = c(WEHV)$. The setup time per activity and the time to proceed with one work order during that activity is determined using expert knowledge. The activity times are estimated in minutes and are converted to hours to use in the equations as explained in Section 4.3.3. For some of the tasks, we do not set a task time since there is no distinction in the task time in case of one work order or multiple work orders that need to be processed simultaneously. In such cases, only the setup time is used and the time to proceed with a work order is set to zero. Also, the occurrences of the activities, as explained in Section 4.3.3, are chosen in consolation with one expert who has the overview of this entire process. The percentages of each X-OR split were set in relation to the initial number of ERP triggers because this was most logical to reason. Both the activity times and occurrences are estimated based on the experience of the past few years and the activity times are set based on the performances of experienced employees. The data shows that assy header stacks shipment from Almelo to Eindhoven occurred at a different frequency than releasing work orders of assy header stacks. This also holds for the frequency of the assy header stack testing. However, we assume that this does not have a large impact on the performances we are measuring and is therefore neglected.

4.3.5 Step 2.5: Performances of current situation

The graphs in Figure 4.8 and Figure 4.9 show the performances of part 3 of the PODD order management process as defined in Section 4.3.3 and the data as described in Subsection 4.3.4. It should be noted that management of the entire PODD supply chain has a higher cost and time. The costs and time shown in these graphs are only a for part 3 of the PODD order management process. In other words, the costs of the total order management process will further accumulate. An approximation of the yearly costs C_y and percentages of time spent by the Supply Chain Engineer $P_y(SCE)$, Strategic Buyer $P_y(SB)$, and Planner in Eindhoven $P_y(PEHV)$ can be concluded from these graphs. As well as the insights on the estimated growth if we do not change the actual order management process. The warehouse operators from Almelo and Eindhoven are excluded from Figure 4.9 since their percentage of time spent is lower than that of the Strategic Buyer. Additionally, lowering the percentage of warehouse operators is not objected and only very small changes will be made regarding their activities in the redesigns. Therefore, we do not further include the percentages of time spent by the warehouse operators in Eindhoven and Almelo. A finding based on these diagrams is that the graphs of C_y, $P_y(SCE)$, and $P_y(PEHV)$ show a similar behavior over time. This can be explained by the fact that the Supply Chain Engineer and Planner of Eindhoven have a high share in the total hours spent by all resources. The last finding is that the increase in production volumes is of great influence on the results of both graphs.

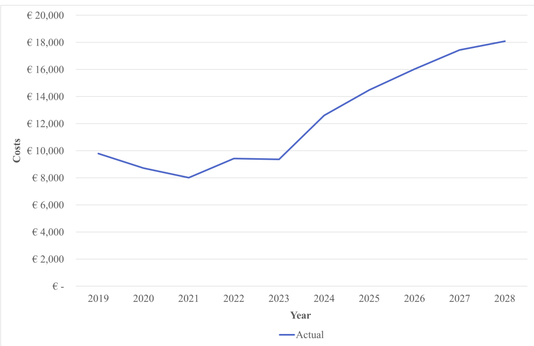

Figure 4.8: Yearly costs C_y of part 3 of the PODD order management process

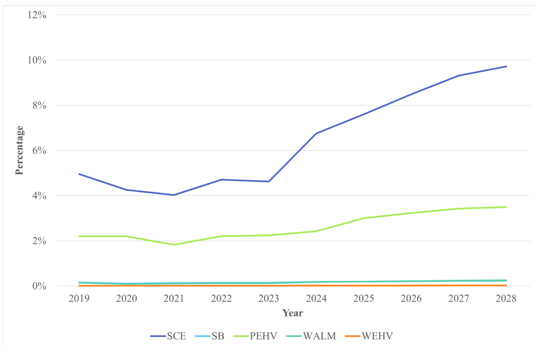

Figure 4.9: Percentage time spent by Supply Chain Engineer $P_y(SCE)$, Strategic Buyer $P_y(SB)$, and Planner Eindhoven $P_y(PEHV)$

4.4 Step 3: Defining and modeling the redesigned situation

This section explains the execution of step 3. First, for step 3.1, a selection of six heuristics is made from the 29 BPR heuristics to apply to the PODD order management process. With the application of these heuristics, we considered how the number of activities in the order management process can be reduced while taking into account the company and process characteristics (e.g., the two different planning domains, resources involved to the process). Each heuristic will have a different impact on the time required to execute the process. An overview of the selected BPR heuristics is shown in Table 4.4. The selected heuristics are from six different categories from the framework. We found that some of the heuristics can be applied in several variants, concluding ten different initial redesigns that are explained in Subsection 4.4.1 to Subsection 4.4.6. The changes in the supply chain structure (i.e., changes in the PFD) and changes in the order management process (i.e., changes in the BPMN diagrams) are shown in Appendix D. The consequences of these redesigns in terms of implementation requirements are given for each heuristic, concluding step 3.2. The consequences of implementation are facing both the order management process of part 3 of the PODD supply chain as other activities. For step 3.3, the redesigns were validated following the same method as for step 2.2 as explained in Subsection 4.3.2.

Table 4.4: Applied BPR heuristics of Reijers & Mansar (2005)

	Heuristic	**Category**	**Form**	**Explanation**
1.	Integration	Customer	Indirectly	Integrate with business process of customer or supplier
2.	Flexible assignment	Organization structure	Indirectly	Assign tasks to the most specialized resource
3.	Specialist -generalist	Organization population	Directly	Reconsider balance of specialists and generalists based on desired performances
4.	Buffering	Information	Directly	Subscribe to updates instead of requesting information from external parties
5.	Task automation	Technology	Directly	Replace manual tasks with automated systems
6.	Outsourcing	External	Indirectly	Outsource a (part of a) business process

4.4.1 Heuristic 1: Integration

Business processes of customers or suppliers can be (vertically) integrated (Reijers, 2003). We decided that it is interesting to test the integration of a part of the process at CD. We expect that integration greatly decreases the management burden, but the main reason for vertical integration is to gain knowledge about a new production technique for Malvern Panalytical. The part of the process we suggest to integrate is the assembly and testing of the header stacks at CD. We found three possibilities to implement the integration heuristic. Namely, by integrating the part of the process of CD with MP Eindhoven and with MP Almelo. Resulting in redesign options 1.1 and 1.2 respectively. Of which redesign 1.1 deviated in options 1.1.1 and 1.1.2 since there are two options regarding the location of the key components. Namely moving the stock to MP Eindhoven or leaving the stock at MP Almelo. These redesign options are explained in 1.1.1 and 1.1.2 respectively. Integration requires changes in the supply chain (i.e., the PFD), which means that we are indirectly changing the order management process (i.e., the BPMN diagrams). How these PFD and BPMN diagrams are changed is explained for each integration variant.

Redesign 1.1.1: Integration part of process CD with MP Eindhoven and move storage of key components to MP Eindhoven

In redesign 1.1.1, the assembly of the assy header stack is moved from CD to MP Eindhoven, and the storage of the key components is moved from MP Almelo to MP Eindhoven. The relocation of the stock is considered because the key components stock will then be located at the site where assembly will be performed. This could be beneficial because it will result in fewer order management tasks (i.e., no shipment of the key components necessary). Changes are necessary in both the PFD of the supply chain and the BPMN of the order management process to realize integration.

The process at CD will end with the step *'Inspect and sort sensor chips'* in the PFD. After this step, the sequential steps will occur at MP Eindhoven. Resulting that the key components are not used for assembly at CD anymore but at MP Eindhoven. Moving the steps of assembling header stacks and test header stacks to MP Eindhoven results in the elimination of one cross-dock activity at MP Almelo and one testing activity of the header stacks. In the original situation, testing the header stacks at both CD and MP Eindhoven is necessary since quality degradation could occur during transportation. However, in the integrated situation, testing once will be sufficient since the assy header stacks stay at MP Eindhoven for further production. Resulting in the elimination of a work order, namely for the assy header stacks.

Changes are necessary for all three BPMN parts for redesign 1.1.1. In part 3.1, the Planner in Eindhoven will be responsible for the tasks that originally are the responsibility of the Supply Chain Engineer. Some of the administrative tasks became unnecessary since more automation is possible in the Eindhoven domain. In part 3.2, almost all tasks became irrelevant. Only the tasks to check component availability and the work order release to produce assy header stacks retain. We deviate from the component availability feedback loop, which was explained as a modeling choice in Subsection 4.3.1. Since the probability of stock-outs for sensor chips and buy-parts is close to zero, we decided not to model this loop since it would not occur regularly. In part 3.3, only the PODD-related process changes. All tasks will be assigned to the Planner in Eindhoven since no interaction is necessary with the Supply Chain Engineer due to the integration. This reduces the time-consuming feedback loop and rescheduling tasks.

Redesign 1.1.2: Integration part of process CD with MP Eindhoven while storage of key components stays at MP Almelo

In redesign 1.1.2, the assembly of the assy header stack is moved from CD to MP Eindhoven and the storage of the key components stay in MP Almelo. This redesign is similar to redesign 1.1.1, however, the key component location stays in Almelo. This ensures that part 3.1 remains the same as the current situation as only part 3.2 will change. The Supply Chain Engineer will be responsible for the shipment orders to send key components from MP Almelo to Eindhoven. The Planner is in this situation responsible for the work orders of the assy header stack. Due to the difference in the location of the physical stock of the key components and where they are consumed, a feedback loop exists in case components are not available. BPMN part 3.3 is the same as the one in redesign 1.1.1.

Redesign 1.2: Integration part of process CD with MP Almelo

In redesign 1.2, the assembly and testing of the assy header stack are moved from CD to MP Almelo. The storage of the key components stays at MP Almelo. In this situation, testing is necessary both at MP Almelo after production and at MP Eindhoven after transportation. Part 3.1 remains the same as in the current situation. Part 3.2 is similar to Part 3.2 from redesign 1.1.1 with the addition of creating a shipment order for assy header stacks from MP Almelo to Eindhoven and receiving activities at MP Eindhoven. Lastly, part 3.3 is similar to the current situation. The minor change is that the Supply Chain Engineer does not have to request a status update at CD but has to investigate the status of the assy header stack production internally at MP Almelo. This will most likely be much easier and faster because the dependence on CD no longer applies.

Implementing integration redesigns

The implementation consequences of redesign 1.1.1, 1.1.2, and 1.2 are listed below:

1. **Strategic sensor chip stock in-house:** The strategic sensor chip stock can be stored in-house instead of being stocked at the supplier.

2. **Gain knowledge about new production techniques:** Malvern Panalytical can gain knowledge about wire bonding. This production technique is also used in other detector chains, thus other chains could also benefit by gaining knowledge about this technique. It is expected to takes to master this technique.

3. **Change in transportation track for CD:** CD needs to be informed that they have to transport the sensor chips to MP Eindhoven, which is further in distance. CD could decide to increase the prices. Or the cross-dock still exists after the sensor chips are produced and transported via MP Almelo (i.e., cross-dock) to MP Eindhoven. This cross-dock then belongs to Part 2 of the PODD supply chain, thus is not included in the analysis since this is out of scope.

4. **Key components stay in-house:** The key components do not need to be sent to the supplier anymore and thus stay within Malvern Panalytical after being purchased. This increases visibility. For redesign 1.1.1 and 1.2, the key components are stocked at only one location. In the current situation and redesign 1.1.2, the key components are stored at two locations.

5. **Move key component stock:** For redesign 1.1.1, the key component stock is suggested to move from MP Almelo to Eindhoven.

6. **Possibility that CD quits the cooperation:** CD is specialized in the assembly of assy header stacks, but not necessarily in wafer detaping and dicing into sensor chips (i.e., the processes in PFD Part 2). Therefore, an implementation risk of this redesign is that CD could decide to terminate the cooperation. Another supplier needs to be found to produce sensor chips in case CD determines to terminate the cooperation.

7. **Return packaging process stays in-house:** Return packaging does not have to be sent to the supplier anymore after the production of the PODDs succeeded. We decided to not select this problem for the solution design. However, this problem is addressed at the same time with interation. The return packaging still needs to be managed, but only in-house resulting in significantly easier management due to better visibility and communication. Finally, the improved management of return packaging results in fewer supply stops for assy header stacks, which is occurring at CD when the return packaging is not returned on time.

8. **Might be strategically rejected:** About eight years ago, higher management already discussed integration. It was strategically rejected. However, we still decided to study integration because the decision was made a eight years ago and higher management did not investigate order management benefits.

9. **Purchasing of additional buy-parts:** CD currently manages the procurement of some general parts from the BOM of the assy header stacks. When integrating, Malvern Panalytical needs to purchase these parts themselves.

10. **Reconsider batch size assy header stack:** Currently, CD handles a batch size of 25. When integrating, it might be more advantageous to align the batch size with the batch size of the subsequent production steps.

11. **Capacity investments:** Many investments will be necessary, such as a clean room or production floor capacity, operators, and machinery.

12. **Consider to replace Supply Chain Engineer:** It could be considered to reallocate the activities that are assigned to the Supply Chain Engineer to a Planner at MP Almelo.

4.4.2 Heuristic 2: Flexible assignment

The flexible assignment is assigning an activity to the most specialized resource (Reijers, 2003). We consider the resource as a broader concept, namely the plant being MP Almelo or Eindhoven. We interpreted this heuristic in two ways and therefore we have two different variants of this heuristic. First, we propose to assign internal production activities to Eindhoven since Eindhoven is most specialized in the assembly of very small parts. The PODD consists of very small parts, therefore we consider to move the production activities from MP Almelo to Eindhoven, which results in redesign 2.1. This option has been considered in the past but not further explored. Therefore, this option is very interesting to include in this research to discover if this option is as beneficial as was suspected. Second, we propose to assign internal production activities to Almelo since Almelo has the most knowledge about detectors (i.e., detector R&D is located in Almelo). This results in redesign 2.2. In contrary to redesign 2.1, moving the production from MP Almelo to Eindhoven is not considered yet. However, due to the different characteristics of these two plants of Malvern Panalytical, it is interesting to investigate this in terms of order management. Both redesigns could be beneficial to reduce the management burden within order management because the responsibility of the internal planning will shift more to a single resource. The flexible assignment redesigns are indirectly changing the order management process. Thus, changes to both the PFD and BPMN diagrams are explained.

Redesign 2.1: Move production MP Almelo to Eindhoven

In redesign 2.1, the production is moved from MP Almelo to Eindhoven. The PFD is adapted by moving the assembly and testing of the drift detectors to MP Eindhoven. Additionally, the generic component stock is moved from MP Almelo to Eindhoven. The BPMN diagrams of part 3.1 and 3.2 remain unchanged. The BPMN diagram of part 3.3 becomes more simplified regarding the order management process of the drift detector. In the current situation, there was an interaction between the Supply Chain Engineer who is responsible for the order management at MP Almelo and the Planner in Eindhoven. The interaction occurs when there is no PODD available at MP Almelo, which is on the BOM of the drift detector. With this redesign, both PODD and drift detector order management is the responsibility of the Planner at MP Eindhoven. This results in a less extensive feedback circle in which the Planner can completely check the status independently because it is within the planner's own domain. Additionally, only the planning of the Eindhoven domain needs to be adapted in case of disruptions.

Redesign 2.2: Move production MP Eindhoven to Almelo

In redesign 2.2, the production is moved to MP Eindhoven to Almelo. In the PFD the production activities of the PODD are moved to MP Almelo. The stock of generic components and the assy caps for PODD type I.A.2 are also moved. BPMN diagram 3.1 remains unchanged. While for redesign 2.1 the BPMN diagram of part 3.2 did not change, it slightly changes for redesign 2.2 due to the cross-dock removal. This results in removing all order management-related tasks for the PODD in Eindhoven, thus no warehouse operator from Eindhoven is involved anymore. Additionally, creating the shipment order becomes irrelevant. Therefore, the Supply Chain Engineer can immediately create the work order to test the products after the assy header stack is received and booked at MP Almelo. Part 3.3 of the order management process changes the most since all activities are assigned to the Supply Chain Engineer. So, for both the PODD and drift detectors, all order management tasks are performed by the same resource. This highly decreases the number of activities that need to be performed because feedback loops can be simplified for the same reasons as for the drift detector in redesign 2.1.

Implementing flexible assignment redesigns

The consequences to implement both redesign 2.1 and 2.2 would be:

1. **Reconsider final drift detector stock location:** Usually, the stock of final components is located on the site where production is finished within Malvern Panalytical. This would be Eindhoven for redesign 2.1 and Almelo for redesign 2.2. However, Malvern Panalytical could consider locating the drift detector stock in Almelo for redesign 2.1 since this is the location where customer demand is managed.

2. **Move generic components:** Procurement and storing of generic components used to assemble the drift detectors needs to be moved to MP Eindhoven for redesign 2.1 and MP Almelo for redesign 2.2.

3. **Expected difficulties because of distance from R&D:** The R&D of the PODD is physically located at MP Almelo. This could lead to difficulties for redesign 2.1 if the production operator has questions about drift detectors that did not pass the final x-ray test. This would not be the case for redesign 2.2.

4. **Move instrument(s):** For redesign 2.1, to perform the pre- and final test that is currently performed in Almelo an X-ray instrument needs to be moved from MP Almelo to Eindhoven. This X-ray machine is fully occupied to test drift detectors, thus moving the X-ray does not have consequences for other production processes. For redesign 2.2, instruments used in production also need to be moved from MP Eindhoven to Almelo. Two of the machines could be moved without interrupting other production processes. However, two other machines are used to produce other products as well and therefore need to be purchased by MP Almelo.

5. **Relocate or replace production operator:** For redesign 2.1, the operator that currently full-time produces the drift detector needs to be relocated from the place of employment (i.e., Almelo to Eindhoven). This could be rejected by the operator, resulting by the fact that a new job needs to be found for the operator. As a result, another operator needs to be hired or assigned and trained to produce the drift detectors in Eindhoven. For redesign 2.2 this situation is the same, but then for relocating multiple operators from MP Eindhoven to Almelo.

6. **Changes in return packaging process:** The return process of the packaging will also have to be redesigned. Return packaging still needs to be sent to CD for redesign 2.1 and 2.2, however, the packaging stays only within one location of Malvern Panalytical. This increases visibility in comparison with the current situation where the return packaging stays at both MP Almelo and Eindhoven.

7. **Capacity of clean-room:** For both redesigns, it needs to be checked if the capacity of the clean-room at MP Eindhoven is sufficient. Note that in Eindhoven, the whole production floor consists of a clean room while in Almelo only a small part of the production floor is a clean room.

8. **Changes in ERP:** The ERP system must be aligned with the physical changes, thus the BOM needs to be moved from one ERP domain to the other one.

9. **Work with special material:** This implementation requirement is only applicable for redesign 2.2. MP Eindhoven is qualified to process a certain material in order to assemble the caps of PODD type I.A.1 and II.A.1. However, this is not the case for MP Almelo. Thus, special working conditions and training must be met in order to become qualified to work with this material.

4.4.3 Heuristic 3: Specialist-generalist

The heuristic specialist-generalist suggests reconsidering the balance of activities assigned to specialists and generalists based on the desired outcomes (Reijers, 2003). In this situation, we consider the Planner as a specialist since the majority of this job consists of planning tasks. We consider the Supply Chain Engineer as the generalist since the majority of this job consists of supply chain improvement projects. Specialists are more likely to work quicker and deliver higher quality while generalists provide more flexibility (Reijers, 2003). However, for the order management process, it is desired to reduce the involvement of the Supply Chain Engineer and assign this resource to other work. Therefore, the desired outcome is to re-allocate the planning activities of CD to the Planner of the MP Eindhoven domain. This concludes redesign 3.1 of which the changes will be explained below.

Redesign 3.1: Move planning of CD and key components to MP Eindhoven

Redesign 3.1 considers moving the order management tasks of CD to the Planner of MP Eindhoven. Physical changes are necessary to the PFD of the supply chain, which consists of the elimination of the cross-dock between CD and MP Eindhoven. In the current situation, the cross-dock is necessary since the order is initiated in the MP Almelo domain. As a result, changing the domain in which the orders will be initiated ensures that the assy header stacks can be directly shipped to MP Eindhoven. Another change in the PFD is that the key component stock location will be moved from MP Almelo to Eindhoven. This redesign changes all three parts of the BPMN diagrams. First, part 3.1 and 3.2 will slightly change since in this planning domain automation of routine tasks is regularly applied. Thus, the Planner will have fewer activities in this redesign than the Supply Chain Engineer in the current situation in part 3.1 and 3.2. Additionally, the activities to manage the cross-docking activity in part 3.2 became irrelevant and can be removed. Finally, changes can be made in the order management process of the PODD in part 3.3. The feedback loop can be simplified since the Planner of MP Eindhoven will be responsible for the orders at CD. Thus, no interaction is necessary anymore between the Planner and the Supply Chain Engineer about status updates of the components ordered at CD. The order management for the drift detector remains unchanged.

Implementing specialist-generalist redesign

Consequences to implement redesign 3.1:

1. **Consider to replace Strategic Buyer:** It could be considered to reallocate the activities that are assigned to the Strategic Buyer located at MP Almelo to an Operational Buyer located at MP Eindhoven. This could fit within the infrastructure of the redesigned situation since internal handling of the supplier orders belongs to the Eindhoven domain.

2. **Capacity limit of Planner:** It needs to be checked if the Planner has enough time available to take over these responsibilities.

3. **Change in transportation track for CD:** CD needs to be informed that they have to transport the sensor chips to MP Eindhoven, which is further in distance. CD could decide to increase the prices.

4. **Move key component stock:** The key component stock is suggested to move from MP Almelo to Eindhoven. Therefore, the key component stock must be moved.

4.4.4 Heuristic 4: Buffering

Buffering enables a subscription to update instead of requesting information from external parties (Reijers, 2003). This could be beneficial to implement for CD because it is a time-consuming process to investigate order status at an external supplier. Requesting the update is not most time-consuming, however, the waiting time to receive an update is. Since we do not include waiting time within this analysis, we cannot capture the full potential of this heuristic. Therefore, we do not test the heuristic how it is meant by having information directly available when it is required. However, we can test the influence on the activity times if push notifications are received after disruptions. A disruption in the supply of CD directly requires changes in the planning of MP Eindhoven and indirectly at MP Almelo. With this redesign, it could be investigated what the effect will be on the feedback loops (including rescheduling) when buffering is applied. Thus, one redesign is considered with the buffering heuristic, namely redesign 4.1.

Redesign 4.1: Updates from Company D

Redesign 4.1 considers to include push updates from CD. This redesign does not require changes in the supply chain structure so the PFD of the current situation remains the same. While the

BPMN diagrams change. We decided that it would be most effective and desired to receive the updates from CD immediately when disruption takes place (i.e., push messages). Part 3.1 and 3.2 of the BPMN remain unchanged. The processes of part 3.3 will be adapted. The original feedback loop changes into a separate flow, of which the BPMN start is an update from CD about a supply deviation. After this update, the planning at both MP Almelo and Eindhoven can be adapted based on this update.

Implementing buffering redesign

Consequences of buffering are:

1. **Requires supplier cooperation:** Collaboration of the supplier is required to send these push updates.
2. **Costly subscription fee:** The supplier might charge additional fee to send these updates (Reijers, 2003).

4.4.5 Heuristic 5: Task automation

With the heuristic task automation, the manual tasks are replaced with automated systems (Reijers, 2003). In the order management process, we identified several exceptional tasks. With exceptional tasks, we imply that these tasks are uncommon tasks within Malvern Panalytical. These exceptional tasks majorly are routine tasks that are rarely occurring in other processes or only in the order management process of the PODD. The other exceptional tasks are asking for status updates and investigating this status, which are not considered routine tasks. Therefore, they are not included within the task automation heuristic. Examples of routine tasks that are already automated at MP Eindhoven but still exist in the Almelo domain are *'Allocate BOM to work orders (update stock level)'*, and *'Book work order of assy header stacks as 'ready"*. More automation is possible in Eindhoven regarding subcontractors than in the Almelo domain. Thus, in redesign 5.1 it is investigated what the improvement in management burden will be by automating routine tasks in the Almelo domain similar to the Eindhoven domain.

Redesign 5.1: Automate routine tasks in planning MP Almelo

To redesign the process following the task automation heuristic, only changes are necessary for the BPMN diagrams of part 3.1 and 3.2. Since only in these parts, external work orders are managed within the Almelo domain. The changes include the removal of all the tasks that can be automated with the ERP module Malvern Panalytical already purchased. An example change will be explained. In the BPMN part 3.2 to order assy header stacks, the task *'Allocate key components (i.e., BOM) to work orders (update stock level)'* can be automated within the prior task *'Release work order to produce assy header stacks'*. A released work order of quantity X results in the automatic allocation of X times the BOM to this work order. Such automation is possible by linking the purchase order to a work order, as done in the Eindhoven domain.

Implementing task automation redesign

The consequences of implementing redesign 5.1 would be:

1. **Changes in ERP system:** Malvern Panalytical must invest in human resources to change the ERP system. Among others, the linkage between the purchase order and work order is necessary within the ERP system in Eindhoven to automate these administrative tasks. The module of the ERP system that makes this automation possible is already purchased.
2. **Consider timing to implement this redesign:** A long-term project about the implementation of another ERP system is in progress. It is therefore important to analyze when in this long-term project time should be invested to implement this redesign.

4.4.6 Heuristic 6: Outsourcing

Outsourcing of a workflow in a whole or parts of it can be considered (Reijers, 2003). With the outsourcing of a (part of a) workflow, the management burden could be decreased. Procurement outsourcing could reduce operational costs by 15-20% and administrative costs by up to 75% (Ellram & Billington, 2001). The procurement and management of the four key components could be outsourced, which is considered in redesign 6.1. However, it is advised by the Strategic Buyer not to outsource the cube. All key components were discussed using the Kraljic matrix and categorized the components being non-critical, bottleneck, leverage, or strategic items (Kraljic, n.d.). The cube is considered a strategic item and the other items are considered leverage or bottleneck items. This forms redesign 6.2, in which we investigate outsourcing the procurement and management of the leverage and bottleneck items.

Redesign 6.1: Outsource procurement and management of key components

Redesign 6.1 considers outsourcing the procurement and management of all four key components. Thus, the parallel flow P1 can be completely removed from the PFD. This results in the removal of whole BPMN part 3.1. In part 3.2, the availability check of the key components and transportation will also be outsourced since this belongs to the management of key components that will be outsourced. Lastly, no changes are required in part 3.3 of the order management process.

Redesign 6.2: Outsource procurement and management of part of key components

In redesign 6.2, we consider outsourcing the procurement of all parts except the cube. Thus, the procurement, storage and management of the collimators, NTCs, and headers, work order management of the assy headers are outsourced. This results in a parallel flow in the PFD of the procurement and storage of the cube only. This redesign does not change the BPMN diagrams much since the cube still needs to be managed. In BPMN part 3.1, the cube needs to be purchased but all other activities are removed. Part 3.2 and 3.3 remain the same as in the current situation.

Implementing outsourcing redesigns

Redesign 6.1 and 6.2 would have the following consequences for implementation:

- **Search for supplier:** A supplier needs to be found that could perform the procurement and management of the key components. This could be CD but there could be a possibility that CD decides not to cooperate. As a result, another supplier has to be recruited.
- **Perform risk analysis:** Before considering implementing outsourcing, it is suggested to perform a risk analysis. Since procurement outsourcing can, for example, lead to a decrease in performances and visibility, undesired part or supplier substitutions, and over-billing (Ellram & Billington, 2001).

4.5 Step 4 and 5: Determine and evaluate results

This section provides the determination and evaluation of the results for the initial ten redesigns, fulfilling step 4 and step 5. The results include both quantitative and qualitative results. The cost and time aspects are quantitatively estimated and the internal quality is qualitatively tested. The quantitative results include the estimated yearly costs to perform the order management tasks and the percentage of time spent per year by the Supply Chain Engineer, Strategic Buyer, and Planner. Four graphs are displaying the results for each redesign using historical and forecasted order data. Additionally, the current situation is plotted in all graphs as a reference. For the redesigns, some values (e.g., the occurrence of paths at X-OR splits and task times) are reconsidered as a result of some of the redesigns. For example, when integrating (heuristic 1), it can be expected that the on-time delivery will increase resulting in a lower occurrence of the feedback loops. For all redesigns, the values for the X-OR splits and task times were reviewed with the same experts as the initial values were set. Lastly, an evaluation is provided of the qualitatively tested satisfaction of key users of the order management process.

4.5.1 Quantitative results

First, the evaluation of the redesigns based on the yearly order management costs C_y is performed. These results for each design (i.e., current situation and redesigns) are shown in Figure 4.10. It can be found that the current situation has the highest order management costs for all years. This implies that all redesigns would improve the order management process from this cost perspective. However, some of the redesigns only slightly improve, which are redesign 4.1 (buffering) and 6.2 (outsourcing). The redesigns 1.1.1, 1.1.2, and 1.2 (integration), and 2.1 (flexible assignment) seem most cost-effective. Redesign 3.1 (specialist-generalist) also shows a great improvement in costs. The remaining redesigns, namely redesign 6.1 (outsourcing), 5.1 (task automation), and 2.2 (flexible assignment) do not improve the cost much in comparison to the other redesigns.

Second, Figure 4.11 shows the results of the percentage of time spent by the Supply Chain Engineer on order management $P_y(SCE)$ for each redesign. Again, the current situation has the highest percentage, which was 4.03% in 2021. If the order management process would not change, the Supply Chain Engineer will spend 9.72% in 2028 on the tasks to manage orders in part 3. Redesigns that slightly improve this performance measure are redesign 4.1 (buffering), 6.2 (outsourcing), and 2.2 (flexible assignment). Redesign 1.1.1 and 1.1.2 (integration) and 3.1 (specialist-generalist) highly reduce the involvement of the Supply Chain Engineer. The moderate improvements are redesign 2.1 (flexible assignment), 6.1 (outsourcing), 5.1 (task automation), and 1.2 (integration).

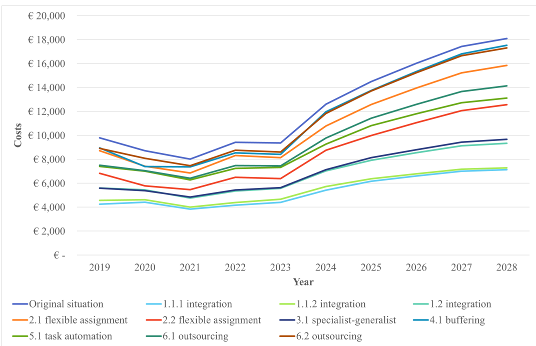

Figure 4.10: Yearly costs C_y of part 3 of the PODD order management process for all designs

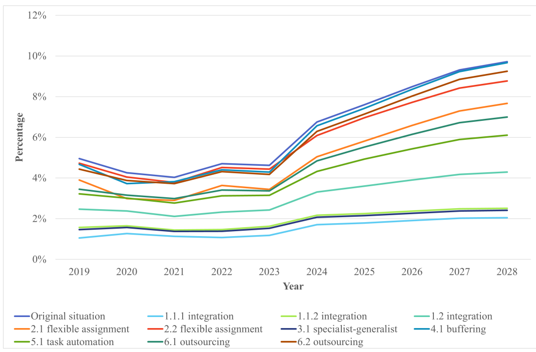

Figure 4.11: Percentage time spent per year on order management activities by the Supply Chain Engineer $P_y(SCE)$ for all designs

Third, Figure 4.12 shows the results of the percentage of time spent by the Strategic Buyer on the order management activities $P_y(SB)$ for each design. In general, the involvement of the Strategic Buyer is very low. For example, $P_y(SB)$ is 0.136% in 2021, which is much lower than $P_y(SCE)$. The current situation has the same results on $P_y(SB)$ as redesign 2.1 and 2.2 (flexible assignment), 3.1 (specialist-generalist), 4.1 (buffering), and 5.1 (task automation). These results are equal since these redesigns do not change anything for the Strategic Buyer in comparison with the actual design. It is noticeable from the graph that the results of all integration redesigns are constantly starting from 2023. The explanation is that the Strategic Buyer only has to do procurement of the key components and it is estimated by experts that the frequency of ordering stabilizes. It is determined that the time spent on purchasing activities is independent of the number of work orders (i.e., WO_t is 0 minutes). Thus, the $P_y(SB)$ stabilizes as well regardless of the growth in the number of orders of all products. Therefore, redesigns 1.1.1, 1.1.2, and 1.2

(integration) have the best score on $P_y(SB)$. Redesigns 6.1 and 6.2 (outsourcing) have a moderate result of this performance measure.

Lastly, the percentage of time spent by the Planner $P_y(PEHV)$ is shown in Figure 4.13. Despite there is no objective for the Planner, we still decided to investigate the $P_y(PEHV)$. Tasks of the Supply Chain Engineer either are deleted or reallocated to the Planner. This partly explains changes in the cost function but also provides insights into the amount of work the Planner will have in case of a redesign. These insights could be helpful to see if it is feasible to reallocate tasks to the Planner. The current situation and redesign 5.1 (task automation), 6.1, and 6.2 (outsourcing) have the same value for $P_y(PEHV)$. These values are all equal since no changes are made for the planner in these redesigns. Contrary to $P_y(SCE)$ and $P_y(SB)$, the current situation does not have the highest value for $P_y(PEHV)$. This is logical because it is not the goal to decrease the involvement of the Planner. Thus, it depends on the redesign whether the involvement of the Planner is either higher or lower. The redesign with the highest involvement of the Planner is redesign 3.1 (specialist-generalist) because all activities to manage CD are moved to this resource. Noticeable is redesign 2.2 (flexible assignment), which has the lowest value for $P_y(PEHV)$ of zero. Moving the production from MP Eindhoven to Almelo results that the planner is no longer involved. Redesign 2.1 (flexible assignment) also results in higher values for $P_y(PEHV)$ than in the current situation because production and thus planning of MP Almelo is moved to Eindhoven. The results of redesign 1.1.1 (outsourcing) are very similar to the current situation. While redesign 4.1 (buffering), 1.1.2 and 1.2 (outsourcing) have a lower $P_y(PEHV)$ than in the current situation.

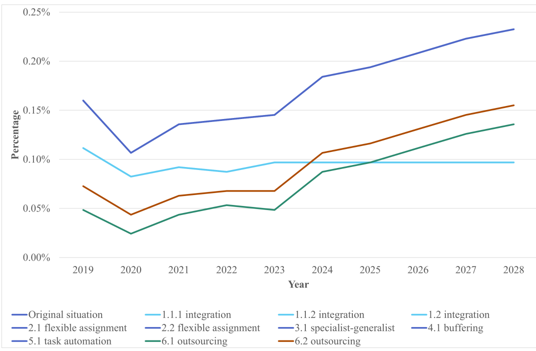

Figure 4.12: Percentage time spent per year on order management activities by the Strategic Buyer $P_y(SB)$ for all designs

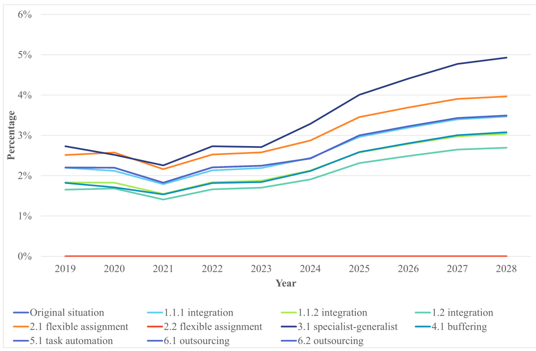

Figure 4.13: Percentage time spent per year on order management activities by the Planner $P_y(PEHV)$ for all designs

Insights are given by considering relations between these graphs. First, the redesigns in which many tasks are removed (e.g., redesign 1.1.1, 1.1.2, 1.2 (integration), and redesign 6.1 (outsourcing)) provide the lowest yearly cost spent on order management. Second, moving tasks from the Supply Chain Engineer to the Planner also explain a decrease in yearly costs spent. The first reason is that the hourly wage of the Supply Chain Engineer is slightly higher than that of the Planner. The second reason is that activities could be more easily automated in the planning domain of Eindhoven, which is the domain of the Planner. Third, as shown in Figure 4.6 the historical number of orders of different products are intersecting with each other while the forecasted number of work orders in Figure 4.7 are not. This explains the intersecting of some of the results in all graphs since functions are highly influenced by the order of data. Additionally, it depends on the redesign on which order data influences the results the most. For example, redesign 1.2 and 3.1 are comparable in terms of yearly costs C_y. However, the difference in costs is explained by multiple factors. In redesign 1.2 all activities related to the key components are removed, thus the number of work orders of key components does not have any influence anymore. While the number of work orders of all order types are involved in redesign 3.1. However, costs are still comparable because in redesign 3.1 the activities are assigned to a resource with lower costs, and several time-consuming tasks are removed because of automation possibilities. In other words, to fully understand the behavior of the graphs, one can consult the redesigns to understand the factors causing this behavior. Based on these graphs, we will give an indication of which redesigns might be most beneficial in terms of these performances. This will be explained in Section 4.7.

The last insight gained is based on the parameter input. In Subsection 4.3.4 it is explained that the percentages of each X-OR split are estimated by an expert. The X-OR splits in BPMN part 3.3 are dependent on the delivery performance of CD. Currently, Malvern Panalytical is dealing with a relatively low delivery performance of this supplier, which negatively affects the C_y, $P_y(SCE)$, and $P_y(PEHV)$. Relatively is used because of confidential data. As mentioned in Subsection 4.3.1 the majority of the activities in the current situation are related to the feedback loop in case a product from the BOM is not available. Activities from the feedback loop are performed if the half-manufactured products supplied by CD are not delivered, which occurs relatively often. Thus, the performance can be improved by aiming for higher delivery performance from the first-tier supplier. For the current design and redesigns in which the feedback loops are unchanged, namely redesigns 5.1, 6.1, and 6.2. Despite the improvement of the feedback loop in most redesigns, an increased delivery performance of CD still leads to an improvement in performance. The degree of improvement will depend on each redesign and is always less than the current feedback loop. Thus, the other redesigns are more robust to lower delivery performance.

4.5.2 Qualitative results

Interviews are conducted to question employee satisfaction with the PODD order management process. The interviewees are the key resources executing this process, which are the Supply Chain Engineer, Strategic Buyer, and Planner. Their satisfaction with the tasks they are assigned to was questioned, thus not their satisfaction with the process in general. Their concerns are already included in the implementation consequences for each redesign in Section 4.4. First, satisfaction with the current situation was questioned. Afterward, the interviewees were introduced to the redesigns and their expected satisfaction with the assigned tasks was questioned. No satisfaction was discussed in case the resource has not assigned any tasks in a redesign. First, the Strategic Buyer, this resource is satisfied with the tasks in the actual process since the activities are usual activities of a Strategic Buyer. Task types do not change in any of the redesigns for the Strategic Buyer. The only change possible is that fewer purchasing tasks are necessary in case of integration or outsourcing as shown in Figure 4.12. Therefore, the Strategic Buyer indicated to be equally satisfied with the redesigns. The involvement of this resource is already very low, thus one task less or more would not change the satisfaction. The Supply Chain Engineer is moderately satisfied (i.e., not very satisfied or very unsatisfied) with the activities of the actual problems. The satisfaction of the Supply Chain Engineer is highest for redesign 1.1.1, 1.1.2, 1.2 (integration), 3.1 (specialist-generalist), and 6.1 (integration). This is mainly caused by the fact that the involvement of the Supply Chain Engineer largely decreases for these redesigns, as confirmed with Figure 4.11. Redesigns 2.1 (flexible assignment) and 5.1 (task automation) will have a slight increase in terms of satisfaction. The Supply Chain Engineer indicated that satisfaction with the other redesigns does not significantly change as there will be no substantial changes in the activities compared to the current process. Lastly, the Planner is satisfied with the activities related to the actual order management process. The satisfaction would increase for redesign 3.1 (specialist-generalist) and 2.1 (flexible assignment). Despite the number of tasks and total workload increases, the Planner would still be more satisfied. This is a result of being responsible for a larger part of the process, increasing visibility for this resource. The Planner also would have a higher satisfaction for redesign 1.1.1, 1.1.2, and 1.2 (integration) because of a lower workload. Since nothing would change for the Planner in redesign 5.1 (task automation), 6.1, and 6.2 (outsourcing), the Planner is equally satisfied with these redesigns as with the current situation.

4.6 Step 6: Combine redesigns

Implementing a combination of redesigns could be more beneficial than implementing a single redesign. Most redesigns are not independent of each other, therefore we cannot sum the savings of the performances together. We have ten different redesigns by applying the six different redesign heuristics. Redesigns from the same heuristic cannot be combined, so there are 40 combinations possible. Since several redesign heuristics are approaching a similar problem, it would not make a significant difference to combine them or they can not be combined at all. On top of that, we can see from the results that some of the redesigns are not improving the current situation much. Ignoring all irrelevant combinations, we end with 20 combination possibilities. Since there are still many combinations left, the two most interesting combinations are further studied. We selected the most interesting combinations based on the performances and related consequences of the ten redesigns. In general, the integration heuristic might be most beneficial in terms of performance measures. However, evaluating the consequences found, integration also is the most challenging to implement and has the highest chance that it will be rejected by higher management. Thus, despite having the most promising performance results, we do not continue testing the integration redesigns (i.e., redesign 1.1.1, 1.1.2, and 1.2). Redesign 6.1 would be beneficial based on the performances found. However, experts within the company say that outsourcing the procurement of the cube is not an option. This results in the rejection of redesign 6.1. The alternative outsourcing option, which is redesign 6.2, does not improve the current situation as much as redesign 6.1. Therefore, based on the performance measures, redesign 6.2 would be less interesting.

After evaluating the remaining possible combinations, the two most promising combinations are 1) redesign 2.1 with redesign 3.1 and 2) redesign 2.2 with redesign 5.1. First, redesign 2.1 and redesign 3.1 both moves the production from MP Almelo and the planning of CD to MP Eindhoven. This redesign combination would highly centralize the planning by moving production from Almelo to Eindhoven and moving planning from CD to Eindhoven. Both the drift detector and PODD planning are assigned to the Planner in Eindhoven because of redesign 2.1. Redesign 3.1 ensures automated planning regarding the subcontracting work orders and eliminates the cross-dock between MP Almelo and Eindhoven. A result of combining the redesigns is that the involvement of the Supply Chain Engineer is eliminated, which is desired. Another promising combination is redesign 2.2+5.1, which moves the production from MP Eindhoven to Almelo and implements task automation at MP Almelo. As can be found in the result section, redesign 2.1 is more beneficial than redesign 2.2. The reason for this is that more tasks are automated in the ERP system in the Eindhoven domain. Thus, combining moving production from Eindhoven to Almelo and applying automation in Almelo could outperform other redesigns.

4.6.1 Quantitative results

First, the quantitative results of the redesign combinations. In Figure 4.14, Figure 4.15, Figure 4.16, and Figure 4.17 the graphs include the results of the two most promising combinations. Figure 4.14 shows that both combinations belong to the top four of all redesign options in terms of yearly costs spent on order management. Regarding the percentages of time spent per year per resource, it can be found from Figure 4.15 that the role of the Supply Chain Engineer differs a lot between the two combinations. In the combination of redesign 2.2+5.1, the involvement of the Supply Chain Engineer is lower than in the current situation but still higher than in alternative redesigns. However, in redesign 2.1+3.1, the Supply Chain Engineer is not involved in the order management process of part 3 of the PODD supply chain. It must be noted that the Supply Chain Engineer is still involved in Parts 1 and 2 of this supply chain, thus not completely eliminated. As mentioned before, the Planner takes over several tasks from the Supply Chain Engineer, thus the percentage of time spent by the Planner shows the opposite for the redesigns. For the Strategic Buyer, it is shown in Figure 4.16 that both redesign combinations have equal performances as the current situation since nothing is changed for this resource.

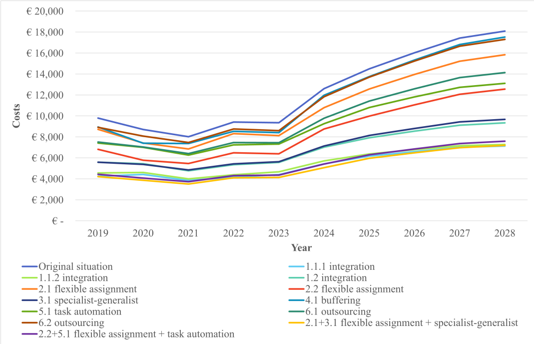

Figure 4.14: Yearly costs C_y of part 3 of the PODD order management process for all designs

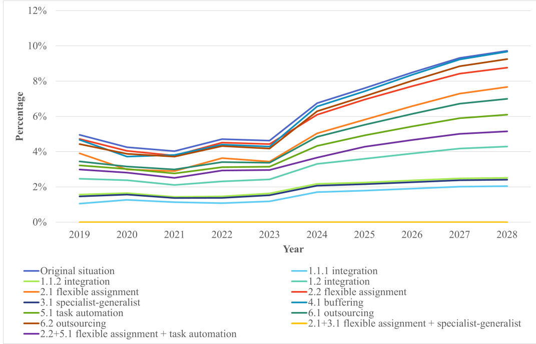

Figure 4.15: Percentage time spent per year on order management activities by the Supply Chain Engineer $P_y(SCE)$ for all designs

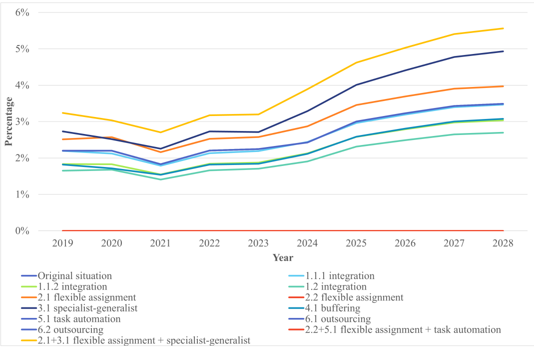

Figure 4.16: Percentage time spent per year on order management activities by the Strategic Buyer $P_y(SB)$ for all designs

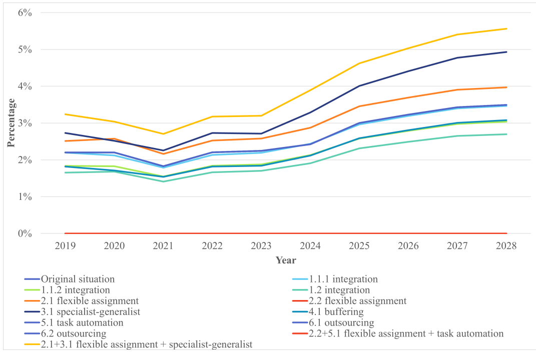

Figure 4.17: Percentage time spent per year on order management activities by the Planner $P_y(PEHV)$ for all designs

4.6.2 Qualitative results

The satisfaction of the resources for redesign 2.1+3.1 is high. The Planner is very satisfied with this option for the same reason as with redesign 3.1. This in short is that despite a higher workload satisfaction is high because of higher end-to-end responsibility. The satisfaction of the Supply Chain Engineer is not discussed since this resource does not have any tasks assigned in this redesign combination. Redesign 2.2+5.1 has a lower overall satisfaction. The Supply Chain Engineer is still allocated to many tasks and is less satisfied with being responsible for more products within the order management, despite the workload is decreased because of the increase in automation. The Planner is not assigned to any tasks in this redesign combination, thus no satisfaction is discussed. Note that the satisfaction of the Strategic Buyer remains unchanged.

4.7 Step 7: Final evaluation

In the previous sections, the results of the chosen measures were given and evaluated for part 3 of the PODD supply chain. Based on the quantitative performances we can suggest which are the most beneficial redesigns. This suggestion is based on the goal to aim for a redesign with the lowest possible yearly costs C_y and percentage of time spent by the Supply Chain Engineer $P_y(SCE)$ and Strategic Buyer $P_y(SB)$. Considering C_y, redesign 1.1.1, 1.1.2 (integration), 2.2+5.1 (flexible assignment and task automation), and 2.1+3.1 (flexible assignment and specialist-generalist) are most cost-effective. Based on $P_y(SCE)$, we can suggest that redesign 1.1.1, 1.1.2 (integration), 3.1

(specialist-generalist), and 2.1+3.1 (flexible assignment and specialist-generalist) would be most beneficial. These suggestions are based on yearly costs C_y and the percentage of time spent by the Supply Chain Engineer $P_y(SCE)$ since the Strategic Buyer has a very low share, we can not draw a conclusion based on this graph. Additionally, we can not draw valid conclusions about employee satisfaction because only the three key resources are included in this evaluation. Besides, the satisfaction of these resources was not always in line for all redesigns. Which is explained by the fact that for some redesigns, activities are changed for one resource but remain (almost) unchanged for the other. Satisfaction also depends on the challenge of the activities, of which the satisfaction varies from person to person.

To conclude, redesign 1.1.1, 1.1.2 (integration), 3.1 (specialist-generalist), 2.2+5.1 (flexible assignment and task automation), and 2.1+3.1 (flexible assignment and specialist-generalist) can be most beneficial based on the estimated yearly costs and estimated percentage of time spent per year of the Supply Chain Engineer. However, as mentioned before, redesigning a process is associated with making trade-offs. These trade-offs mainly consist of undesired effects on other performances and implementation costs, time, and risks. Therefore, potential effects on other performances and the impact in terms of implementing costs, time, and risk should be quantified first before an informed decision can be made about implementing one of the redesigns. The lists of implementation consequences as shown in Table 4.5 and explained in Section 4.4 provide a foundation for further investigation in this area.

Table 4.5: Overview of the most beneficial redesigns and their implementation consequences

Redesign	**Heuristic**	**Implementation consequences**
Redesign 1.1.1 Redesign 1.1.2	Integration	1. Strategic sensor chip stock in-house 2. Gain knowledge about new production techniques 3. Change in transportation track for CD 4. Key components stay in-house 5. Move key component stock 6. Possibility that CD quits the cooperation 7. Return packaging process stays in-house 8. Might be strategically rejected 9. Purchasing of additional buy-parts 10. Reconsider batch size assy header stack 11. Capacity investments 12. Reconsider to replace Supply Chain Engineer
Redesign 3.1	Specialist-generalist	1. Consider to replace Strategic Buyer 2. Capacity limit of Planner 3. Change in transportation track for CD 4. Move key component stock
Redesign 2.2+5.1	Flexible assignment	1. Reconsider final drift detector stock location 2. Move generic components 3. Expected difficulties because of distance from R&D 4. Move instrument(s) 5. Relocate or replace production operator 6. Changes in return packaging process 7. Capacity of clean-room 8. Changes in ERP 9. Work with special material
	Task automation	1. Changes in ERP system 2. Consider timing to implement this redesign
Redesign 2.1+3.1	Flexible assignment	1. Reconsider final drift detector stock location 2. Move generic components 3. Expected difficulties because of distance from R&D 4. Move instrument(s) 5. Relocate or replace production operator 6. Changes in return packaging process 7. Capacity of clean-room 8. Changes in ERP 9. Work with special material
	Specialist-generalist	1. Consider to replace Strategic Buyer 2. Capacity limit of Planner 3. Change in transportation track for CD 4. Move key component stock

Chapter 5

Conclusion

This research investigated the PODD supply chain by the support of the main research question: ***What is the improved PODD supply chain management structure to cope with complexity and to scale up production volumes at Malvern Panalytical?***. To answer this main research question we developed seven supportive research questions that were answered consecutively. The first three research questions covered a field study at Malvern Panalytical and provided the diagnosis. The latter four research questions form the plan of action phase of this research. The conclusion first provides the answers to the research questions in Section 5.1. Thereafter, the limitations of this study are discussed and suggestions for further research are provided in Section 5.2. Subsequently, recommendations for Malvern Panalytical are given in Section 5.3. Section 5.4 concludes this chapter with the contribution to literature.

5.1 Answering the research questions

The supportive research questions are answered consecutively.

RQ.1 *What does the current PODD supply chain management structure look like?*
To understand the supply chain management structure, the supply chain composition was studied first. The supply chain consists of multiple-tier suppliers that are controlled by Malvern Panalytical. Resources from different departments at both MP Almelo and Eindhoven manage the external and internal order processes.

RQ.2 *What are current and potential challenges in the PODD supply chain management structure considering the complexity and scalability?*
Multiple challenges in the PODD supply chain were found. Most challenges are manageable in the current situation, however, considering the necessary production growth the challenges become undesirable. All challenges, except for one problem, are related to the time-consuming management burden. The fact that the production capacity of some machines will become a problem is not fitting this research since we are focusing on the supply chain management structure. However, it is still mentioned because it will become a bottleneck considering the expected growth.

RQ.3 *Which of the identified challenges are most impactful?*
Considering all challenges found, we selected two challenges that are in span of control of Malvern Panalytical. The selection is based on the balance between feasibility and relevance to address these business problems. The challenges are: (1) The decentralized planning at MP Eindhoven and Almelo and (2) The inventory at the external supplier CD needs to be manually tracked and managed. These two challenges can be summarized as the order management process of part 3 of the PODD supply chain. This complex order management process prevents the supply chain from being easily scalable, which is undesired because production growth is necessary.

RQ.4 *What performance measures can be selected to evaluate the most impactful challenges?*
We decided to apply Business Process Redesign (BPR) as a base for the redesigning process. Based on the literature research, various perspectives on performance measurements in the supply chain are addressed. The main message of most studies is to evaluate the performances of different measurement types to inclusively measure overall performances. Our goal is to improve the PODD order management process. We include a cost, time, and (internal) quality measure, which are the yearly costs of man-hours spent to execute the order management tasks, the percentage of time spent by a resource versus the available hours per year, and employee satisfaction respectively.

RQ.5 *Based on these measures, what are the performances of the supply chain with the current demand and forecasted future demand?*
The yearly costs of Part 3 of the order management process will be almost doubled in the future in comparison to the costs of the past years if we do not change this process. The same reasoning holds for the percentage of time spent per year on most resources.

RQ.6 *What organizational changes are necessary for the PODD supply chain to cope with the most impactful problems and to improve the performances?*
Redesign possibilities for the actual order management process are found using the 29 BPR heuristics as a guideline. We found six heuristics that might be beneficial to lower costs and time spent by the Supply Chain Engineer and Strategic Buyer, which is objected to. The redesigns tested are integration, flexible assignment, specialist-generalist, buffering, task automation, and outsourcing. On top of that, two combinations of redesigns were tested because of the potential to improve. Based on the cost and time perspective we found a selection of the most promising redesigns.

RQ.7 *How shall the changes be implemented within the current infrastructure?*
Redesigning business processes is accompanied by making trade-offs. Therefore, before deciding whether to adopt one of the redesigns, it is important to first quantify potential implications on other performances as well as the influence on implementation costs, time, and risk. The lists of implementation effects serve as a foundation for further investigation.

Concluding, we answer the main research question. The PODD supply chain management structure can be improved by changing the order management process. By improving the order management process Malvern Panalytical is better able to scale supply chain operations. By designing the process more efficiently, it can be ensured that an increase in demand has less effect on the management burden than in the current situation. We found that if nothing will change, the Supply Chain Engineer will spend up to 10% of the total time available per year on order management and the costs to perform order management activities continue to rise. Spending this much time on order management of part 3 of the PODD supply chain is undesired. The management burden can be lowered by implementing the integration or specialist-generalist redesign, or the combination of redesign flexible assignment with task automation, or the combination of redesign flexible assignment with specialist-generalist. However, the implementation costs, time, and risk need to be investigated further before one of the redesigns can be chosen. Another way to slightly improve the order management process is to higher the delivery performance of the first-tier supplier. This can be an improvement in the current design but also in each redesign. The degree of reduction of the management burden due to delivery performance improvement will depend on the number and type of activities in the feedback loop. A redesign with feedback loops that consist of fewer activities compared to the currently implemented design is suggested in order to decrease the impact of delivery performance.

5.2 Limitations and further research

In this section, the limitations of this research that are a direction for further research are discussed. A limitation of this research is that the predicted impacts are mostly based on estimated data. First, the company does not measure time spent on certain activities, thus these must be estimated. Therefore, we needed to estimate activity times and the occurrences of the activities. Second, the wage per hour for all resource types was estimated. Third, we do not have forecasts available for the key components and assy headers. Thus, an estimation is made based on how we expect that MRP will deal with these orders. Furthermore, for some redesigns, reconsideration was necessary for activity times and occurrences, which were also estimated. The expert knowledge is assumed reliable and realistic. However, it still is a limitation because it is based on estimations and expectations and not on real data. Additionally, all estimations are based on a steady process i.e., average activity times, and average occurrences of feedback loops. We did not test the impact of certain changes because too many changes could be tested. For example, a new employee that will need more time in the beginning while performing tasks is not incorporated, we estimated the times based on experienced employees. Feedback loops could perform more or less in case of improved or decreased on-time delivery performances.

Furthermore, this research has some limitations regarding assumptions and simplifications made in the analysis in Chapter 4. First, we did not incorporate waiting times in our analysis. We decided only to focus on activity times of the order management process since the time spent on these activities is what we aim to decrease. However, it is likely that the redesigns also have an impact on waiting times, influencing the total lead time. Second, we assumed that the feedback loops occur only once for simplicity reasons, while this is not the case in reality. As a result, the costs and time performance measures would be higher in practice and proportions between different redesigns may also slightly differ. Third, we assumed that the buy parts are always in stock. Overall, this mostly represents reality. However, there is one general buy-part in specific that has several supply problems. As a result, the costs and time performance measures would also be higher in practice. The advantage is that this simplification would influence the actual situation and all redesigns with the same increase. Thus, it would not influence the conclusions provided in this study. However, it is suggested to further examine these assumptions and simplifications if it is desired to have more accurate results than the approached results in this analysis.

Another limitation of this research is that findings cannot be generalized. We found redesigns heuristics lead to improvements (e.g., a decrease in order management costs). However, while redesigning, we focused on our objectives and supply chain (management) characteristics. The most important characteristics are, a MTS environment based on MRP-logic, dealing with the two different planning domains, and manually controlling components in-house that are consumed by the supplier. Thus, other processes at Malvern Panalytical and processes of other companies can only benefit from this analysis if the supply chain management structure has similar characteristics. This also holds for the selection of the performance measures, which is very context sensitive as mentioned by Reijers & Mansar (2005). Further research is needed to enable generalizable results and would be a valuable contribution from both academic and business perspectives.

Lastly, the adapted approach to arrange and test redesigns to an existing business process is developed for this research. Before we can conclude that this approach could be used to search for improvement of other business processes or for order management processes at other companies, this should be tested first. Therefore, more case studies can be added to validate whether this approach can be used to improve other business processes. At least in addition to quantifying the impact to implement a redesign is necessary to determine if the benefits of the redesign are worth the investment.

5.3 Company recommendations

First of all, we recommend the company to decide the importance of the limitations of this research and to further investigate if preferred. Subsequently, we suggest Malvern Panalytical to use the results from this analysis to decide whether to change the current order management process to one of the redesigned options. The current design or the redesigns can be further improved if a higher delivery performance of the first-tier supplier can be achieved, which can be discussed with this supplier. The found redesigns can decrease complexity and create a more scalable supply chain management structure. However, Malvern Panalytical has to further analyze the return on investment of the implementation. Implementation aspects are listed in this research to provide a foundation for this analysis. The return on investment can be compared with the estimated savings, which are provided in this research.

Second, we have recommendations for some specific redesigns if implementation will be considered. First, if Malvern Panalytical considers a redesign, it is advised to investigate implementing this in part 1 and 2 of the PODD supply chain. For example, redesign 5.1 (task automation) since in part 1 and 2 similar manual tasks occur that can be automated. Second, if the combination of redesign 2.1 and 3.1 is considered. It is suggested to investigate to implement redesign 3.1 (specialist-generalist) before redesign 2.2 (flexible assignment). Redesign 3.1 already is relatively cost-effective and decreases the involvement of the Supply Chain Engineer while this redesign is expected to be easier to implement than redesign 2.2. The advantage of implementing one redesign at a time is that Malvern Panalytical could already benefit from savings caused by redesign 3.1 in case it takes relatively more time to implement redesign 2.2. This reasoning also holds for the combination of redesign 2.2 and 5.1, of which it might be most effective to first implement redesign 5.1 and afterward redesign 2.2.

Third, change management is recommended for the successful implementation of the new way of working. Since the supply chain management structure is developed this way to have the desired amount of control it is important to share, discuss, and validate the redesign before implementation. This research can be internally used to support the understanding of certain redesigns. Even if higher management decides not to redesign the order management process, it shall be important to involve stakeholders of the order management process in this decision.

5.4 Contribution to literature

This study contributes to the literature by selecting BPR as a foundation to improve the order management process and providing an approach that fits this context. To our knowledge, little research is conducted to improve the execution of the order management process. BPR was already applied to processes that have similarities with order management. Thus, we provide a case study in which we tested six BPR heuristics and ten initial redesigns, and two redesign combinations within the order management process.

Researchers suggested further research to test redesign combinations (Jansen-Vullers et al., 2008). In this research, two redesign combinations are tested. Both redesign combinations are in the top five best-performing redesigns found. Thus, it can be concluded that testing combinations of redesigns are interesting for this case study. We found that we cannot simply accumulate savings from two redesigns because of potential overlapping. Thus, one should address a combination of two redesigns as a separate redesign when testing potential performance improvement.

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Appendix A

Initial cause-and-effect diagram

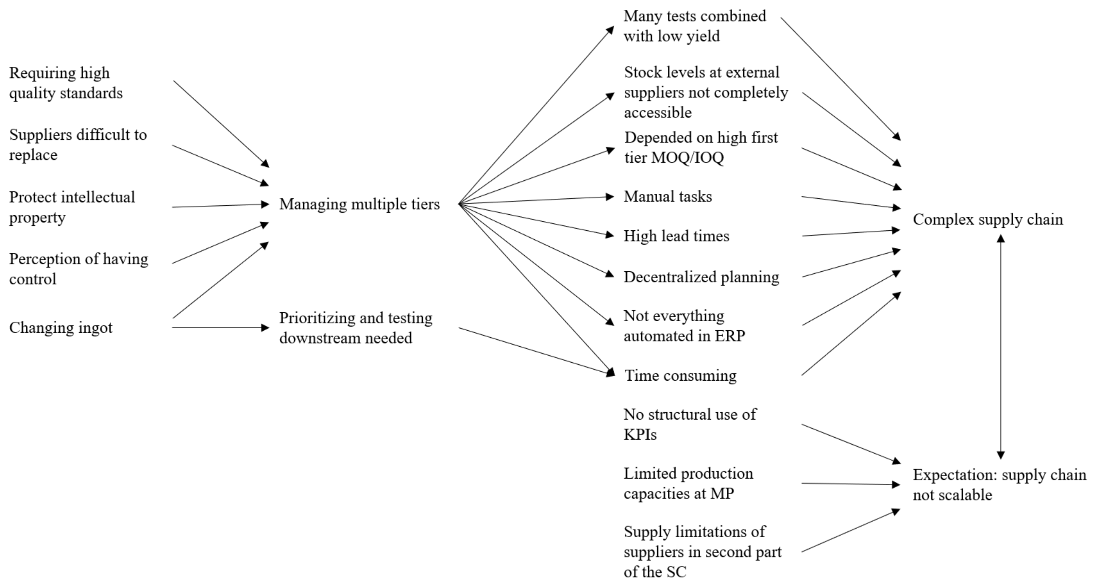


Figure A.1: Initial cause-and-effect diagram used for project proposal

Appendix B

BPMN of order management process part 1 and 2

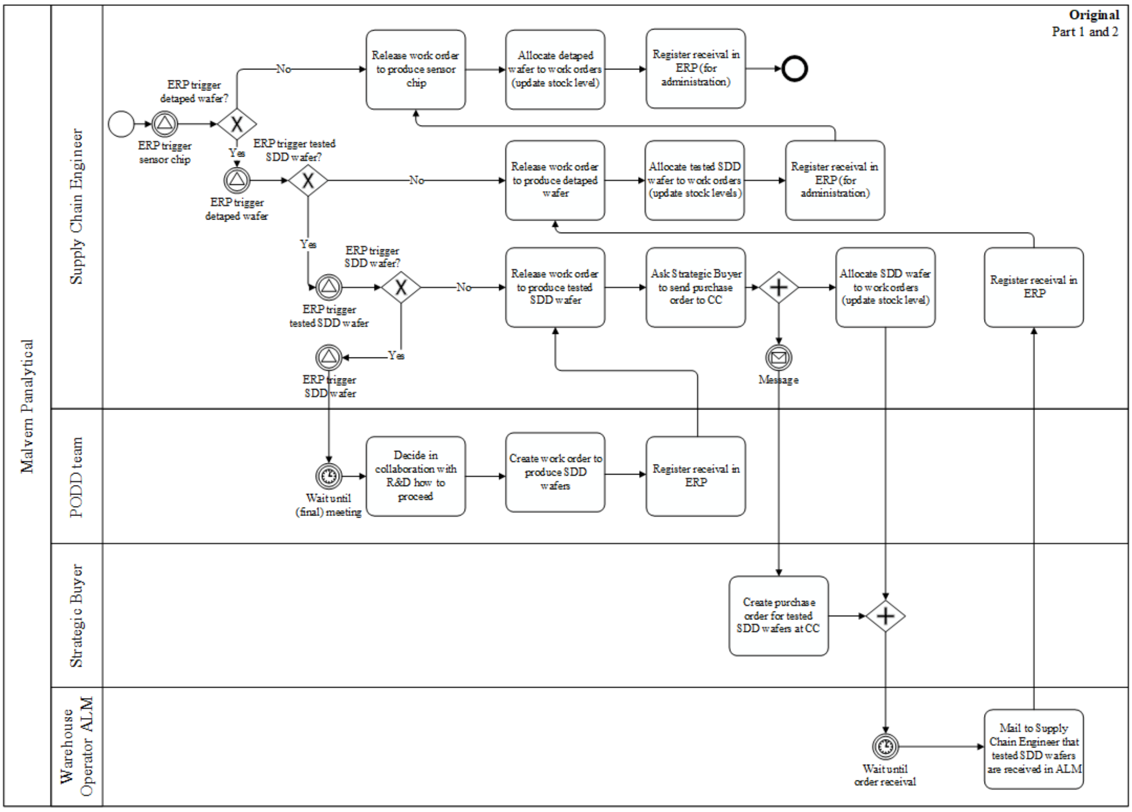


Figure B.1: BPMN part 1 and 2: order management process to order wafers until sensor chips

Appendix C

Business process redesign

See next page.

Category	**Best practice**	**Explanation**
Customer	Control relocation	Relocate control more towards the customer
	Contact reduction	Minimize customer and third party contact
	Integration (8)	Integrate with business processes of customer or supplier
Business process operation	Order types	Determine whether tasks belong to the business process, if not create a new business process.
	Task elimination (1)	Eliminate unnecessary tasks
	Order-based work	Consider to remove batch-processing and periodic activities
	Triage	Consider to split up one general task into at least two alternative tasks or vice versa
	Task composition (2)	Combine or split tasks to balance workload
Business process behavior	Re-sequencing (6)	Relocate tasks to get a more logical order
	Knock-out	Arrange knock-outs in decreasing effort and rising termination probability
	Parallelism (9)	Consider performing tasks in parallel
	Exception	Use the business process for non-exceptional orders only
Organization structure	Order assignment (5)	Assign as many tasks as possible to a single order
	Flexible assignment	Assign tasks to the most specialized resource
	Centralization	Centralized management of geographically distributed resources
	Split responsibilities	Prevent task division to employees from different functional units
	Customer teams	Create a team of employees from different departments working on complete handling of specific orders
	Numerical involvement (10)	Reduce number of participants involved
	Case manager	One responsible employee for a specific order or customer
Organization population	Extra resources	Increase number of resources in case of capacity issues
	Specialist-generalists (7)	Reconsider balance of specialists and generalists based on desired performances
	Empower (4)	Reduce middle management by providing more authority to employees
Information	Control addition	Check incoming and outgoing materials
	Buffering	Subscribe to updates instead of requesting information from external parties
Technology	Task automation	Replace manual tasks with automated systems
	Integral technology (3)	Try to overcome physical limitations in a business process through the application of new technology
External environment	Trusted party	Gather information at trusted parties instead of determining in-house
	Outsourcing	Outsource a (part of a) business process
	Interfacing	Use a standardized interface with external environment

Table C.1: Best practices for each category within BPR (Reijers & Mansar, 2005)

Appendix D

PFD and BPMN diagrams of the redesigns

D.1 Redesign 1.1.1

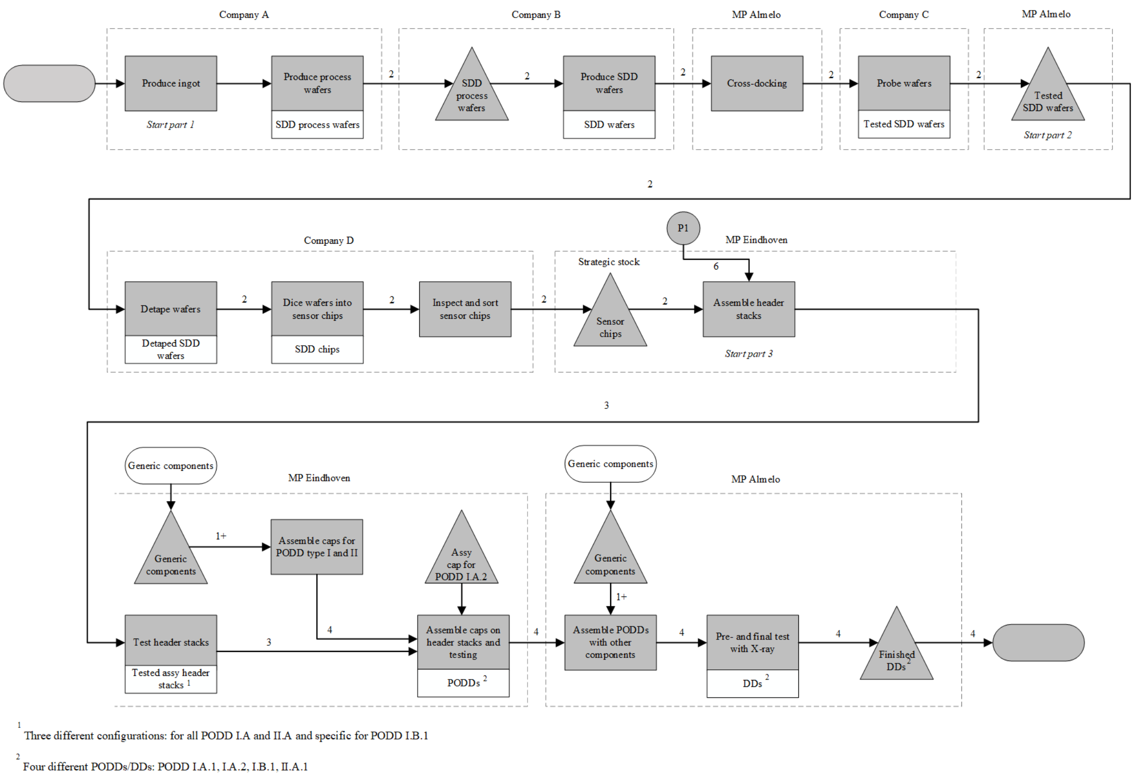


Figure D.1: PFD for redesign 1.1.1: Integration part of process CD with MP Eindhoven and key component storage at MP Eindhoven

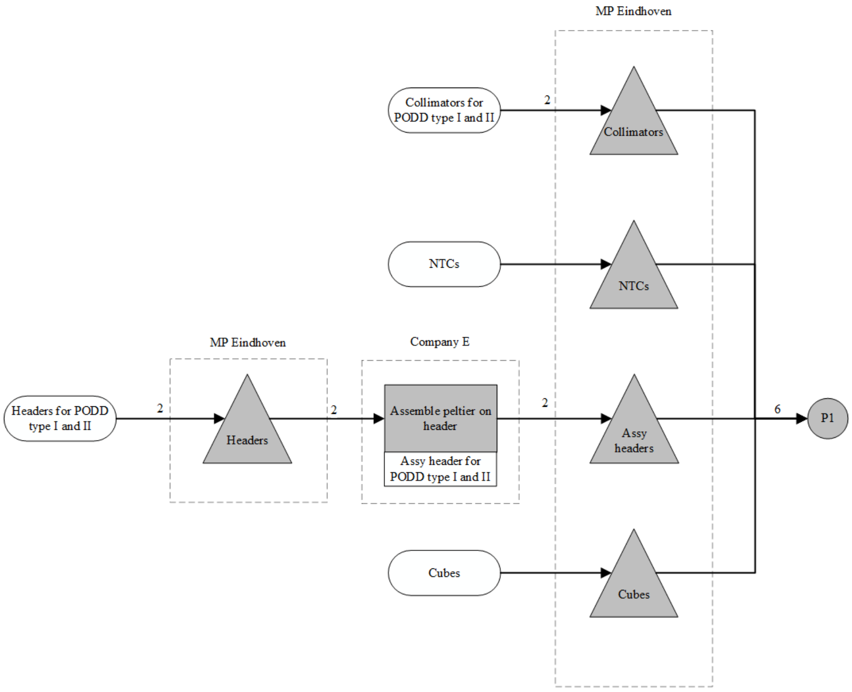


Figure D.2: PFD parallel flow for redesign 1.1.1: Integration part of process CD with MP Eindhoven and key component storage at MP Eindhoven

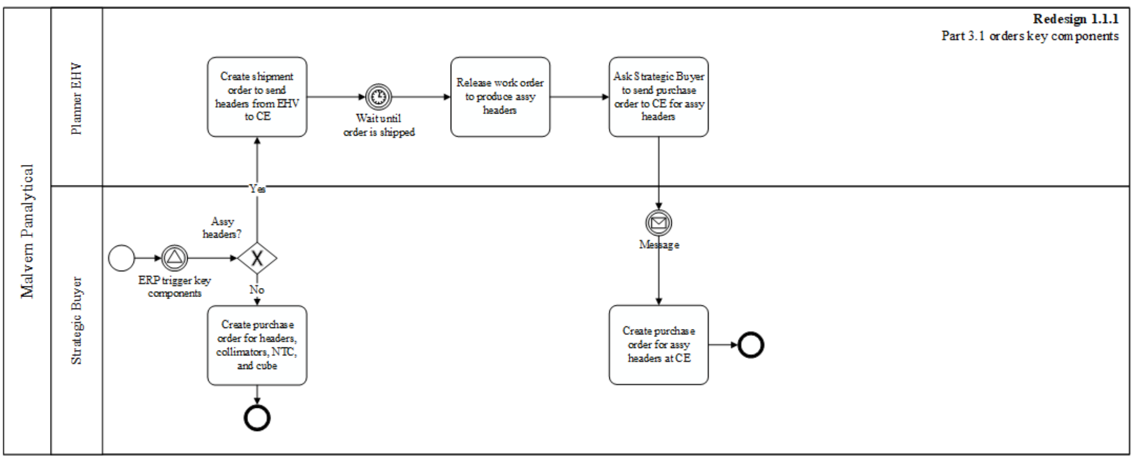


Figure D.3: BPMN part 3.1 of redesign 1.1.1: Integration part of process CD with MP Eindhoven and key component storage at MP Eindhoven

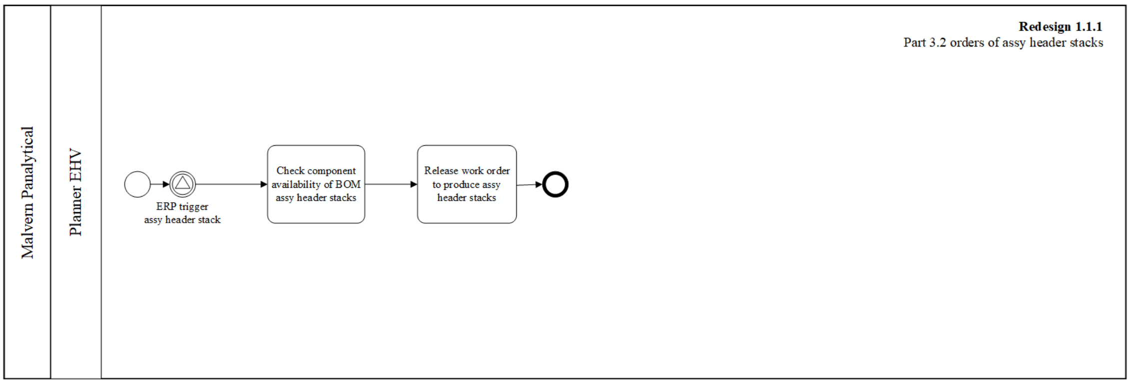


Figure D.4: BPMN part 3.2 of redesign 1.1.1: Integration part of process CD with MP Eindhoven and key component storage at MP Eindhoven

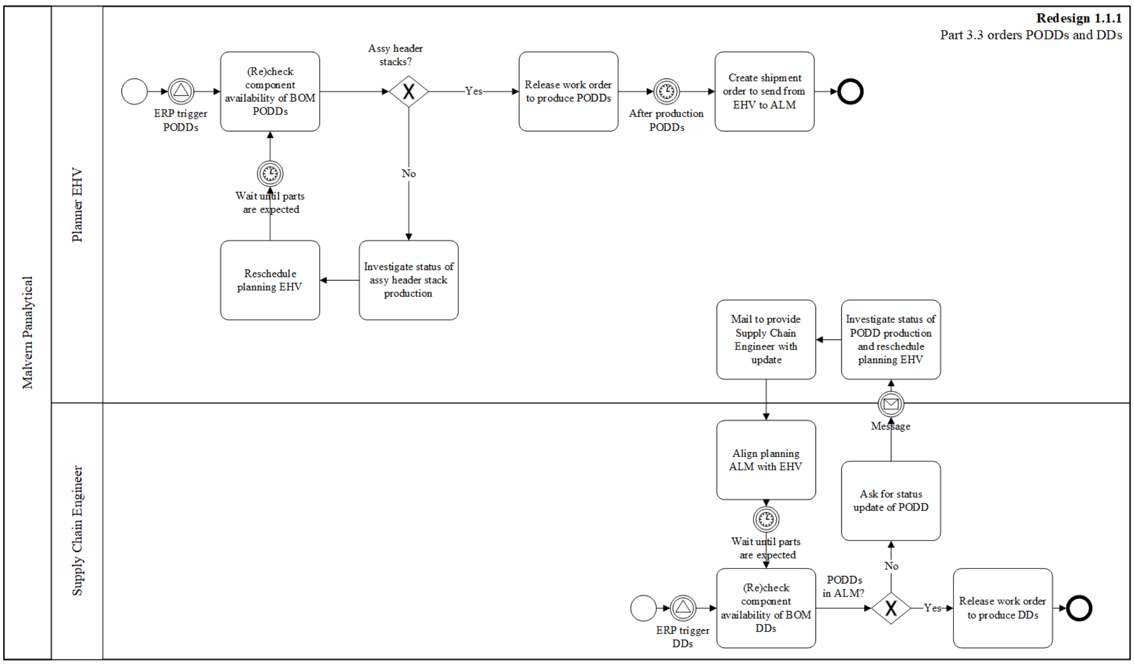
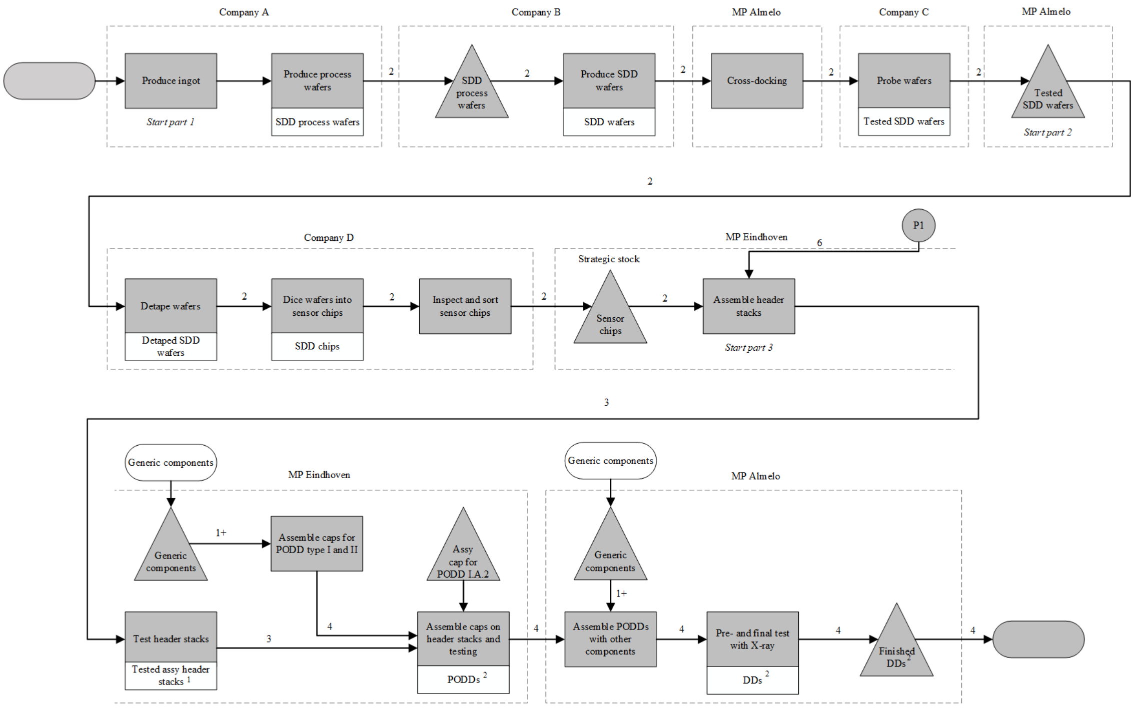


Figure D.5: BPMN part 3.3 of redesign 1.1.1: Integration part of process CD with MP Eindhoven and key component storage at MP Eindhoven

D.2 Redesign 1.1.2



1 Three different configurations: for all PODD I.A and II.A and specific for PODD I.B.1

2 Four different PODDs/DDs: PODD I.A.1, I.A.2, I.B.1, II.A.1

Figure D.6: PFD of redesign 1.1.2: Integration part of process CD with MP Eindhoven while storage of key components stays at MP Almelo

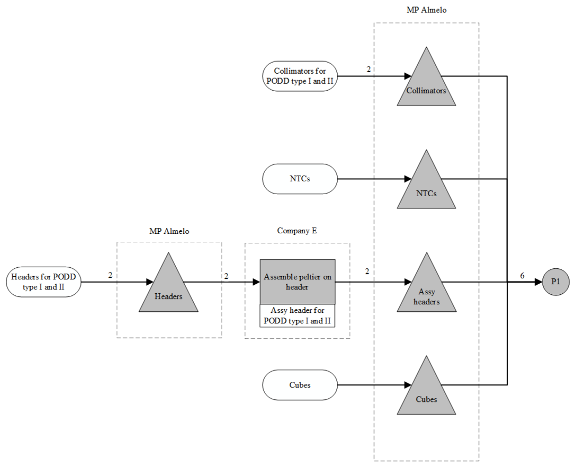


Figure D.7: PFD parallel flow of redesign 1.1.2: Integration part of process CD with MP Eindhoven while storage of key components stays at MP Almelo

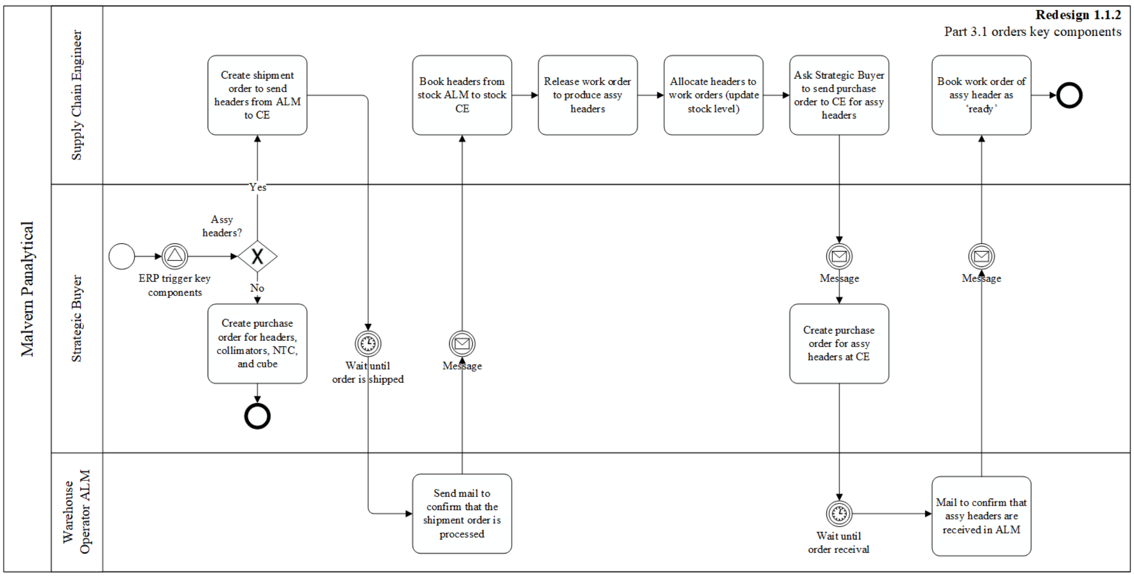


Figure D.8: BPMN part 3.1 of redesign 1.1.2: Integration part of process CD with MP Eindhoven while storage of key components stays at MP Almelo

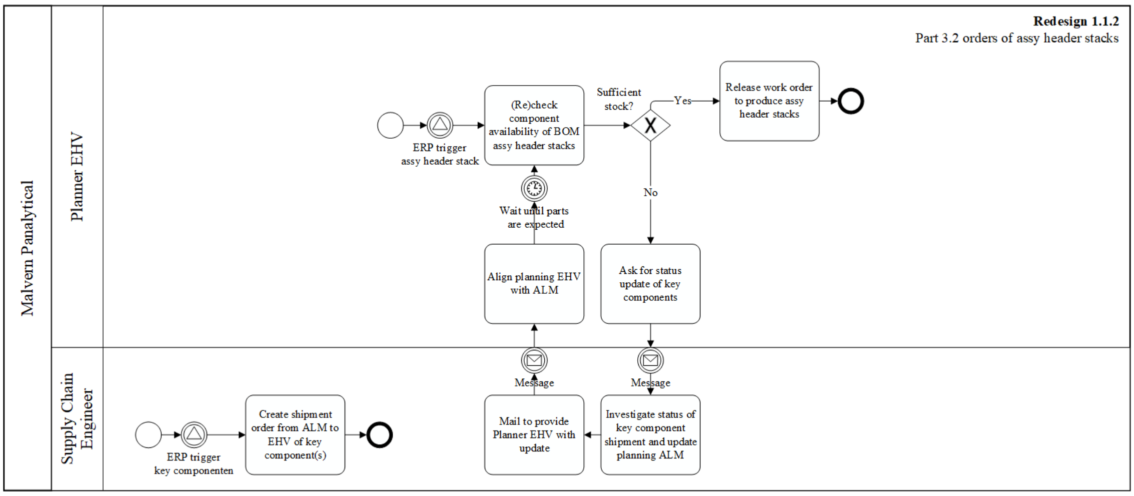


Figure D.9: BPMN part 3.2 of redesign 1.1.2: Integration part of process CD with MP Eindhoven while storage of key components stays at MP Almelo

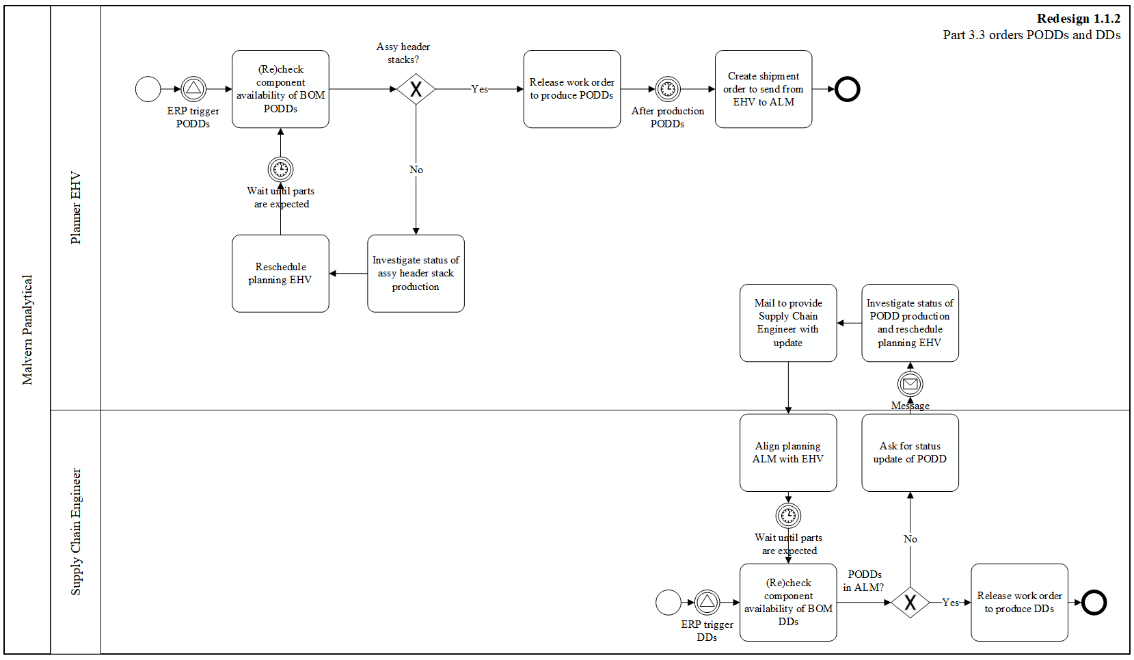
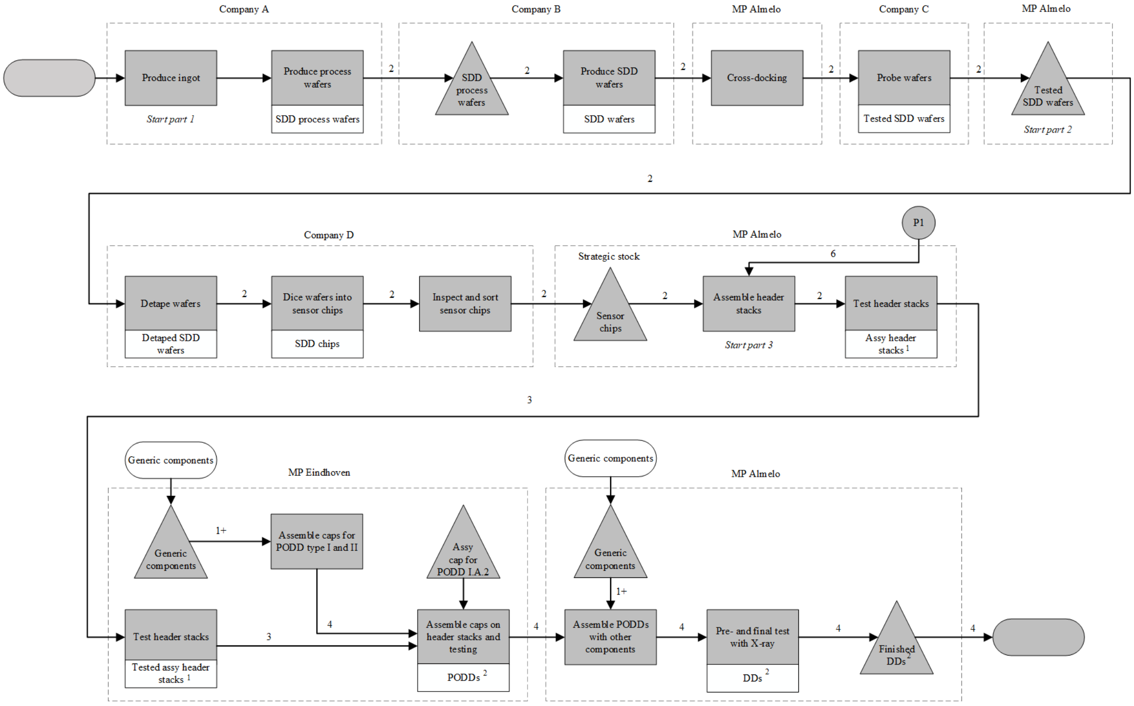


Figure D.10: BPMN part 3.3 of redesign 1.1.2: Integration part of process CD with MP Eindhoven while storage of key components stays at MP Almelo

D.3 Redesign 1.2



[1] Three different configurations: for all PODD I.A and II.A and specific for PODD I.B.1

[2] Four different PODDs/DDs: PODD I.A.1, I.A.2, I.B.1, II.A.1

Figure D.11: PFD of redesign 1.2: Integration part of process CD with MP Almelo

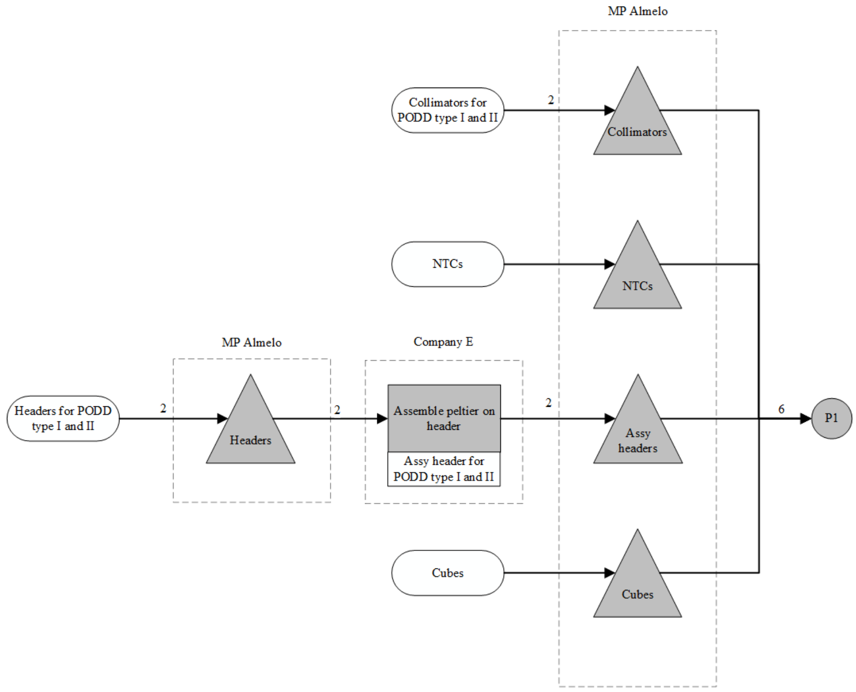


Figure D.12: PFD parallel flow of redesign 1.2: Integration part of process CD with MP Almelo

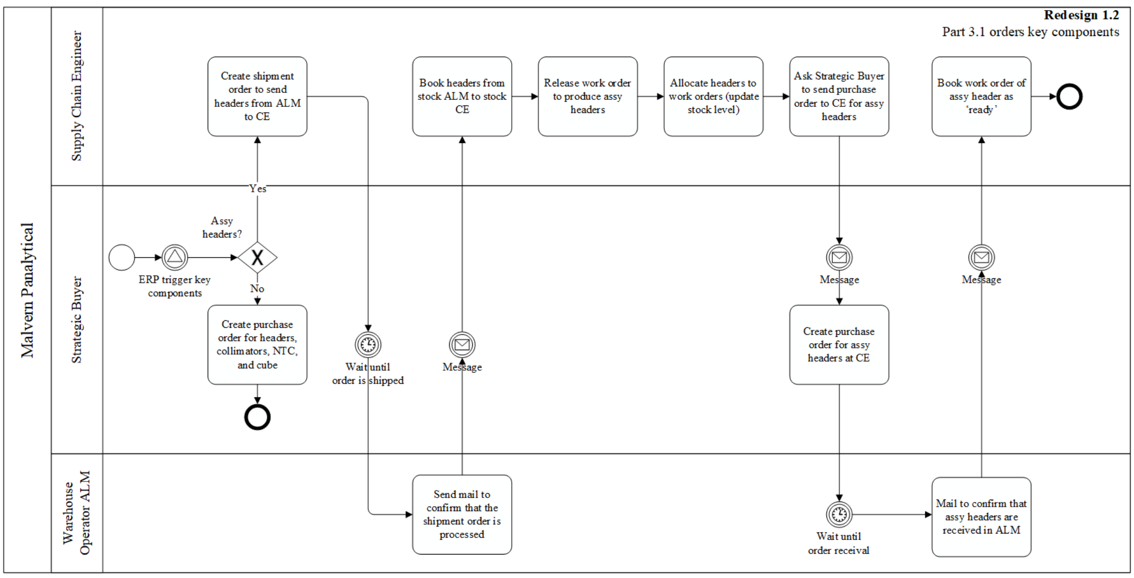


Figure D.13: BPMN part 3.1 of redesign 1.2:Integration part of process CD with MP Almelo

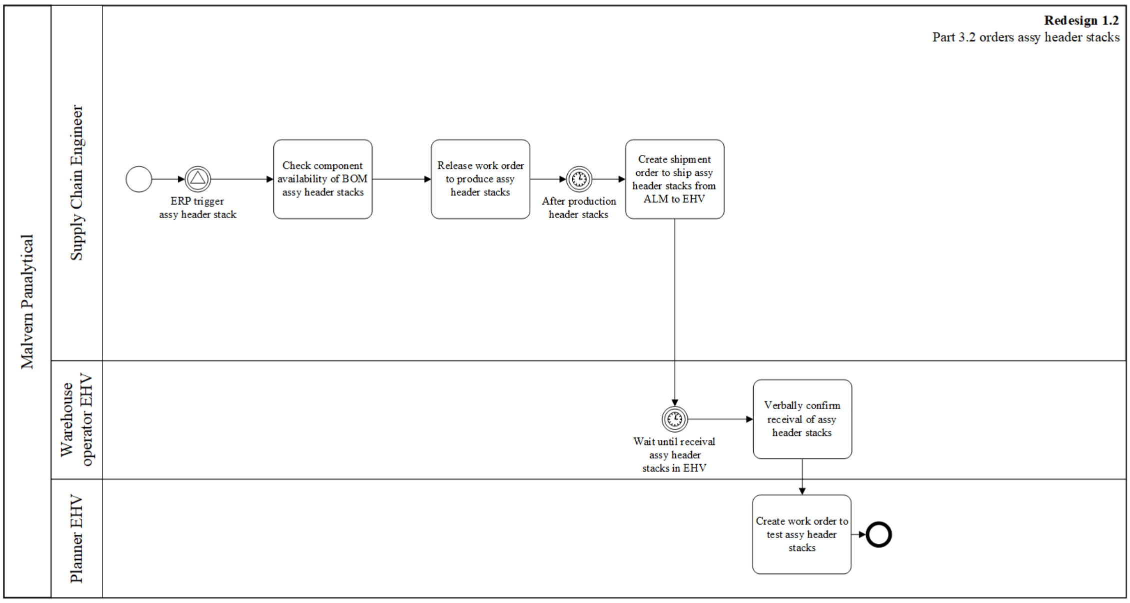


Figure D.14: BPMN part 3.2 of redesign 1.2:Integration part of process CD with MP Almelo

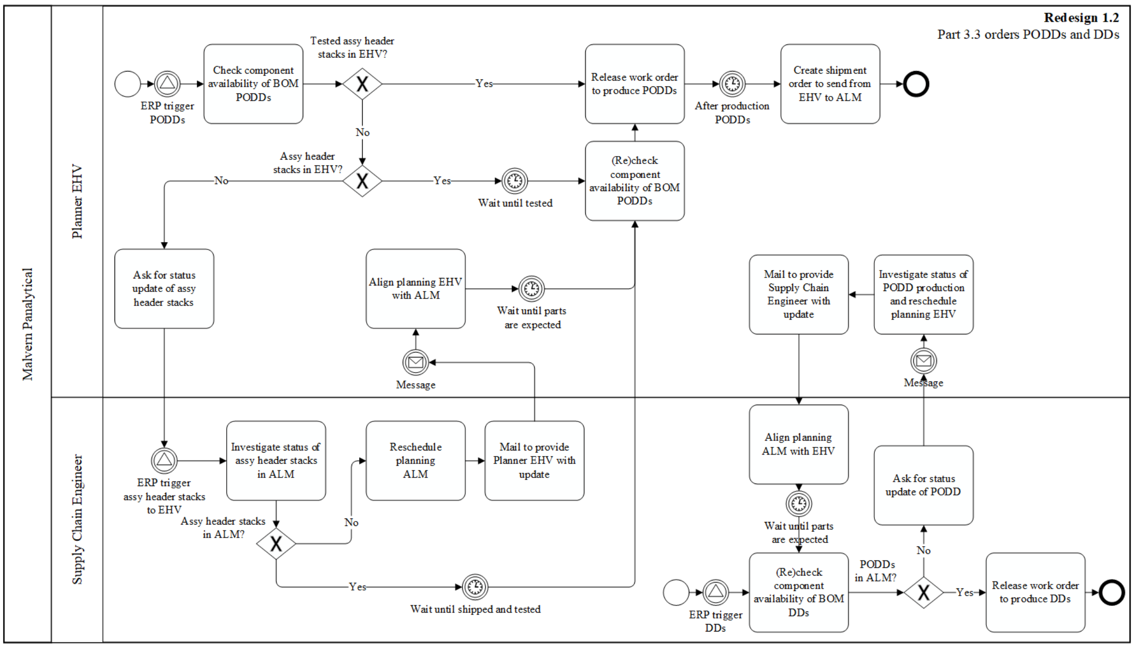


Figure D.15: BPMN part 3.3 of redesign 1.2: Integration part of process CD with MP Almelo

D.4 Redesign 2.1

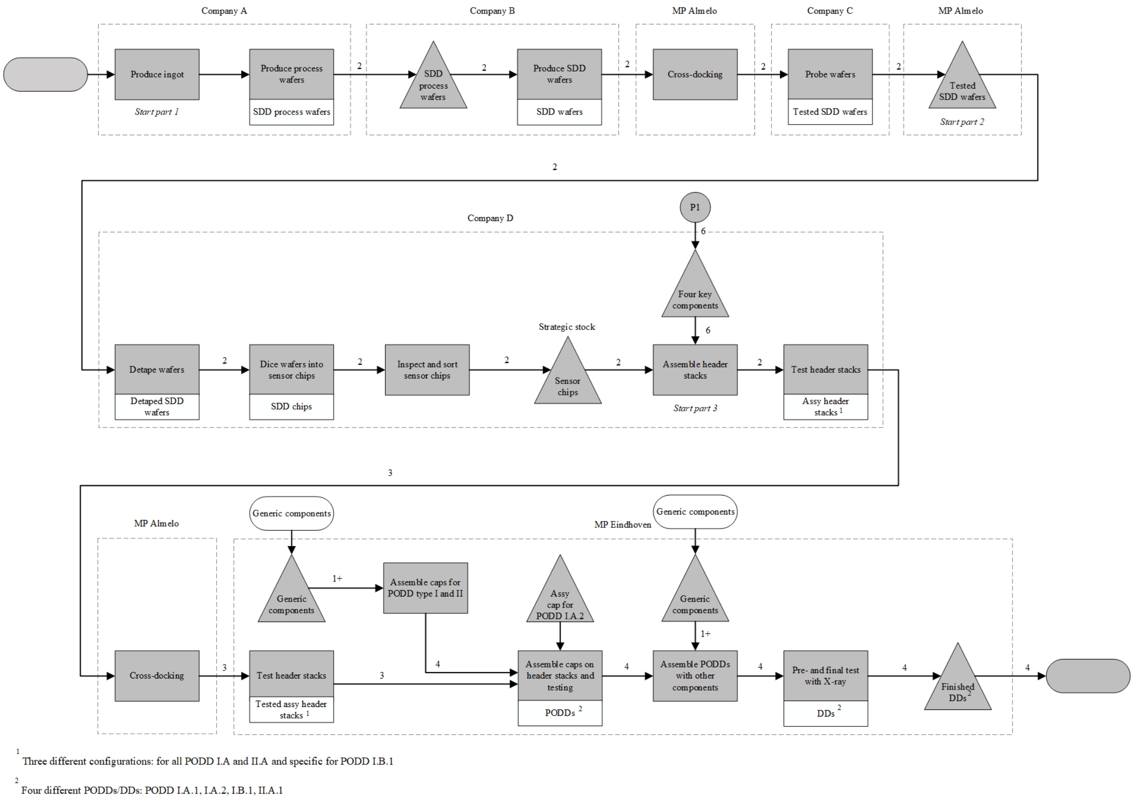


Figure D.16: PFD of redesign 2.1: Move production MP Almelo to Eindhoven

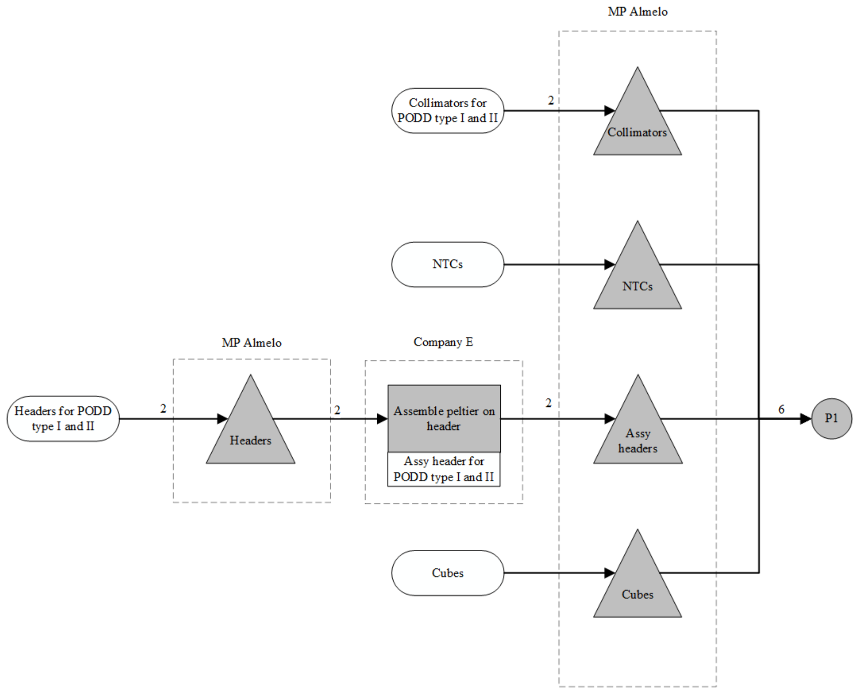


Figure D.17: PFD parallel flow of redesign 2.1: Move production MP Almelo to Eindhoven

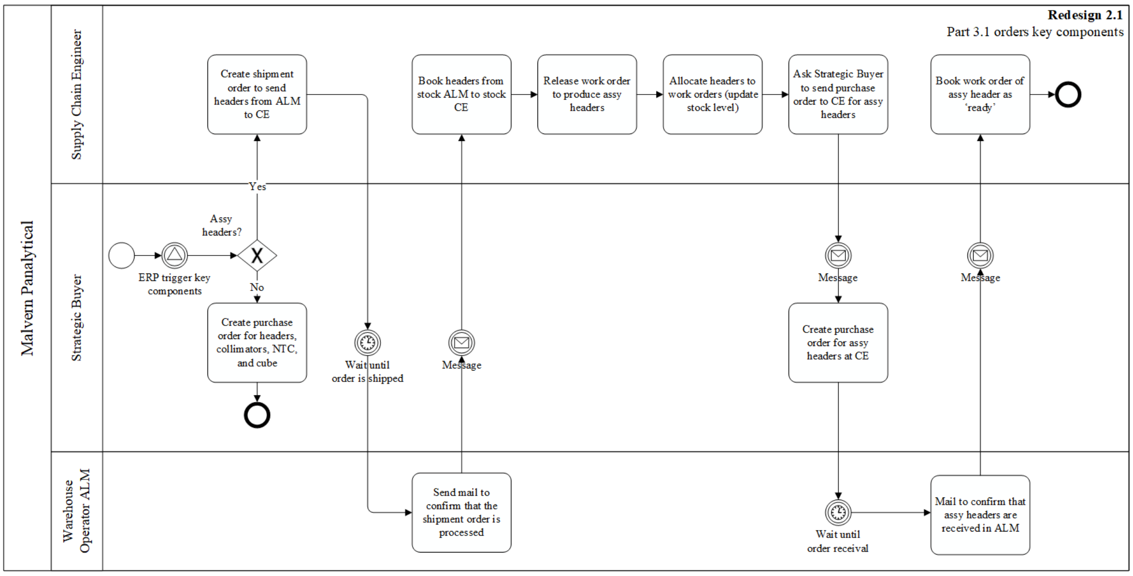


Figure D.18: BPMN part 3.1 of redesign 2.1: Move production MP Almelo to Eindhoven

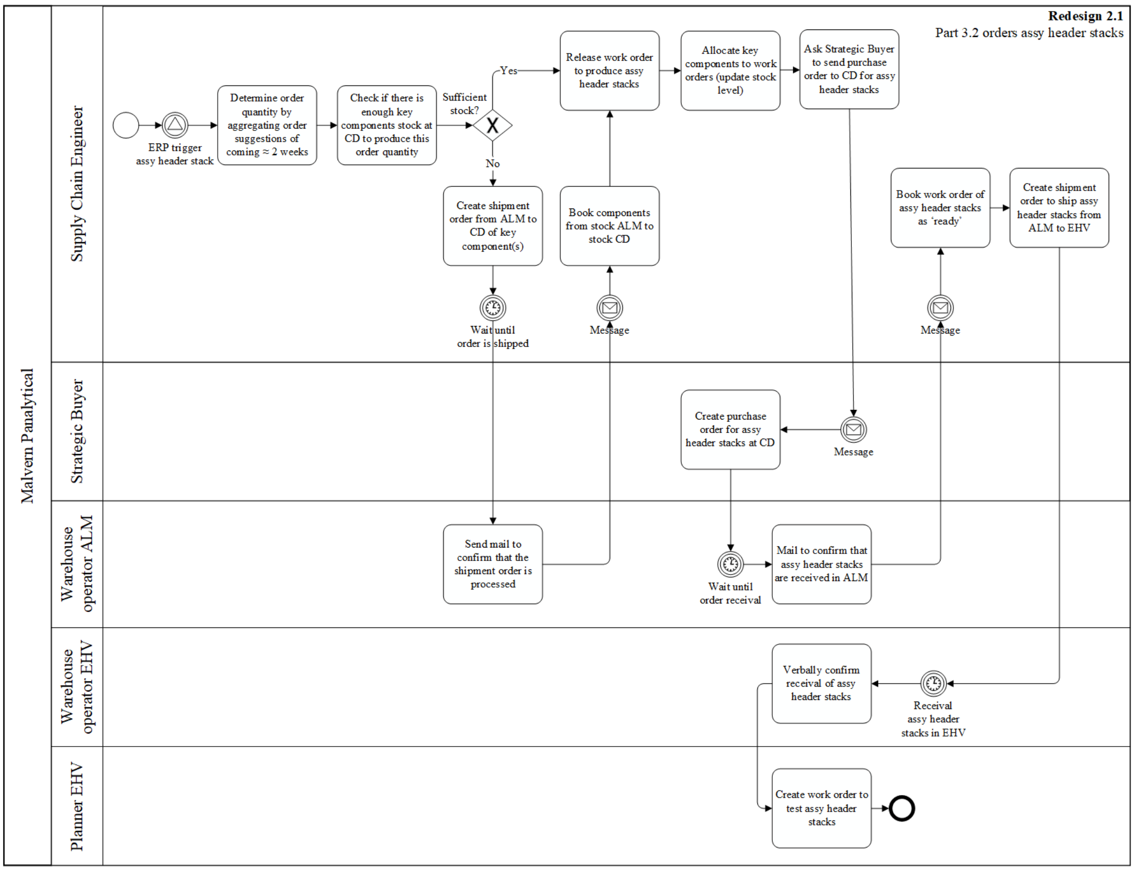


Figure D.19: BPMN part 3.2 of redesign 2.1: Move production MP Almelo to Eindhoven

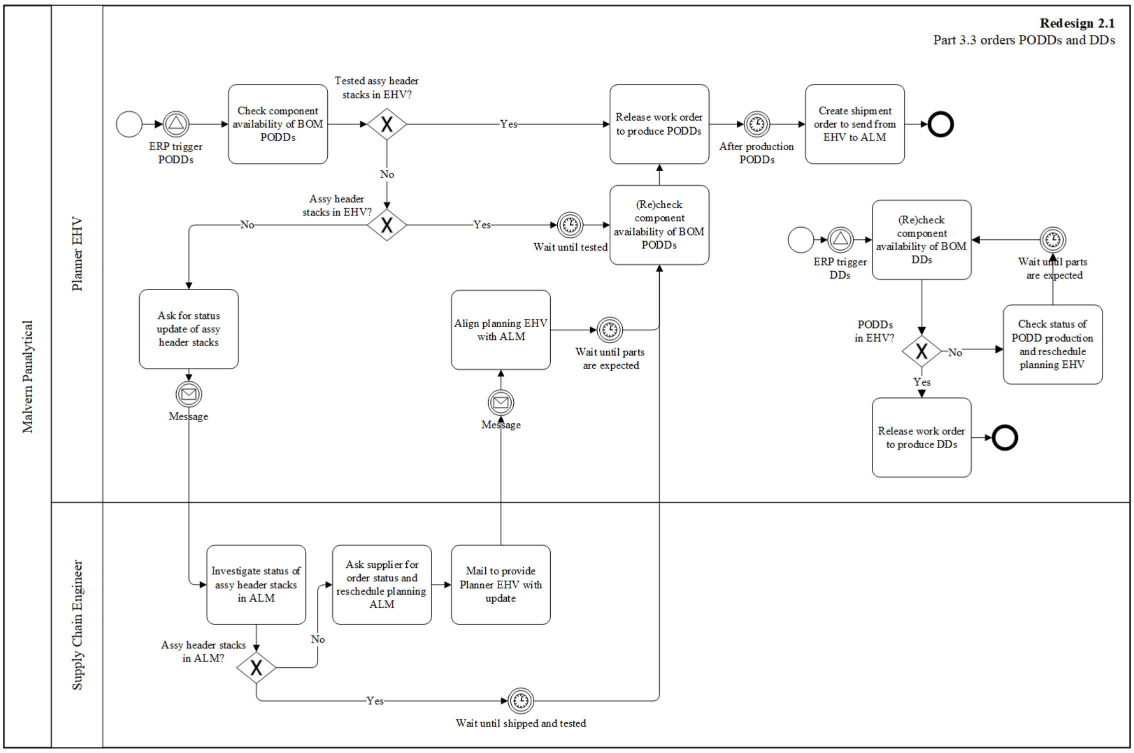


Figure D.20: BPMN part 3.3 of redesign 2.1: Move production MP Almelo to Eindhoven

D.5 Redesign 2.2

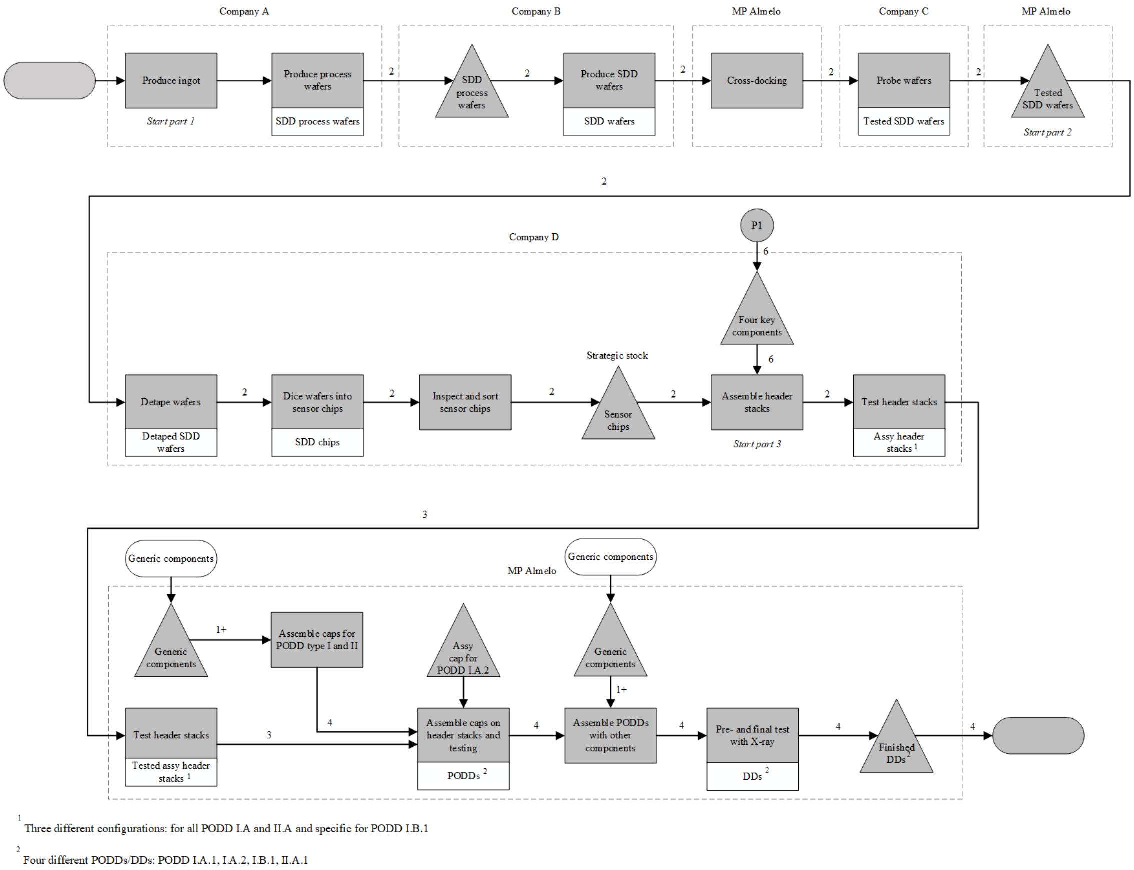


Figure D.21: PFD of redesign 2.2: Move production MP Eindhoven to Almelo

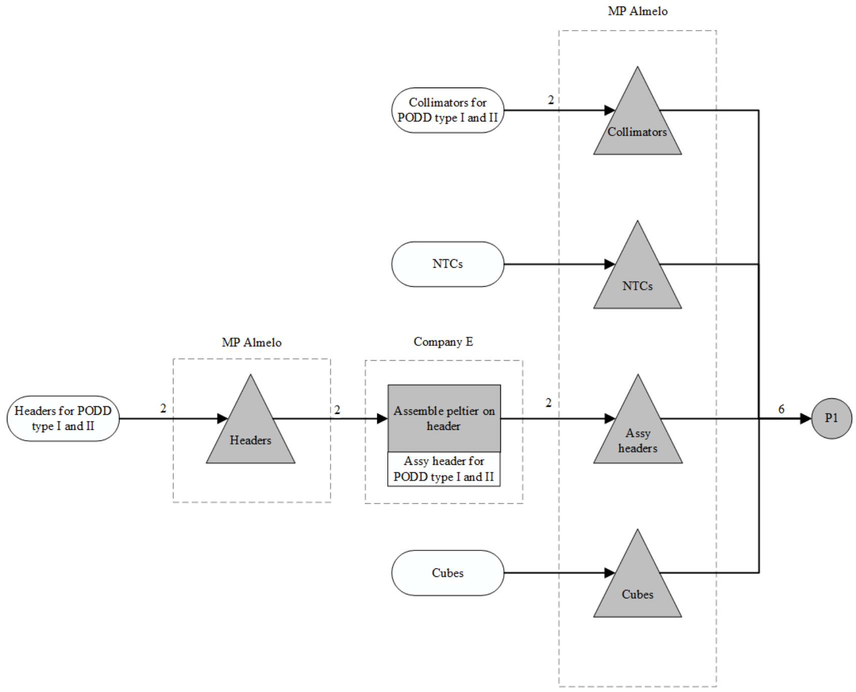


Figure D.22: PFD parallel flow of redesign 2.2: Move production MP Eindhoven to Almelo

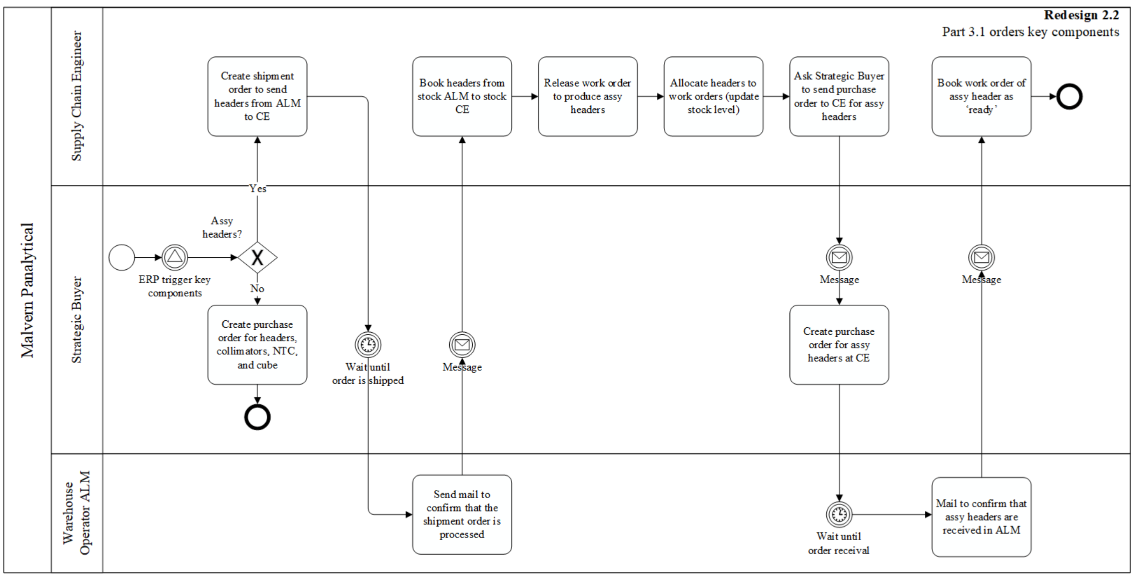


Figure D.23: BPMN part 3.1 of redesign 2.2:Move production MP Eindhoven to Almelo

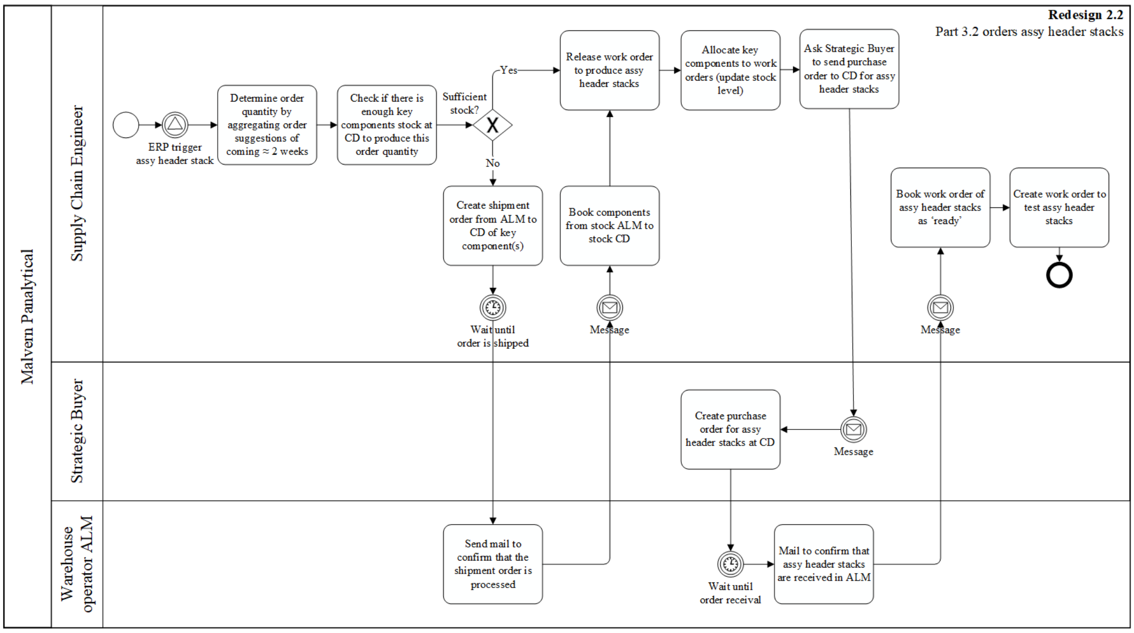


Figure D.24: BPMN part 3.2 of redesign 2.2: Move production MP Eindhoven to Almelo

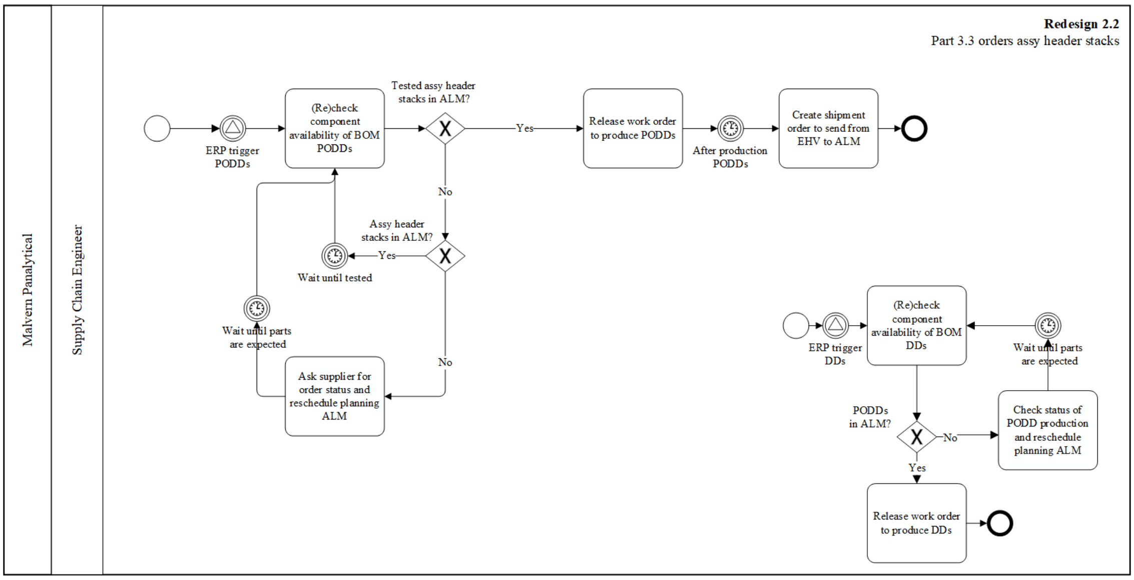


Figure D.25: BPMN part 3.3 of redesign 2.2: Move production MP Eindhoven to Almelo

D.6 Redesign 3.1

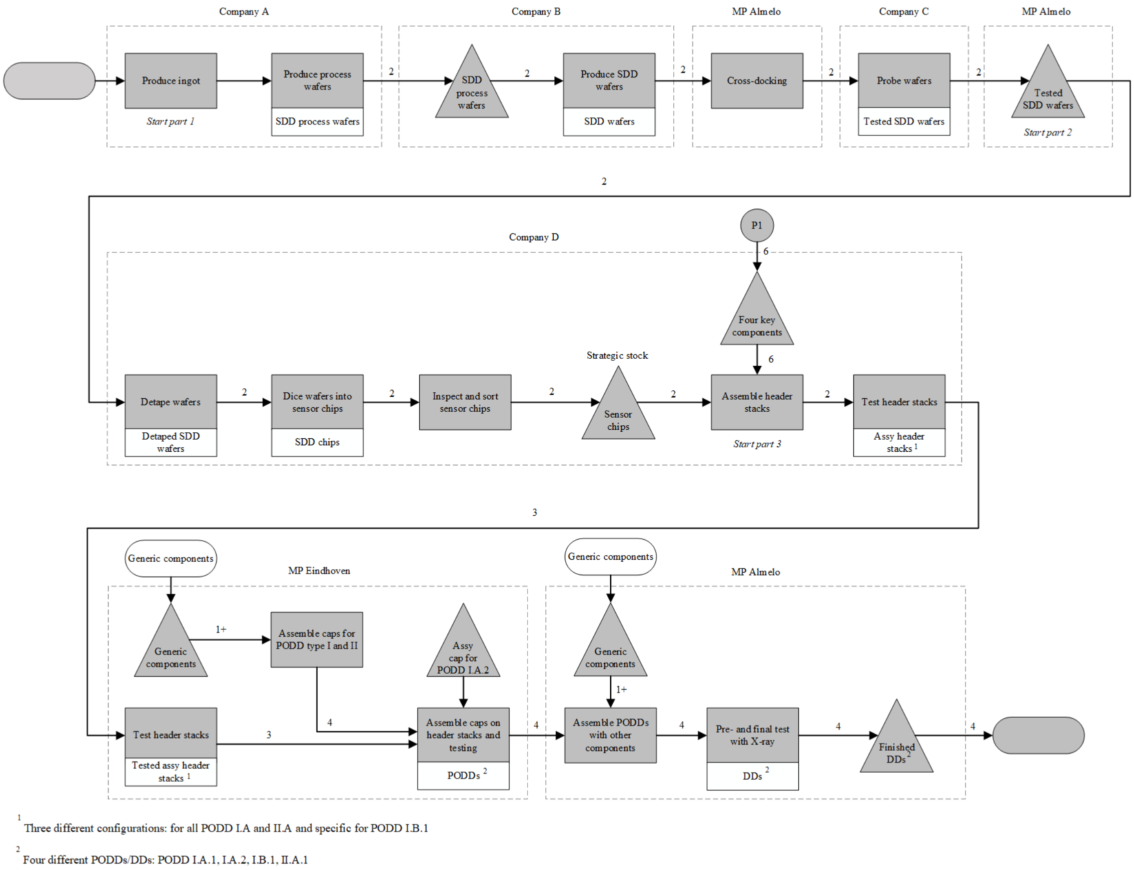


Figure D.26: PFD of redesign 3.1: Move planning of CD and key components to MP Eindhoven

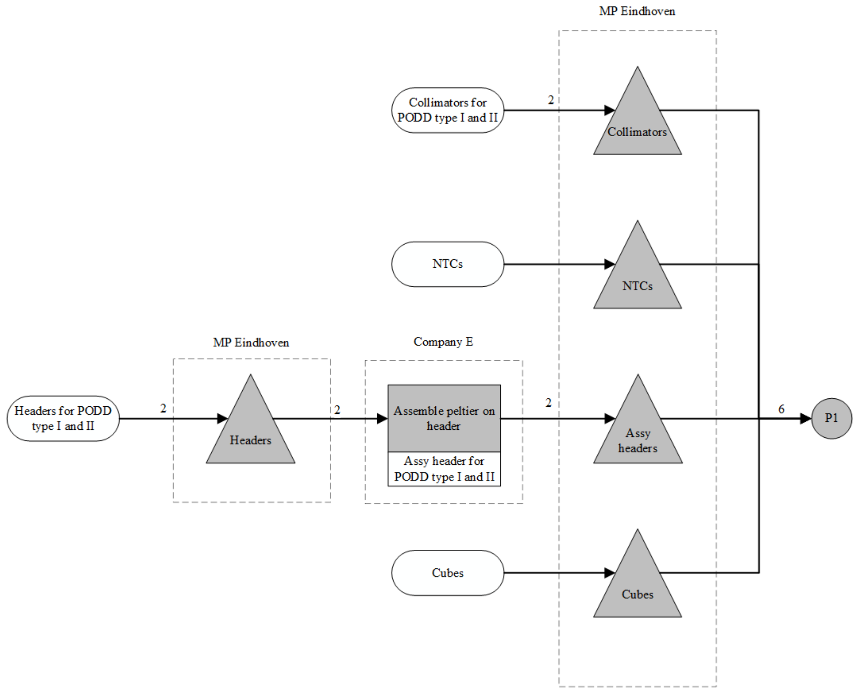


Figure D.27: PFD parallel flow of redesign 3.1: Move planning of CD and key components to MP Eindhoven

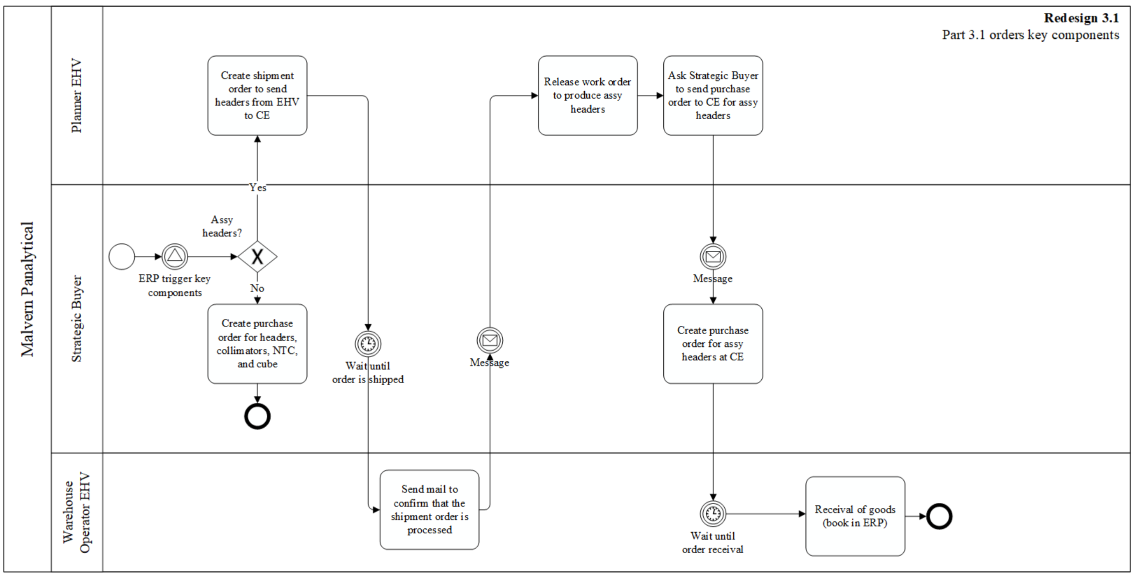


Figure D.28: BPMN part 3.1 of redesign 3.1: Move planning of CD and key components to MP Eindhoven

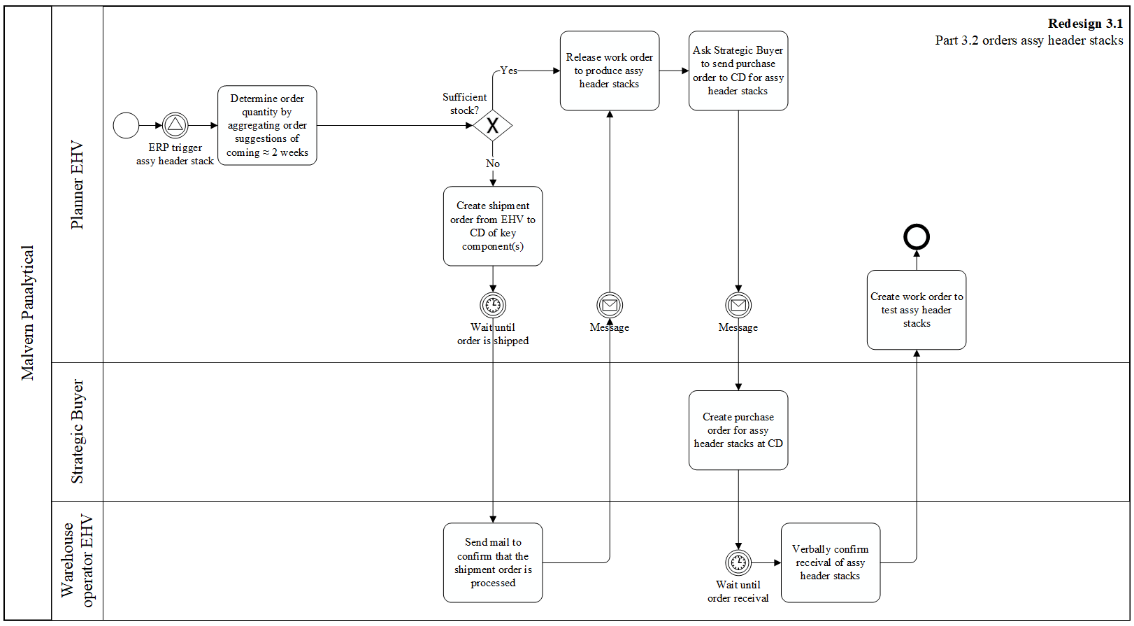


Figure D.29: BPMN part 3.2 of redesign 3.1: Move planning of CD and key components to MP Eindhoven

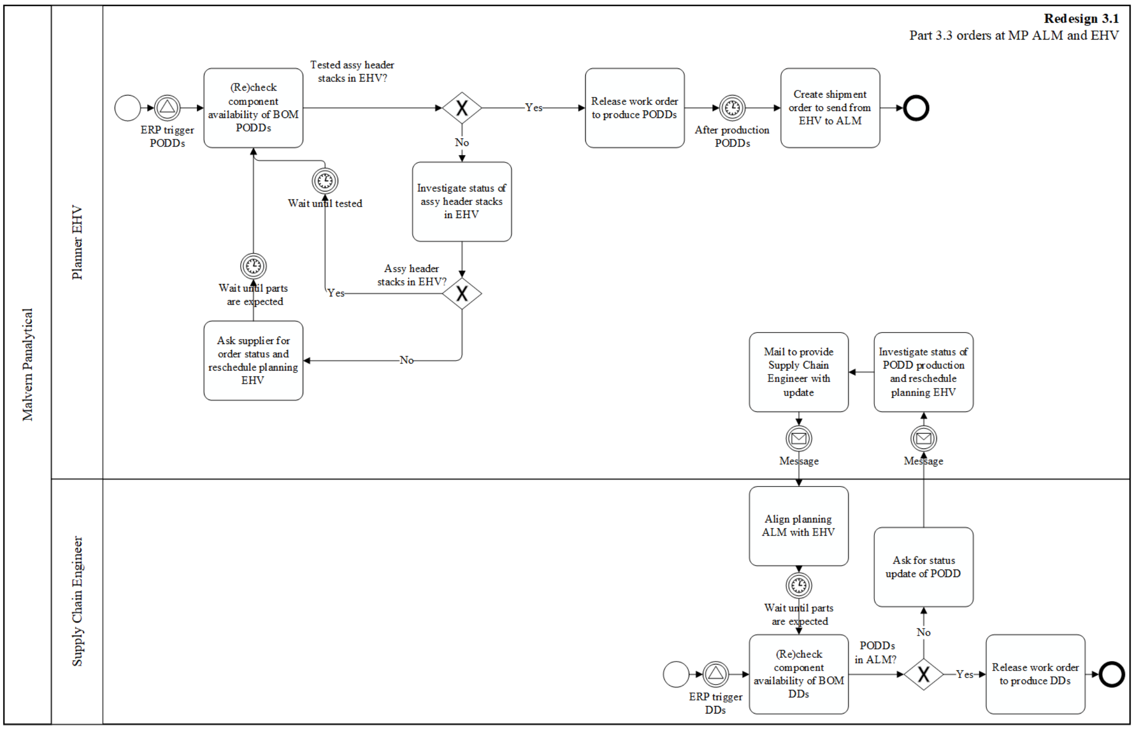


Figure D.30: BPMN part 3.3 of redesign 3.1: Move planning of CD and key components to MP Eindhoven

D.7 Redesign 4.1

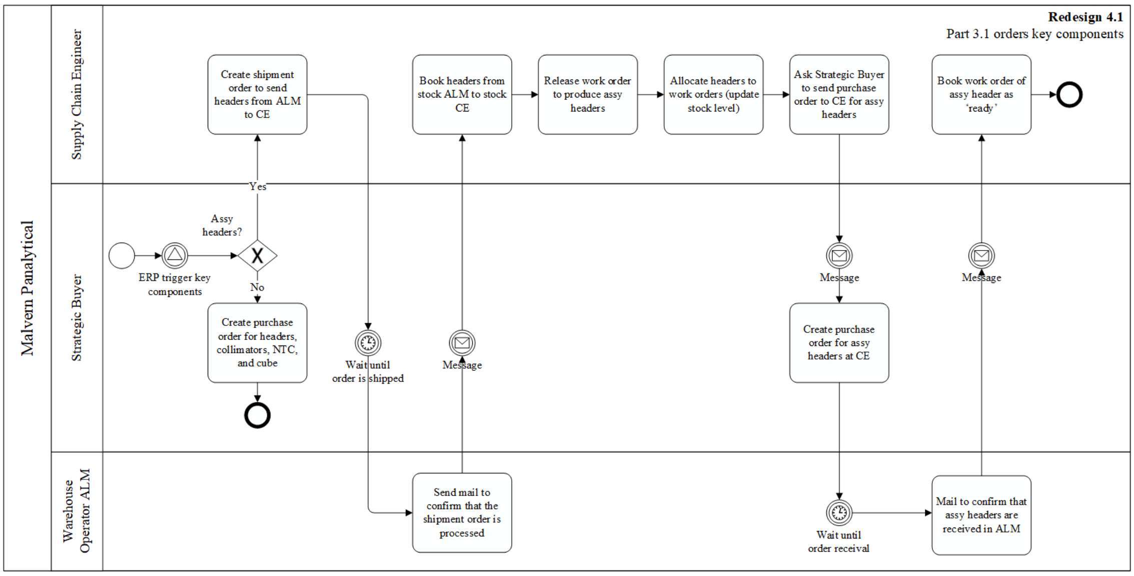


Figure D.31: BPMN part 3.1 of redesign 4.1: Updates from Company D

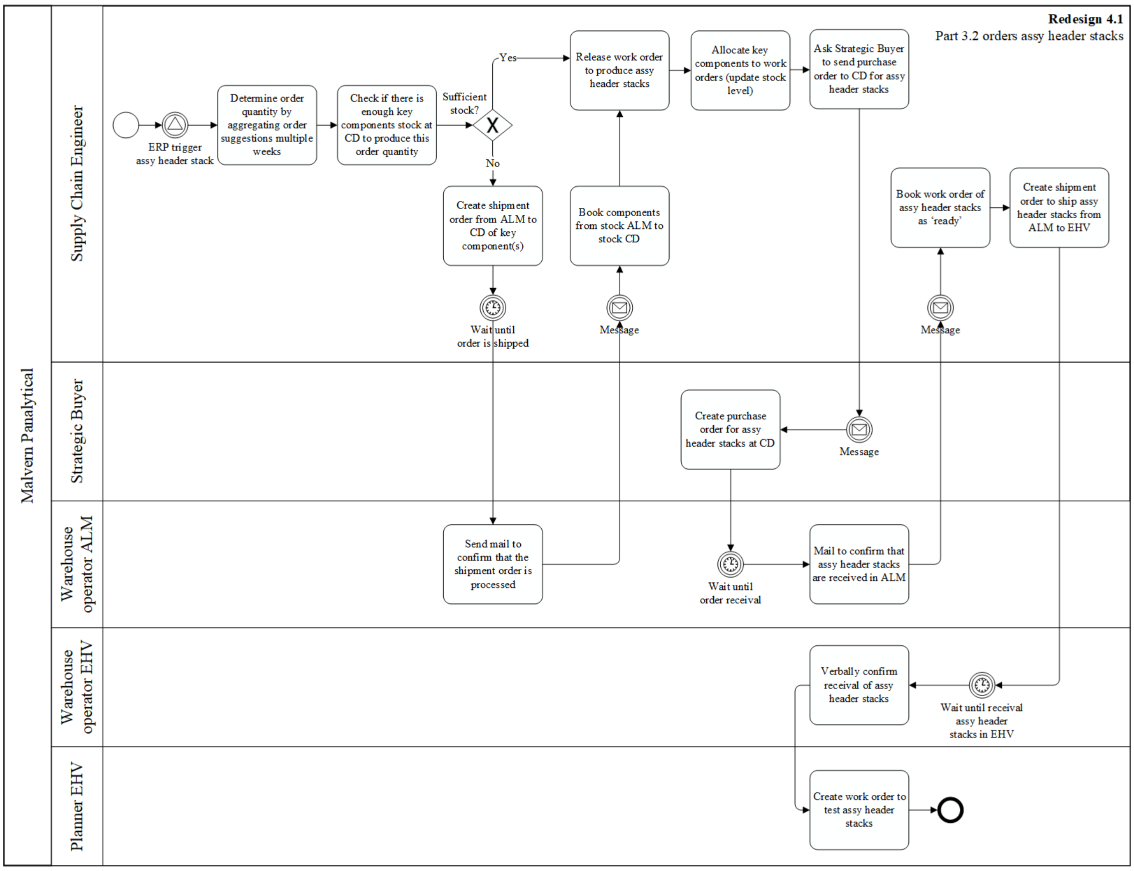


Figure D.32: BPMN part 3.2 of redesign 4.1: Updates from Company D

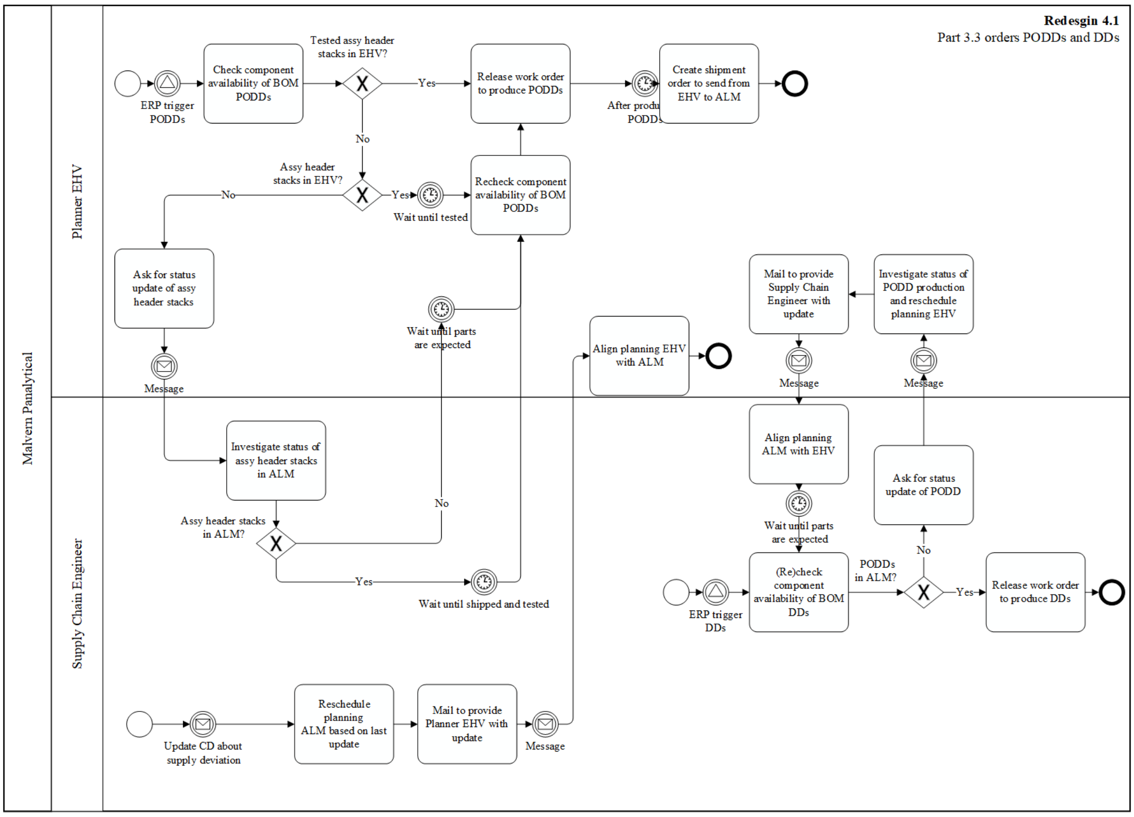


Figure D.33: BPMN part 3.3 of redesign 4.1: Updates from Company D

D.8 Redesign 5.1

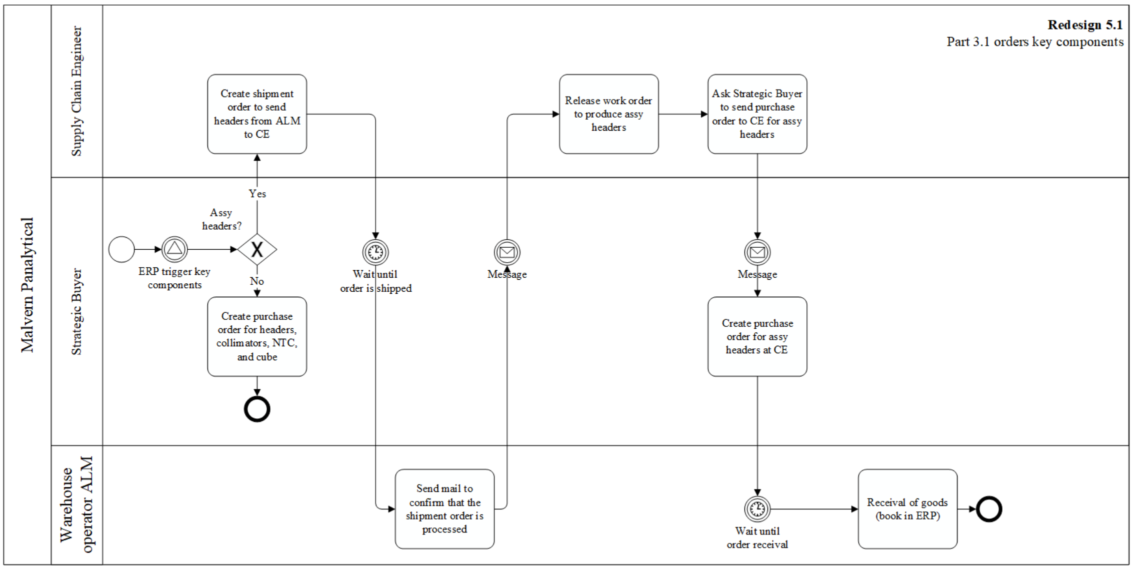


Figure D.34: BPMN part 3.1 of redesign 5.1: Automate routine tasks in planning MP Almelo

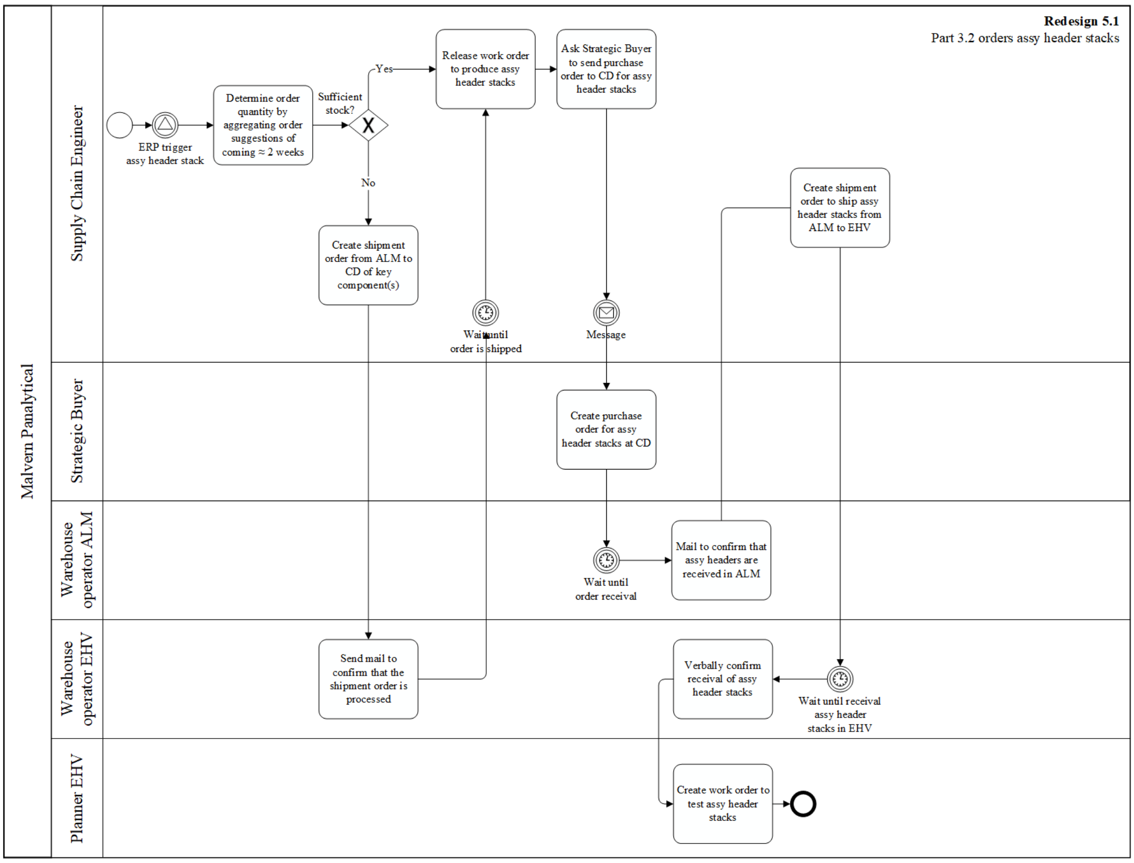


Figure D.35: BPMN part 3.2 of redesign 5.1: Automate routine tasks in planning MP Almelo

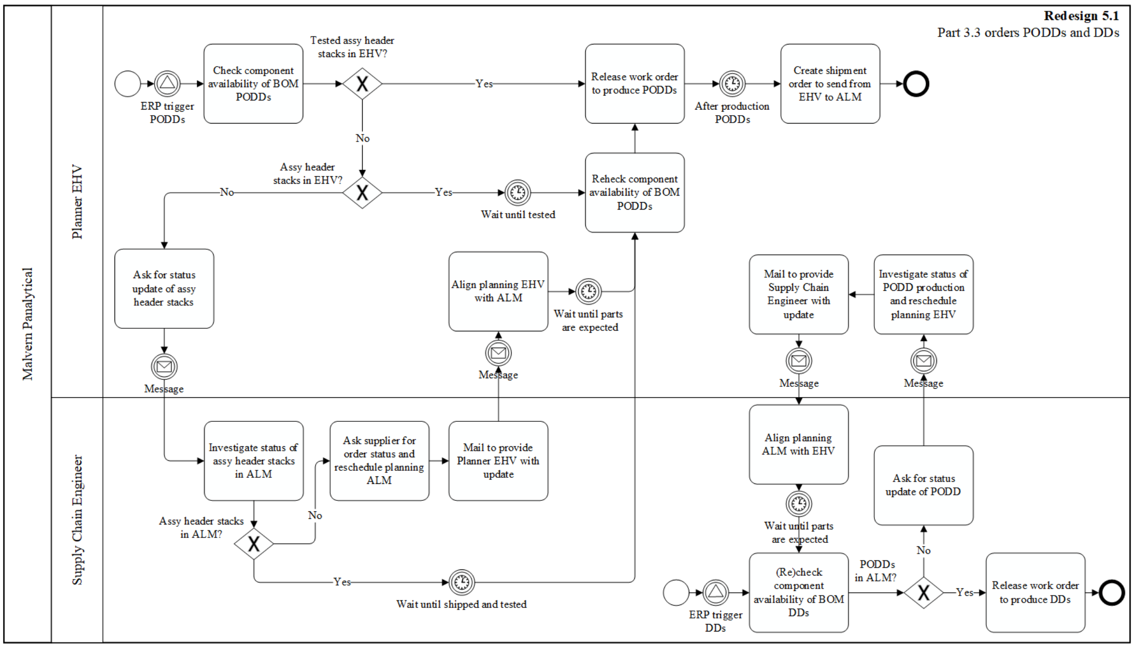


Figure D.36: BPMN part 3.3 of redesign 5.1: Automate routine tasks in planning MP Almelo

D.9 Redesign 6.1

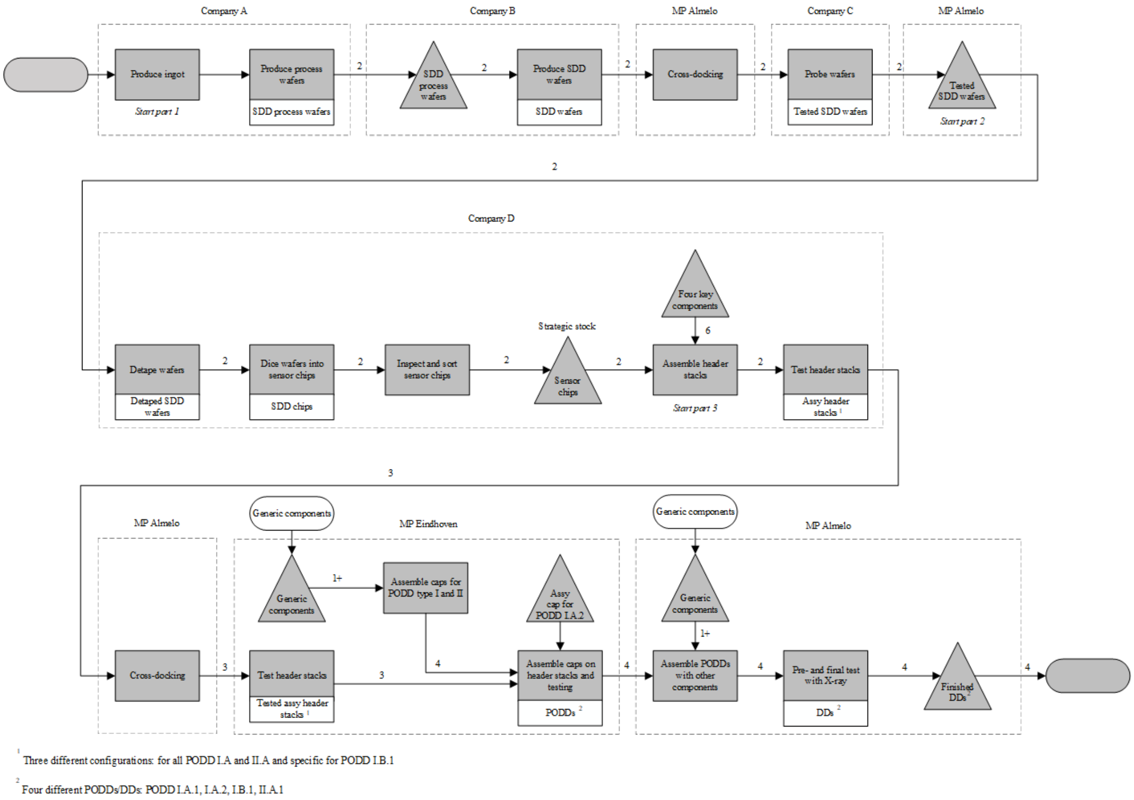


Figure D.37: PFD of redesign 6.1: Outsource procurement and management of key components

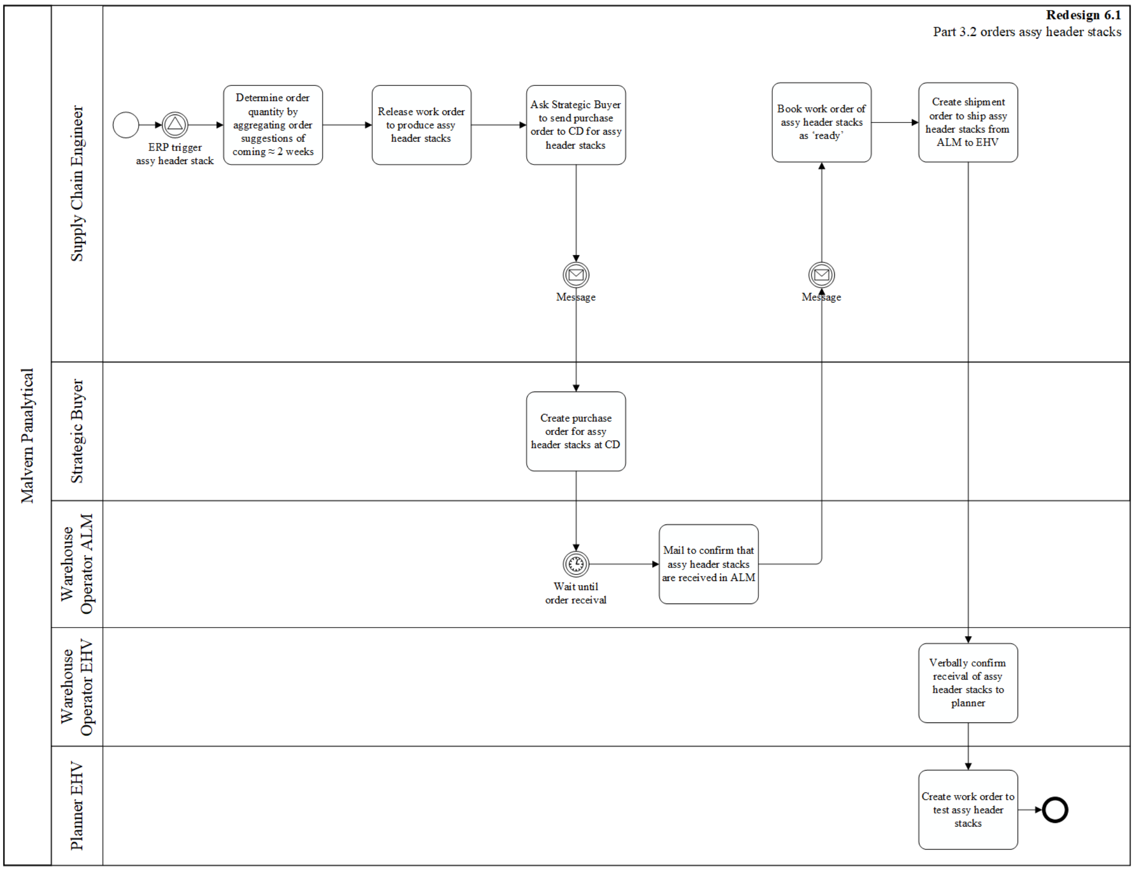


Figure D.38: BPMN part 3.2 of redesign 6.1: Outsource procurement and management of key components

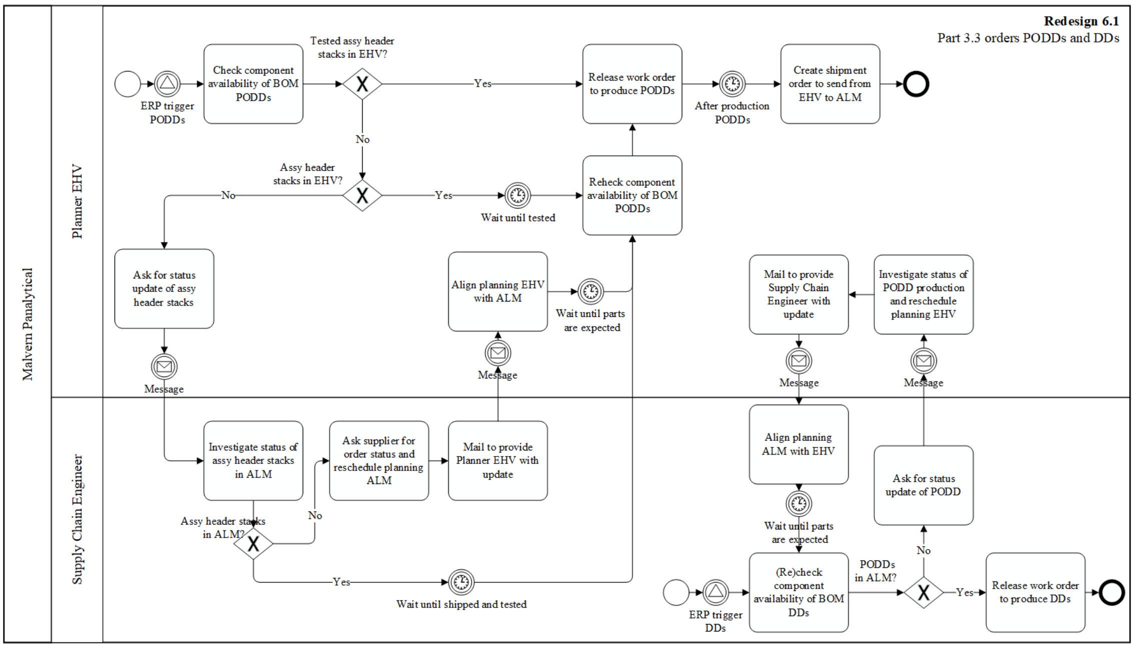


Figure D.39: BPMN part 3.3 of redesign 6.1: Outsource procurement and management of key components

D.10 Redesign 6.2

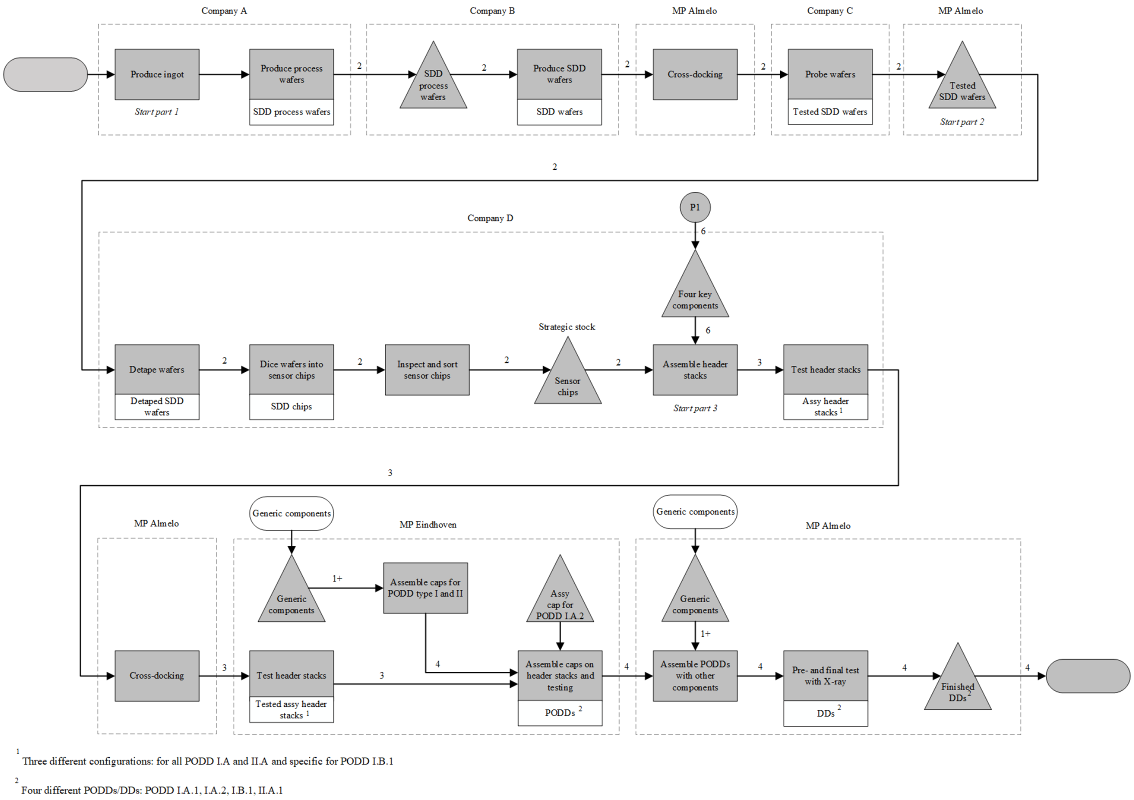


Figure D.40: PFD of redesign 6.2: Outsource procurement and management of part of key components

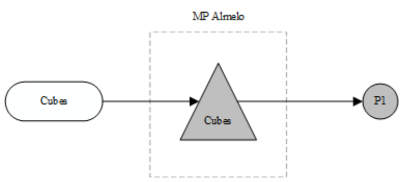


Figure D.41: PFD parallel flow of redesign 6.2: Outsource procurement and management of part of key components

Figure D.42: BPMN part 3.1 of redesign 6.2: Outsource procurement and management of part of key components

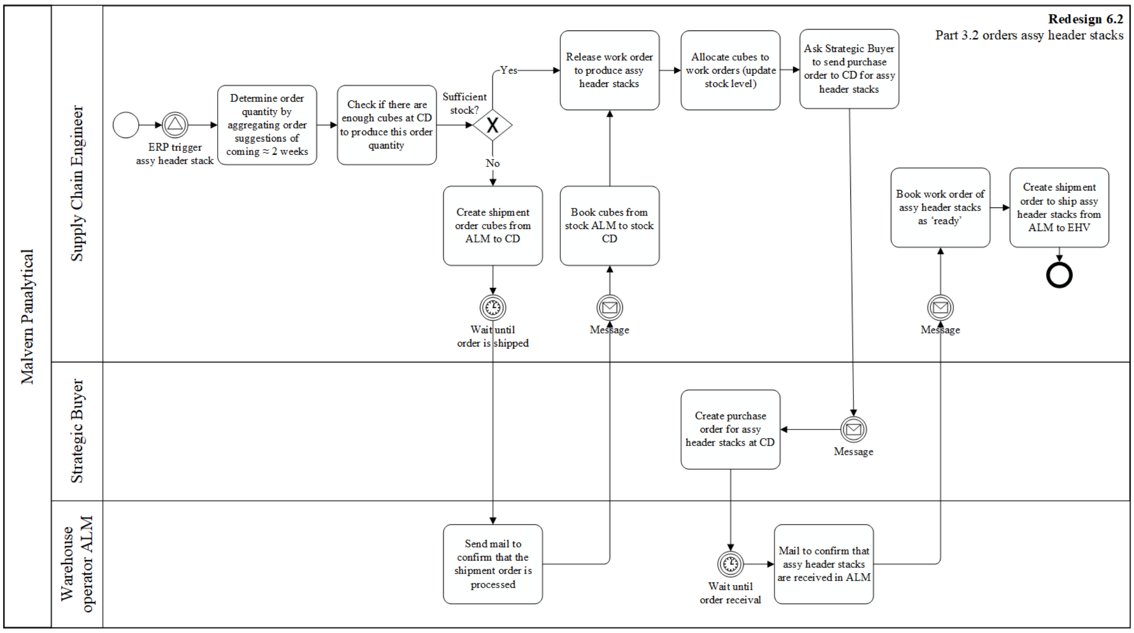


Figure D.43: BPMN part 3.2 of redesign 6.2: Outsource procurement and management of part of key components

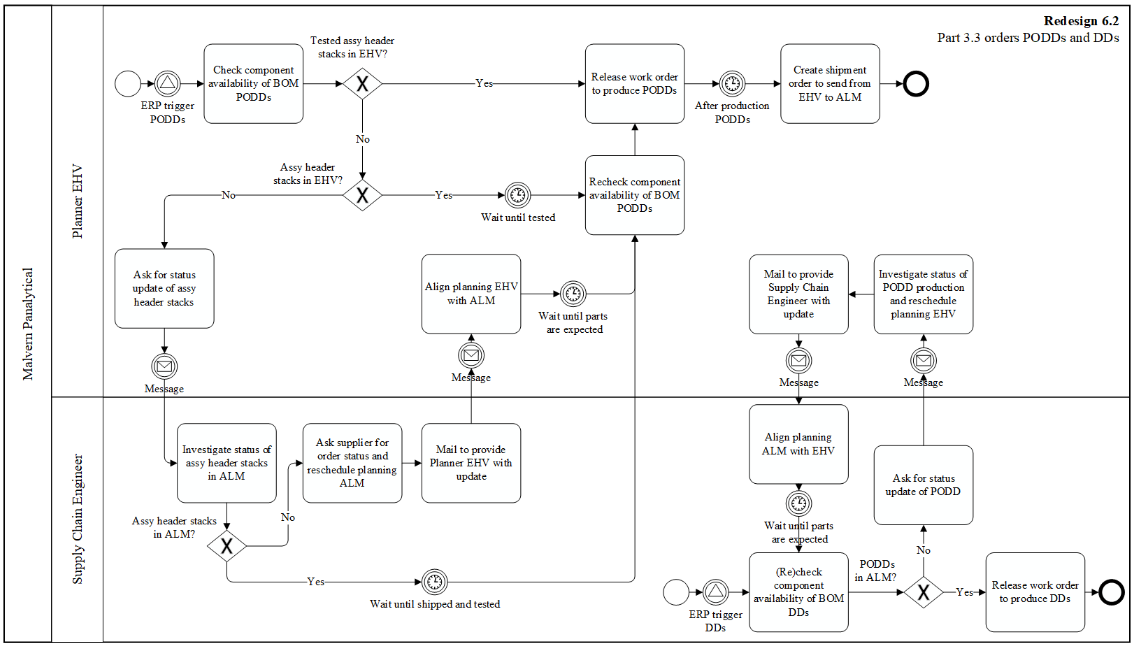


Figure D.44: BPMN part 3.3 of redesign 6.2: Outsource procurement and management of part of key components

D.11 Redesign 2.1 + 3.1

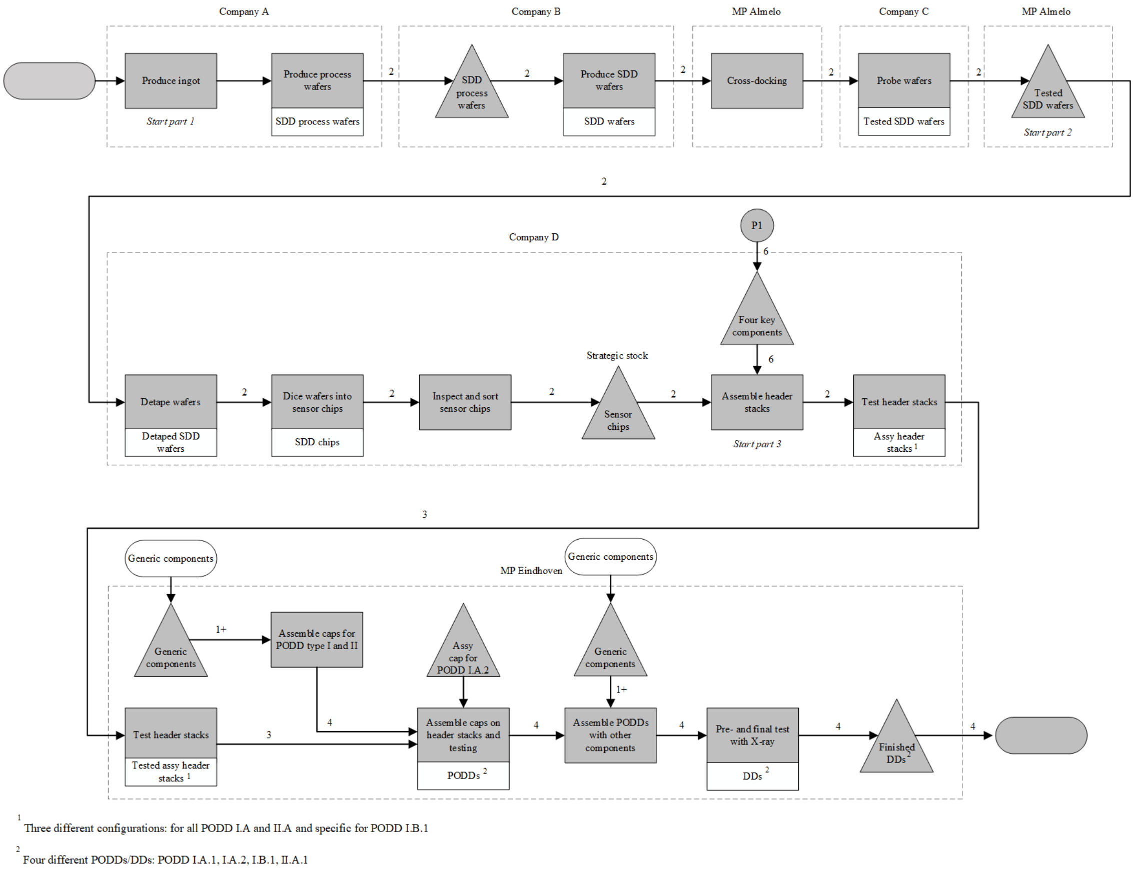


Figure D.45: PFD of redesign 2.1 + 3.1: Move production MP Almelo and planning CD to Eindhoven

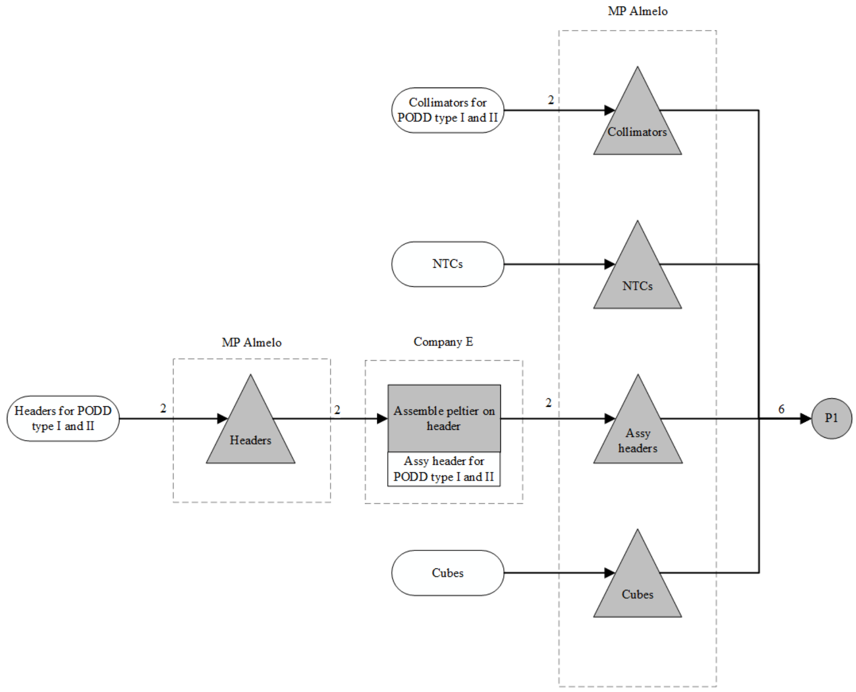


Figure D.46: PFD parallel flow of redesign 2.1 + 3.1: Move production MP Almelo and planning CD to Eindhoven

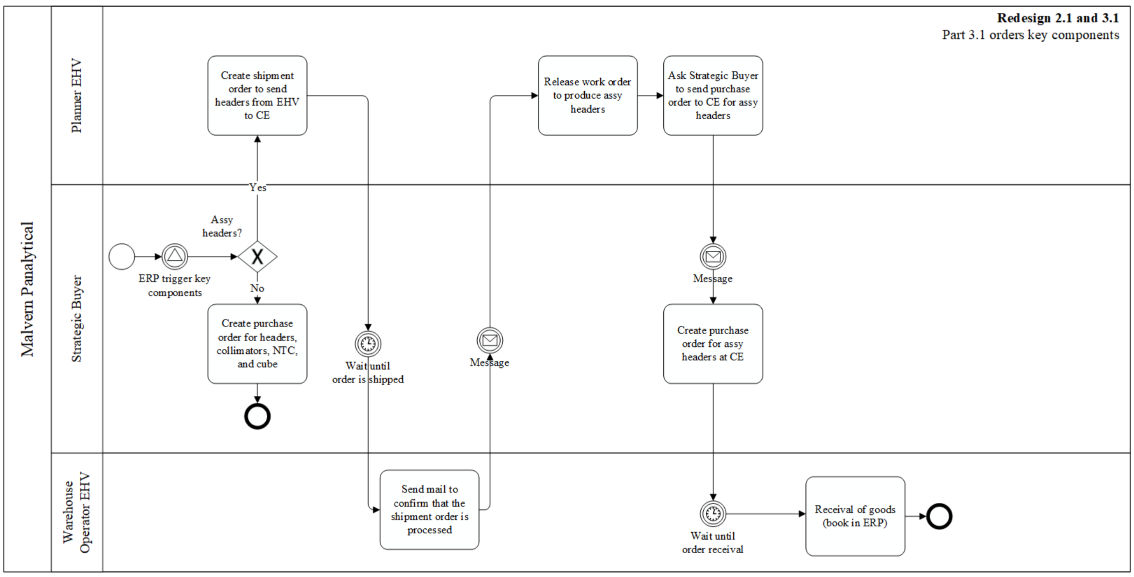


Figure D.47: BPMN part 3.1 of redesign 2.1 + 3.1: Move production MP Almelo and planning CD to Eindhoven

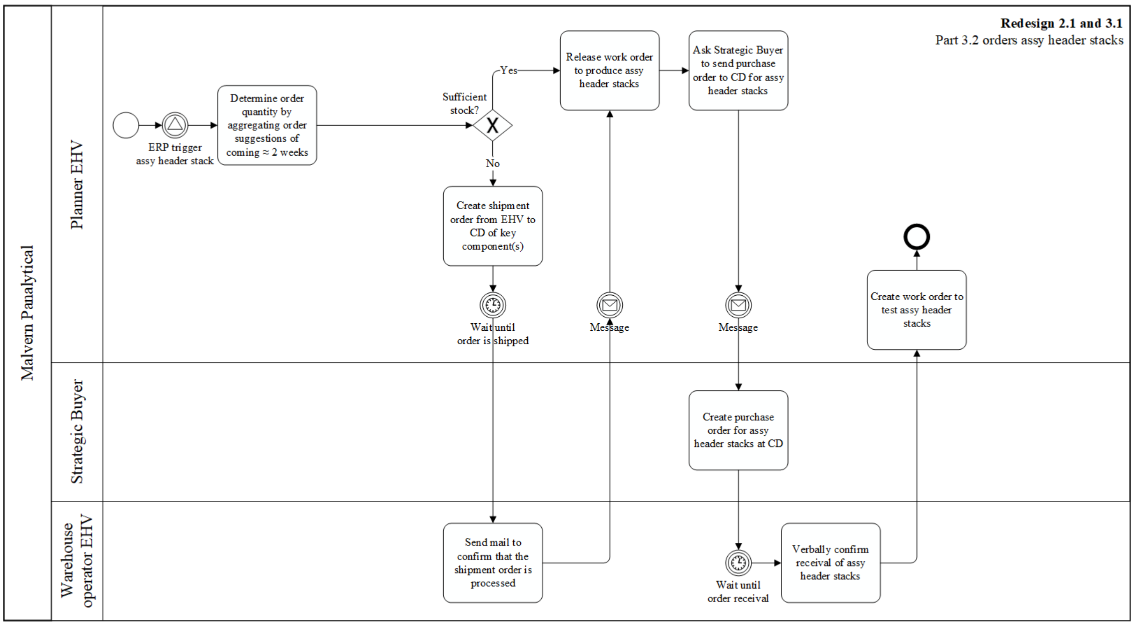


Figure D.48: BPMN part 3.2 of redesign 2.1 + 3.1: Move production MP Almelo and planning CD to Eindhoven

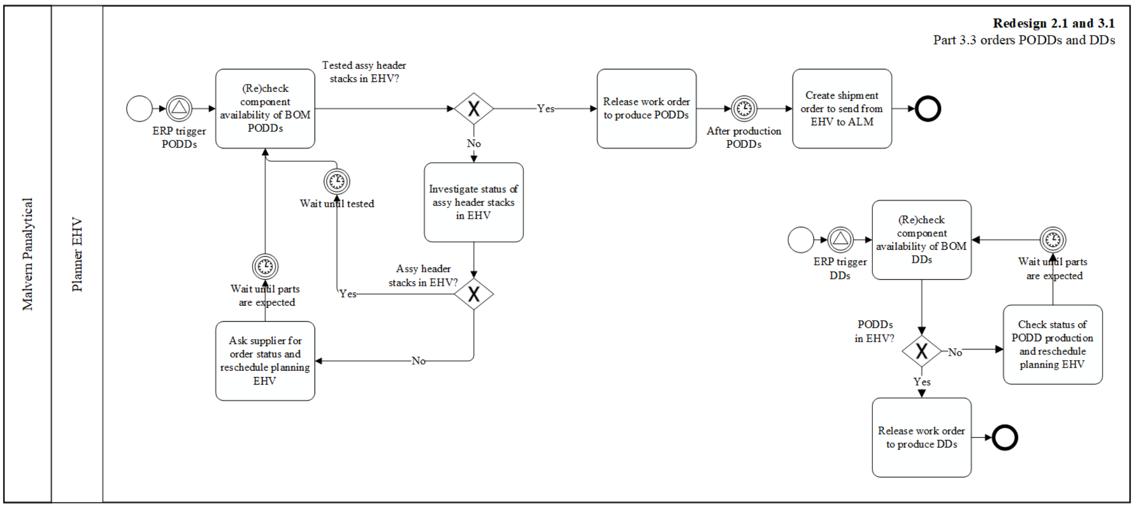
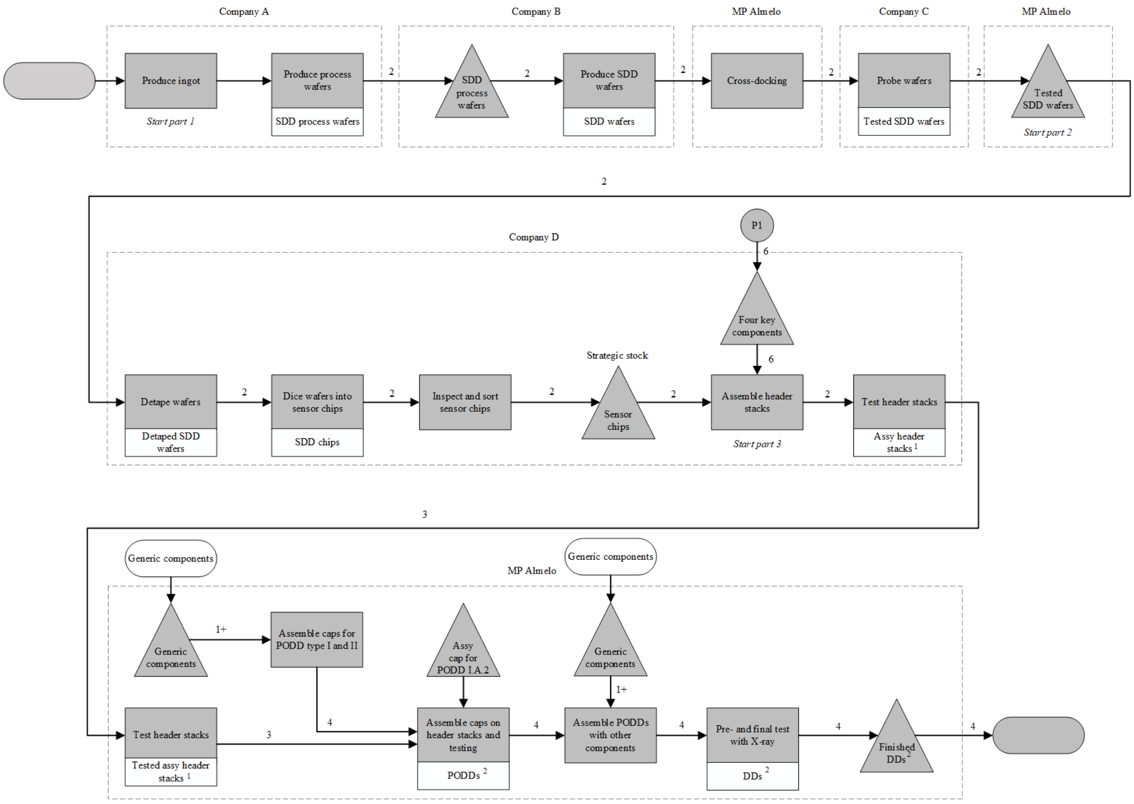


Figure D.49: BPMN part 3.3 of redesign 2.1 + 3.1: Move production MP Almelo and planning CD to Eindhoven

D.12 Redesign 2.2 + 5.1



[1] Three different configurations: for all PODD I.A and II.A and specific for PODD I.B.1

[2] Four different PODDs/DDs: PODD I.A.1, I.A.2, I.B.1, II.A.1

Figure D.50: PFD of redesign 2.2 + 5.1: Move production MP Eindhoven to Almelo and automate routine tasks at MP Almelo

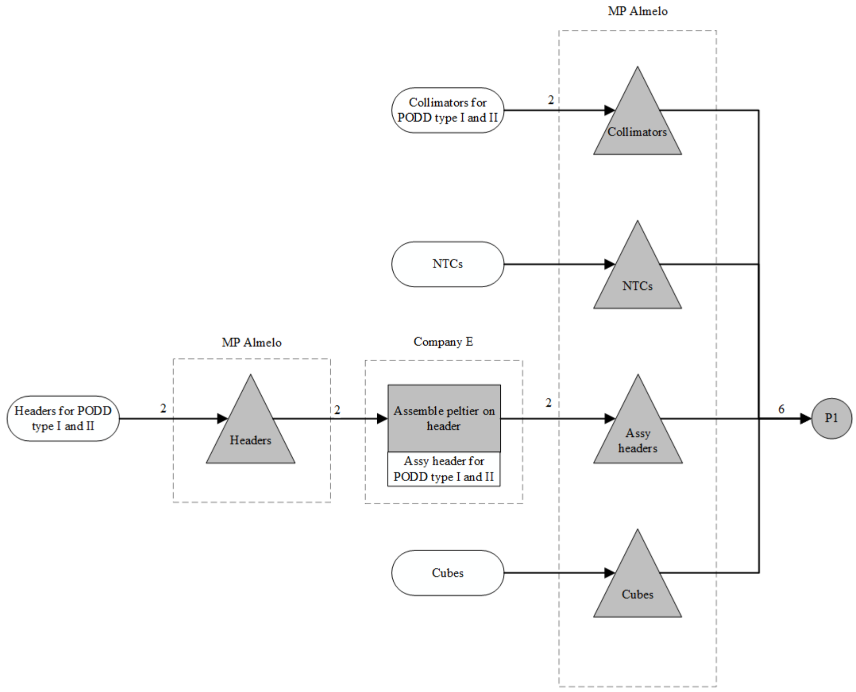


Figure D.51: PFD parallel flow of redesign 2.2 + 5.1: Move production MP Eindhoven to Almelo and automate routine tasks at MP Almelo

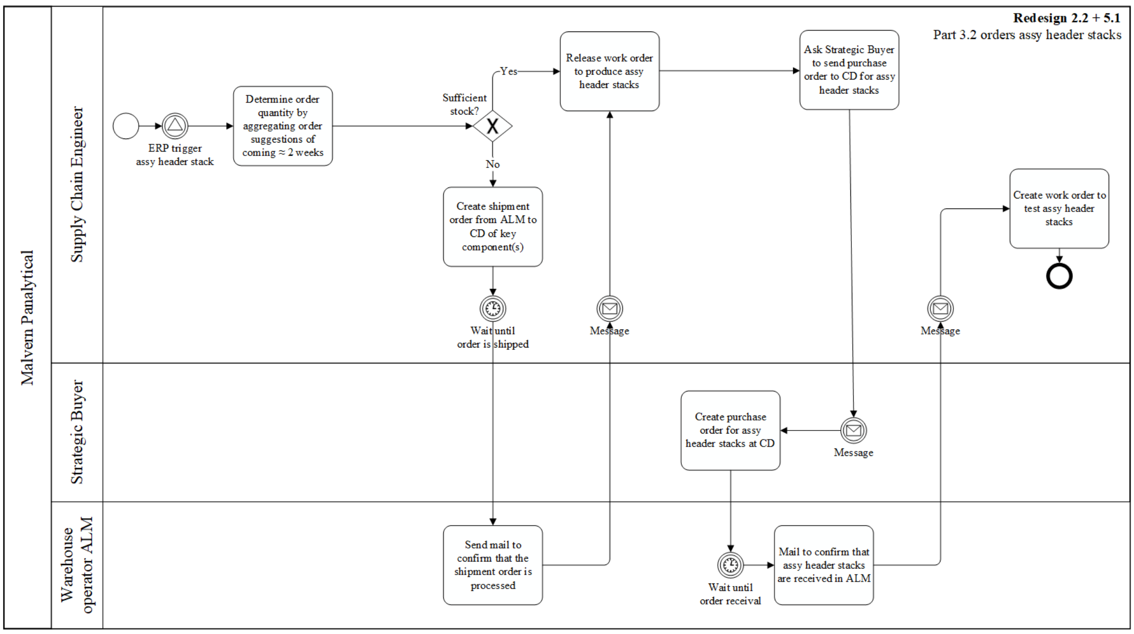


Figure D.52: BPMN part 3.1 of redesign 2.2 + 5.1: Move production MP Eindhoven to Almelo and automate routine tasks at MP Almelo

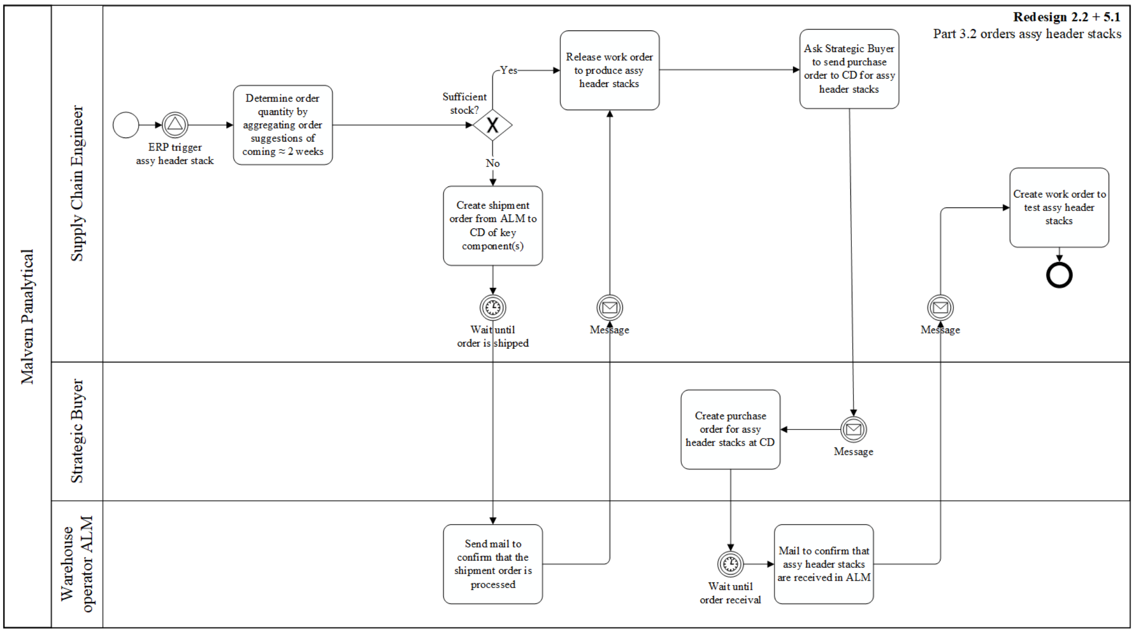


Figure D.53: BPMN part 3.2 of redesign 2.2 + 5.1: Move production MP Eindhoven to Almelo and automate routine tasks at MP Almelo

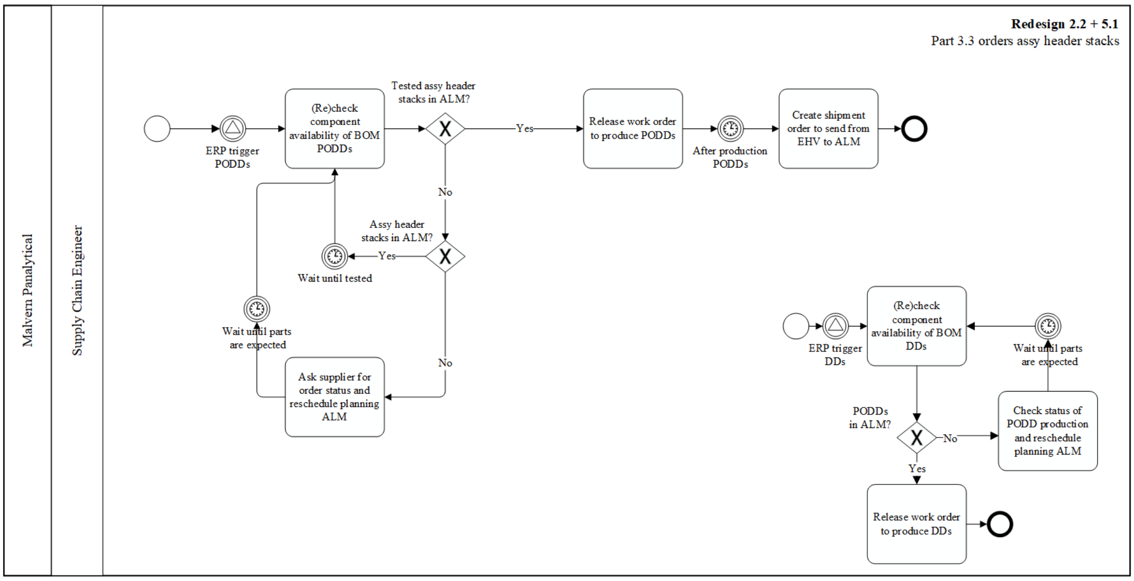


Figure D.54: BPMN part 3.3 of redesign 2.2 + 5.1: Move production MP Eindhoven to Almelo and automate routine tasks at MP Almelo