THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Production planning and control for remanufacturing

Understanding uncertainty, planning environments, and managerial decision-making

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"All that I am, or hope to be, I owe to my angel mother"

Abraham Lincoln

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Abstract

The transition toward a circular economy has increased interest in remanufacturing as a strategy for extending product lifecycle and reducing resource consumption. Remanufacturing depends on used products to start production, creating uncertainties related to the timing, quantity, and condition of product returns. These uncertainties complicate production planning and control (PPC) and challenge many assumptions underlying conventional planning approaches. Although previous research has made substantial contributions through analytical models and optimization methods, limited attention has been devoted to how remanufacturing firms plan and control production in practice and how managers make planning decisions in such planning environments.

The purpose of this thesis is to investigate how remanufacturing firms plan and control production. Specifically, the thesis examines the challenges faced in PPC for remanufacturing, how remanufacturing planning environment shapes PPC approaches, and how managers in remanufacturing planning environments make and communicate PPC-related decisions across strategic, tactical, and operational managerial decision-making levels. To address these issues, the thesis draws on research in PPC, remanufacturing, contingency theory, and judgment and decision-making theory.

The thesis adopts a sequential multi-study research design combining quantitative and qualitative methods. The thesis comprises three appended papers. The first paper uses survey data collected from remanufacturing firms in Europe and United States of America to explore PPC challenges. The second paper employs a multiple-case study to investigate how planning environments shape PPC approaches. The third paper also adopts a multiple-case study design but investigates how managers across strategic, tactical, and operational decision-making levels make and communicate PPC-related decisions. These three papers provide an empirically grounded understanding of PPC in remanufacturing environments.

The findings show that uncertainty remains a characteristic of remanufacturing environment and continues to complicate planning and control activities. The thesis further shows that PPC approaches vary across planning environments and are shaped by how firms respond to uncertainty. In addition, the thesis identifies aspects of how managers make and communicate PPC-related decisions when the information needed for those decisions is unavailable or incomplete.

This thesis contributes to the literature by extending the understanding of PPC in remanufacturing beyond analytical and optimization models. It shows that planning and control depend not only on technical issues but also on developing planning processes and capabilities, contextual conditions, and managerial decision-making processes. By integrating these perspectives, the thesis provides a more comprehensive understanding of how remanufacturing firms plan and control production.

Keywords: remanufacturing; production planning and control; uncertain planning environment

LIST OF APPENDED PAPERS

Paper I
Ali, A. H. I., van Loon, P., Guide, V. D. R., Jonsson, P., & Agrawal, T. (2026). *Production planning and control for remanufacturing: State-of-the-art practice and challenges.*

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Earlier versions presented at: The Paris Circular Operations Workshop 2025, Paris, France, and the EurOMA Sustainable Operations and Supply Chains Forum 2025, Porto, Portugal.

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Status: Submitted to an international journal.

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Paper III
Ali, A. H. I., Hetti Arachchige, C. M., van Loon, P., & Kans, M. (2026). *Managerial decision-making interactions in remanufacturing production planning and control.*

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Gothenburg, September 2026

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1. Introduction

This thesis examines production planning and control (PPC) in remanufacturing environments, with a particular focus on the management of used product returns. Section 1.1 provides the background and context of the study, while Section 1.2 presents the research problem. Section 1.3 outlines the thesis purpose and scope, and Section 1.4 introduces the research questions. Section 1.5 presents the overall structure of the thesis.

1.1 Background

The transition toward a circular economy has increased the strategic importance of remanufacturing as a means of extending product lifecycle and reducing the consumption of virgin materials. Unlike recycling, which focuses on recovering material value, remanufacturing restores used products to a condition comparable to, or sometimes better than, newly manufactured products while providing a warranty equivalent to that of a new product (Souza, 2013). Remanufacturing preserves much of the product's embedded material, labor, and energy value (Franzè et al., 2024) . As governments and industries increasingly pursue circular economy objectives (European Commission, 2020, 2023; US International Trade Commission, 2012; Wang et al., 2024), remanufacturing is also gaining traction in supporting these objectives (Sundin et al., 2026). Companies such as Caterpillar, Schlumberger, and Xerox have integrated remanufacturing into their operations, generating economic and environmental benefits through the recovery of products and components (Mutha et al., 2022; Ridley et al., 2019).

Despite its benefits, remanufacturing presents operational challenges that differ significantly from those encountered in manufacturing. Remanufacturing challenges several assumptions underlying PPC in manufacturing. Manufacturing PPC is typically developed for environments with relatively predictable material planning and inventory replenishment, stable process flows, and well-defined product specifications (Huttunen & Helo, 2026; Olhager & Selldin, 2007; Stevenson et al., 2005; Thürer et al., 2022). In remanufacturing, however, planners often face difficulty predicting return timing, quantity, and condition of used products (the main input to start production), referred to as cores (Goltsos, Ponte, et al., 2019; Naumov et al., 2025; Wei et al., 2015). Core and material availability cannot always be determined in advance, processing requirements may vary substantially between cores, and recovery rates may be uncertain until inspection and disassembly have been completed (Gunasekara et al., 2023; Kamper et al., 2019; Karabağ et al., 2025). Hence, PPC in remanufacturing involves not only planning under uncertainty but also managing situations in which key planning parameters are initially unknown.

In this thesis, uncertainty is viewed as a multidimensional characteristic of the remanufacturing planning environment. Uncertainty comes from lack of/or incomplete planning information, including demand, the timing and quantity of returns, return quality, recovery yields, and processing requirements. These different forms of uncertainty do not affect PPC in the same way. While some mainly influence material availability and inventory decisions (DePuy et al., 2007; Karabağ et al., 2025; Naumov et al., 2025), others affect capacity planning, scheduling, and resource allocation decisions (Gong et al., 2020; Huster et al., 2023; Reddy & Kumar, 2021). Understanding how firms plan and control remanufacturing production therefore requires attention not only to the existence of uncertainty but also to how different

uncertainty conditions shape planning activities and managerial decision-making in remanufacturing.

1.2 Research problem

Research on PPC for remanufacturing has predominantly approached uncertainty as an analytical problem to be addressed through forecasting models, inventory optimization, and decision-support systems (Denizel et al., 2010; Goltsos, Syntetos, et al., 2019; Gong et al., 2020; Junior & Filho, 2017; Karabağ et al., 2025, 2026; Zhou et al., 2018). While these studies have substantially contributed to understanding how planning decisions can be optimized, they implicitly assume that uncertainty can be adequately represented and managed through formal models and planning systems. In practice, however, managers often operate with incomplete and evolving planning information, and complete and accurate information is rarely available. This is partly because actors (e.g., suppliers, customers) within remanufacturing supply chains do not always share planning information in a timely or accurate manner (de Brito & van der Laan, 2009; Kurilova-Palisaitiene et al., 2015; Zhou et al., 2025). As a result, formal models may not fully capture the dynamic conditions created by continuously changing information. Hence, PPC may depend not only on analytical tools and planning systems but also on information sharing, coordination among stakeholders, managerial decision-making, and the experience and judgment of planners. In particular, the following aspect remains unexplored.

First, empirical understanding of PPC in remanufacturing remains fragmented despite a substantial body of research. Previous studies have identified uncertainties related to variability in demand, product returns, and recovery yields as key challenges for PPC (Gong et al., 2020; Guide, 2000; Junior & Filho, 2012, 2016; Kamper et al., 2019; Liu et al., 2024). Hence, much of existing evidence focused on demand management (e.g., Mutha et al., 2023; Yilmaz & Belbag, 2016; Zhou et al., 2025), core acquisition and management (e.g., Clottey, 2016; Gunasekara et al., 2023; Karabağ et al., 2025), and product recovery (e.g., Abbey et al., 2019; Corominas et al., 2012; Zahraei & Teo, 2018). The growing adoption of product servitization, digital technologies, data-driven decision-making, and increasing regulatory requirements has transformed the operational context of remanufacturing (Chen & Huang, 2021; Mutha et al., 2022; Rasool et al., 2026). As a result, it remains unclear whether the PPC challenges (i.e., challenges arising from uncertainty associated with variability in factors such as product returns) identified in earlier studies continue to adequately reflect current practice. Updated empirical research is therefore needed to understand how remanufacturing firms today deal with these challenges in PPC activities.

Second, limited attention has been given to how remanufacturing planning environments shape the ways firms approach PPC. Although previous studies have examined remanufacturing practices and planning challenges (Ferrer & Whybark, 2001; Guide et al., 2003; Jia et al., 2016; Karabağ et al., 2025, 2026) , few of these studies explain how characteristics of the planning environment influence the design of PPC. The relationship between planning context and PPC practices thus remains insufficiently understood. Contingency theory (CT) emphasizes that managerial practices should be examined in light of the contextual conditions under which they operate (Sousa & Voss, 2008). While contingency-based planning has been extensively studied in manufacturing environment (Jonsson & Mattsson, 2003; Kristensen & Jonsson, 2018; Romero-Silva et al., 2024; Wu et al., 2025), in remanufacturing, few contingency-based research exists. This perhaps because remanufacturing research has traditionally focused on operational and technical challenges, such as product recovery, disassembly, and process

efficiency (Goltsos, Ponte, et al., 2019; Sundin et al., 2026; Yanıkoğlu & Denizel, 2021), rather than on the examining the relationship between management practices (e.g., inventory management) and contextual factors (e.g., variable demand). Understanding how contextual factors shape PPC practices can therefore advance both remanufacturing research and contingency-based research, while helping remanufacturers develop planning and control approaches that address the specific uncertainties and challenges that they face. While contingency theory helps explain the contextual factors under which specific PPC activity can be practiced, it provides limited insight into how planning decisions are made. To address this limitation, the thesis also draws upon judgment and decision-making (JDM) theory. These perspectives enable PPC to be examined both as a contextual phenomenon and as a managerial process under uncertainty.

Third, the judgment dimension in managerial decision-making in PPC remains underexplored. The JDM theory provides a useful perspective for examining how managers make decisions under conditions of complexity, uncertainty, and incomplete information (Simon, 1955). Classical decision theory assumes that decision-makers evaluate available alternatives rationally and select the option that maximizes outcomes (March & Simon, 1958). Similarly, much of the PPC literature implicitly assumes that planning decisions can be based on accurate planning information (cf. Huttunen & Helo, 2026; Romero-Silva et al., 2024; Thürer et al., 2022). Simon's (1979) concept of bounded rationality challenged this assumption by arguing that decision-makers face cognitive limitations that constrain their ability to process information and evaluate all possible alternatives. This is evident in remanufacturing environments where managers are required to make decisions despite incomplete information regarding future returns, product condition, and recovery outcomes (Naumov et al., 2025). In such situations, planning cannot entirely rely on formal systems or the availability of complete and accurate information. Instead, managers may depend on experience, judgement, communication, and coordination across organizational functions to support decision-making (Bendoly et al., 2010, 2022; Croson et al., 2013). Therefore, managers may rely on judgement and experience when making decisions (Bendoly et al., 2022; Gaur et al., 2007), yet relatively little is known about how uncertainty influences PPC-related decisions across managerial-decision-making levels. Understanding this relationship might provide important insights into how remanufacturing firms coordinate planning activities and respond to uncertainty in practice.

1.3 Purpose and scope of the thesis

The purpose of this thesis is to develop an empirically grounded understanding of how uncertainty-related challenges, planning environments, and interactions among managers in decision-making shape PPC practices in remanufacturing firms. While existing research has primarily examined PPC through analytical and optimization models, this thesis focuses on contextual and decision-making and communication dimensions of PPC in practice.

The thesis draws on research in PPC, remanufacturing, uncertainty, contingency planning, and JDM. These streams of literature provide concepts for examining PPC challenges, planning environments, and managerial decision-making in remanufacturing firms. Throughout the thesis, the term firm and plant are used interchangeably when referring to remanufacturing

entity. Likewise, the terms planning and controlling production and PPC are used interchangeably.

While PPC encompasses a number of planning activities (e.g., material requirement planning, capacity requirement planning, and scheduling), this thesis does not examine each activity separately. Instead, it focuses on how key activities (e.g., core acquisition and management) are planned and controlled within remanufacturing firms. The unit of analysis is the focal firm's PPC system and the planning processes through which planning decisions are made and communicated. The thesis is limited to remanufacturing (i.e., does not include other circular economy strategies, such as recycling, which involve different operational characteristics and planning requirements) (Thierry et al., 1995). Although external actors such as suppliers, customers, and logistics providers may influence remanufacturing operations, the primary focus is on PPC within the focal firm.

1.4 Research questions

As pointed out in Sections 1.1 and 1.2, remanufacturing is characterized by several sources of uncertainty that make PPC challenging. Although previous research has identified these sources of uncertainty, knowledge of the sources themselves provides limited insight into the specific PPC challenges encountered in remanufacturing practice. Identifying these challenges is important because uncertainty may affect different PPC activities in different ways, requiring different managerial responses. Accordingly, the first step is to establish what PPC challenges faced in remanufacturing practice. This motivates the first research question:

RQ1: What challenges do remanufacturing firms face today in production planning and control?

PPC approaches, such as planning methods, inventory levels and timing, and timing to produce, are also likely to depend on the conditions under which planning takes place (cf. Kaipia & Holmström, 2007). Differences in characteristics of the planning environment (e.g., variability in demand, product returns, material availability) can affect how firms perform production planning activities (cf. Karabağ et al., 2025) and therefore may require different planning responses. Investigating differences in planning environments is therefore important for understanding variation in PPC approaches across remanufacturing firms. This motivates the second research question:

RQ2: How do remanufacturing planning environments shape production planning and control approaches?

PPC is not only a technical planning activity. It also involves managerial decision-making and communication across managerial levels (cf. Kim et al., 2014). Decisions concerning production strategies, material planning, capacity, and scheduling span strategic, tactical, and operational levels and therefore require information to be communicated and coordinated across these levels. In remanufacturing, such decision-making is challenging because managers must cope with uncertainty regarding product returns, including their timing, quantity, and quality, as well as uncertainty in demand (Naumov et al., 2025) . These conditions can limit the information available to managers when making PPC-related decisions and increase the need

for communication across managerial levels. Yet comparatively little attention has been given to how managers make and communicate PPC-related decisions under such conditions. Accordingly, the third research question is:

RQ3: How do managers in remanufacturing firms make and communicate production planning and control-related decisions?

The three research questions build on one another by addressing different but related aspects of PPC in remanufacturing. RQ1 focuses on uncertainty and the associated PPC challenges, RQ2 investigates how firms adopt PPC approaches in different planning environments, and RQ3 investigates how managers make and communicate PPC-related decisions across managerial levels.

1.5 Structure of the thesis

The thesis is structured as follows. Chapter 2 presents the theoretical framework, introducing the concepts PPC, remanufacturing, and the uncertainties that characterize remanufacturing operations. The chapter also reviews the literature on PPC in remanufacturing and develops the theoretical framework that guides the thesis analysis. Chapter 3 describes the research methodology, including the research design, data collection methods, data analysis, and reflections on methodological choices and research quality. Chapter 4 presents the findings of the three papers included in the thesis. Chapter 5 discusses the findings in relation to existing literature. Finally, Chapter 6 concludes the thesis by summarizing its main theoretical contributions, discussing practical implications, acknowledging limitations, and outlining directions for future research.

2. Theoretical framework

This chapter introduces the concept of PPC by explaining its purpose and key activities. It then provides an overview of remanufacturing and discusses the uncertainties that characterize remanufacturing operations. The chapter concludes by reviewing the scholarly debate on PPC in remanufacturing and presents the theoretical framework that guides the data collection and analysis in this thesis.

2.1 Traditional PPC

This section focuses on PPC in manufacturing environment, refers to hereafter traditional PPC. It first defines PPC and then discusses its significance and key activities.

2.1.1 Defining PPC

PPC consists of two elements: planning and control. In operations management (OM), planning refers to the process of determining future activities that an organization intends to carry out, while control involves monitoring execution, identifying deviations from the plan, and taking corrective actions when necessary (Stevenson, 2015). Planning is therefore not a one-time activity. As Wu et al. (2025) noted, it is a continuous process that often requires adjustment as circumstances change and new information becomes available. Control complements planning by establishing acceptable limits of variation and ensuring that operations remain aligned with organizational objectives (Stevenson, 2015).

In manufacturing environments, PPC guides decisions regarding what to produce, how to produce it, and when production should take place to meet customer demand (Guerrero et al., 2025). These decisions vary across planning horizons because of changing internal conditions, such as resource availability, and external factors, such as fluctuations in demand and supply markets (Olhager & Selldin, 2007). Managing such variability requires an effective planning and control function. Accordingly, PPC has been defined as the "*planning, development, co-ordination, organization, management and control of material flows from raw materials suppliers to end-users*" (Jonsson & Mattsson, 2009, p.6). This definition signifies the role of PPC in balancing demand and supply while coordinating the activities required to support production operations.

2.1.2 Significance of PPC

To understand the significance of PPC, it is first necessary to consider three fundamental planning parameters: planning frequency, planning horizon, and planning object. Planning frequency refers to how often plans are created or updated, such as weekly, monthly, or annually (Jonsson & Mattsson, 2009). Regular updates help ensure that plans remain relevant and effective in achieving their objectives (Thürer et al., 2016) . Planning horizon defines the period covered by the plan, which may range from weeks to years. A clearly defined horizon enables establishing realistic targets and monitoring performance over time (Jonsson & Mattsson, 2009). The planning object refers to the unit for which a plan is developed, such as an individual product, a product family, a stock-keeping unit (SKU), or a combination of these (idem).

The relationship between these planning parameters changes across managerial decision-making levels. Long-term planning, for example, typically focuses on product groups or

aggregate output volumes, whereas short-term operational planning focuses on individual products and production orders (Jonsson & Mattsson, 2003). Medium-term planning often combines both perspectives by linking aggregate plans with product-specific requirements.

PPC plays an important role in manufacturing across tactical and operational levels. At the tactical level, PPC supports the availability of materials and production resources needed to meet customer demand on time (Kaipia & Holmström, 2007; Kasper et al., 2024). It also improves the organization's ability to respond to changes in demand and customer orders while balancing trade-offs among customer service, inventory levels, and inventory-related costs (Hong & Leffakis, 2017; Huttunen & Helo, 2026; Land & Gaalman, 2009; Olhager, 2013).

At the operational level, PPC helps support resource utilization, production flexibility, and rapid changeovers (Lane & Szwejczewski, 2000; Márquez & Ribeiro, 2022; Martin et al., 2023; Romero-Silva et al., 2024). It also supports material planning, shop-floor control, and the efficient coordination of production activities (Jonsson & Mattsson, 2003; Martin et al., 2023; Thürer et al., 2022). In addition, PPC at operational level can help reduce throughput times, shorten production lead times, minimize work-in-process inventory, and improve overall production performance (Braglia et al., 2020; Piplani & Ang, 2018; Stevenson et al., 2005; Thürer et al., 2022). These objectives are achieved through a set of interconnected planning and control activities.

2.1.3 PPC key activities

Historically, PPC activities were often carried out independently within different organizational functions (Olhager, 2013). Manufacturing production planning textbooks highlight that PPC comprises several interrelated activities, including demand forecasting, master production scheduling (MPS), material requirements planning (MRP), capacity requirements planning (CRP), process planning, and shop-floor scheduling (Jonsson & Mattsson, 2009; Vollmann et al., 2005). Several studies also emphasis these interrelationships (cf. Christensen et al., 2023; Olhager, 2010; Olhager & Rudberg, 2002) . These activities are commonly grouped into three planning levels, as illustrated in Figure A.

The PPC process typically begins with demand forecasting. Forecasts estimate current and future customer demand for products (Danese & Kalchschmidt, 2011). At higher planning levels, demand information is often developed through the sales and operations planning (S&OP) process and expressed in aggregated volumes (Olhager, 2013). As planning moves closer to production, these estimates are progressively disaggregated into product-specific requirements and schedules (Babai et al., 2022).

After accounting for existing inventory, net demand is calculated and used as the basis for the master production schedule (MPS) (Mönch et al., 2018; Tang & Grubbström, 2002). The MPS specifies production quantities and delivery dates. Once the MPS is established, material requirements planning (MRP) and capacity requirements planning (CRP) are performed in parallel (Olhager & Wikner, 2000). While the MPS determines what needs to be produced to satisfy market demand, MRP and CRP ensure that the required materials and production capacity are available to support those plans (Christensen et al., 2023). When material and capacity requirements have been confirmed, production activities can be planned and scheduled on the shop floor in accordance with the MPS (Olhager & Wikner, 2000). Throughout this

process, information flows in both directions, enabling coordination, adjustments, and other PPC-related decision-making.

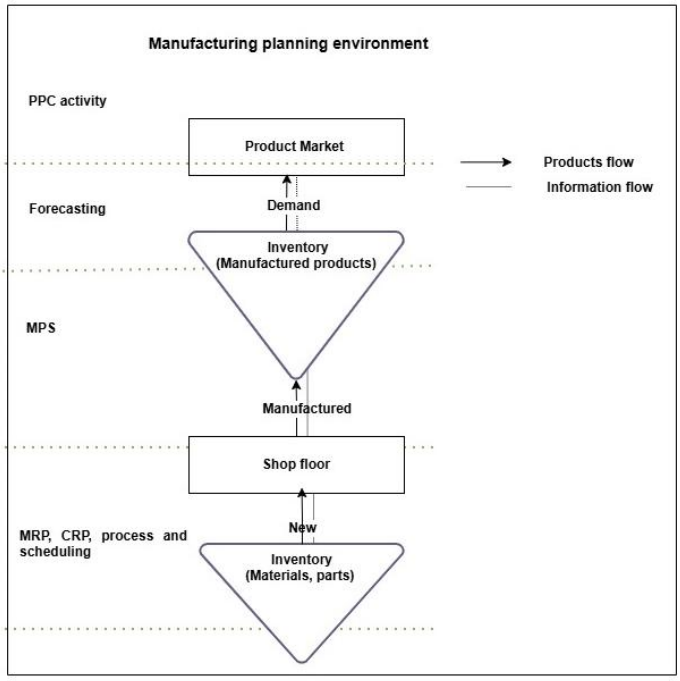

Figure A: The PPC in traditional manufacturing
Adapted from Jonsson & Mattsson (2009)

2.2 Remanufacturing

This section introduces the concept of remanufacturing and defines its scope within this thesis. It also discusses the main sources of uncertainty that characterize remanufacturing operations and distinguish them from manufacturing as described in literature.

2.2.1 Defining remanufacturing

Remanufacturing has been practiced for decades and is applied across a wide range of industries, including automotive, aerospace, medical equipment, electrical and electronic equipment (EEE), heavy-duty and off-road (HDOR) equipment, machinery, marine, rail, and furniture sectors (Duberg, 2024; Östlin et al., 2008; Parker et al., 2015). It is recognized for extending product lifespan, improving resource utilization, and reducing waste. Unlike other product recovery options, such as repair and refurbishment, remanufacturing involves disassembling used products, replacing or restoring worn components, and reassembling them to achieve a quality level equivalent to that of a new product (Thierry et al., 1995). Remanufacturing can also be economically attractive (Guide, 2000) and helps mitigate parts/components shortages, hence increasing resilience against supply disruptions (Bag et al., 2019).

Several definitions of remanufacturing have been proposed in the literature (cf. APICS, 2014; Lund, 1984; Souza, 2013; Sundin, 2004). This thesis adopts the definition proposed by Sundin et al. (2026, p.19), which reflects both industrial practice and academic research. According to this definition, remanufacturing is:

"*An industrial process whereby cores are going through a sequence of steps including inspection, cleaning, disassembly, reprocessing, reassembly, and final testing to assure same-as-new or better-than-when-new product quality and performance".*

This definition highlights several aspects that are central to this thesis. First, remanufacturing involves three essential processes: disassembly, reprocessing, and reassembly. These processes form the boundary conditions for the phenomenon investigated in this thesis. Although the term remanufacturing is also used in other sectors, such as the textile industry (Dissanayake & Sinha, 2015), remanufacturing activities in these contexts do not necessarily involve the core processes (per se) of disassembly, reprocessing, and reassembly, such applications therefore fall outside the scope of this thesis.

Second, the definition emphasizes the importance of cores, that is, used products that serve as the primary input to the remanufacturing process. The availability and condition of these cores determine whether remanufacturing operations can take place. However, cores are associated with considerable uncertainty regarding their quantity, timing of return, and quality. These uncertainties are what distinguish remanufacturing from manufacturing environments and are discussed in the following section.

2.2.2 Uncertainties in remanufacturing

Uncertainty occurs "…*when decision-makers cannot estimate the outcome of an event or the probability of its* occurrence" (de Lima et al., 2022, p.3). In practical terms, uncertainty arises when organizations lack sufficient information to accurately anticipate future events and their consequences. Research on uncertainty in operations management has been addressed extensively by, among others, Simangunsong et al. (2012), Flynn et al. (2016), and Sengupta et al., 2025). Mason-Jones and Towill coined the term '*uncertainty cycle'* and discussed four common sources of uncertainty in operations management: demand uncertainty, supply uncertainty, process uncertainty, and control uncertainty (as cited in Goltsos, Ponte, et al., 2019). These sources are particularly relevant in remanufacturing, where uncertainty is often greater than in manufacturing.

Demand uncertainty refers to variations in the timing and volume of customer demand for products and services (Gaur et al., 2007). Common sources include changes in customer preferences, market conditions, and purchasing behaviour (Flynn et al., 2016). Seasonal fluctuations (Elyasi et al., 2024) and the amplification of demand variability along supply chains, commonly known as the bullwhip effect (Geary et al., 2006), further contribute to demand uncertainty. In remanufacturing, demand can be influenced by additional factors. For example, customers may own products, and thus the demand in this instance depends partly on the customer's willingness to return products. Firms may own products while selling their services to customers. In this instance, firms may have control over product returns and availability (Mutha et al., 2022; Östlin et al., 2008). Demand is also affected by the relationship between remanufactured and new products. From the perspective of an original equipment manufacturer (OEM), sales of remanufactured products may reduce demand for new products if both serve same customer segments (Atasu et al., 2010). Any significant reduction in new product sales may influence the future availability of returned products for remanufacturing.

Pricing presents another source of demand uncertainty. Although remanufactured products are generally sold at lower prices than new products, remanufacturing costs can be comparable

to or even exceed costs of new (Bakal & Akcali, 2006). If remanufactured products become more expensive than their new counterparts, it may be difficult to attract customers on price bases, hence it becomes difficult to predict demand forecasts. Customer perceptions add another uncertainty. Even when remanufactured products meet the same technical standards and warranty requirements as new products (Souza, 2013), customers may perceive them as less reliable or lower in quality (Khor & Hazen, 2017). Such perceptions can reduce willingness to purchase and willingness to pay (Abbey et al., 2015; Abdulla et al., 2024; Zhu & Tian, 2016). These factors contribute to demand uncertainty because they affect customers' purchasing decisions in ways that are difficult to forecast. Variations in price competitiveness and customer perceptions of remanufactured products can lead to fluctuations in demand, creating uncertainty regarding future sales volumes and market acceptance for remanufactured products.

Supply uncertainty comes from the firm's supply network inability to reliably deliver materials, parts, or services needed to create value for customers (Geary et al., 2006). Simangunsong et al. (2012) identified numerous sources of supply uncertainty and a variety of strategies for mitigating or coping with their effects. In general, supply uncertainty concerns whether the necessary resources will be available in the required quantity, quality, and time frame (Flynn et al., 2016). In remanufacturing, the primary source of supply uncertainty is the availability of suitable cores (Guide & Van Wassenhove, 2001; Hoffmann et al., 2025; Karabağ et al., 2025; Wei et al., 2015). Existing research identifies two major dimensions of this uncertainty. The first concerns variations in the quantity, timing, and quality of returned cores (Guide, 2000; Jia et al., 2016; Junior & Filho, 2012; Karabağ et al., 2026). Among these, uncertainty regarding core condition is often considered the most challenging (Goltsos, Ponte, et al., 2019; Naumov et al., 2025). The second dimension relates to the availability of new materials and replacement parts needed during reassembly (DePuy et al., 2007; Ferrer & Whybark, 2001; Guide & Srivastava, 1997). Core quality depends on several factors, including product age, usage intensity, and the stage of the product life cycle (Atasu et al., 2010; Jia et al., 2016). Moreover, the handling of cores throughout reverse logistics can significantly affect their condition. Studies have shown that some operators perceive returned products as waste rather than valuable assets, leading to improper handling and transportation practices (Mutha et al., 2022). Deterioration in core condition increases the need for replacement materials and increases the remanufacturing cost (DePuy et al., 2007; Karabağ et al., 2025).

Process uncertainty refers to variability within production operations (Geary et al., 2006). For example, in traditional manufacturing, MRP is based on the assumption of a fixed relationship between finished products and their components, as defined by a static bill of materials (BOM) (Olhager & Wikner, 2000). In remanufacturing, this assumption may not always be held because the BOM may change depending on the condition and quality of the returned products. Since the condition of returning products is not always known before inspection or disassembly and can vary from lot to lot (Kamper et al., 2019), the BOM becomes dynamic rather than fixed (Goltsos, Syntetos, et al., 2019). Hence, accurate materials, resource requirements, and routing of the products in the plant can only accurately be determined after assessing the product conditions (DePuy et al., 2007; Hoffmann et al., 2025; Kamper et al., 2019). A product can be routed through the same process multiple times because of quality issues (Guide, 2000); for instance, an item that has undergone machining could require additional machining if it fails a performance test at a later stage. This adds complexity to managing material flows, workforce and machine, and controlling processes.

Control uncertainty refers to uncertainty that stems from the mechanisms a firm uses to cope with demand, supply, and process uncertainties. Unlike the previous sources, it is not inherent in the operating environment but is generated by the firm's own planning and control system (Goltsos, Ponte, et al., 2019). Control uncertainty arises when managerial policies, analytical models, or planning assumptions fail to adequately reflect operational realities. For example, at the demand planning level, a firm may select a particular forecasting method but failing to consider (or neglecting) the assumptions underlying that method can lead to inaccurate demand estimates (Babai et al., 2022). Choosing a method that does not reflect the true demand pattern can introduce control uncertainty. Similarly, inappropriate or overly simplified assumptions (e.g., static versus dynamic BOMs) in MRP can lead to inaccurate material requirements and inventory imbalances, including shortages and excess stock (Huttunen & Helo, 2026; Thürer et al., 2022). These challenges are amplified in remanufacturing because planners must simultaneously cope with uncertain demand for remanufactured products and unpredictable product returns (Goltsos, Ponte, et al., 2019; Jia et al., 2016; Wei et al., 2015). Recent experimental evidence shows that these uncertainties significantly impact managerial- decision making efficiency (Naumov et al., 2025). Understanding how different sources of uncertainty interact and influence PPC activities is therefore essential for designing effective planning and control systems in remanufacturing. Table A summarizes the main sources of uncertainty in remanufacturing discussed in this section.

Table A: Sources of uncertainty in remanufacturing

Uncertainty	Description	Key references
Demand uncertainty	Variability in the market demand for remanufactured products	(Abdulla et al., 2024; Bakal & Akcali, 2006; Östlin et al., 2008; Ijomah, 2009; Atasu et al., 2010; Abbey et al., 2015; Zhu & Tian, 2016; Khor & Hazen, 2017; Mutha et al., 2022).
Supply uncertainty	Variability in the quantity, timing, and quality of used products (cores) required to start the remanufacturing operations.	(Guide, 2000; Guide & Van Wassenhove, 2001; Ferrer & Whybark, 2001; DePuy et al., 2007; Atasu et al., 2010; Junior & Filho, 2012; Wei et al., 2015; Jia et al., 2016; Goltsos et al., 2019; Mutha et al., 2022; Babai et al., 2025; Hoffmann et al., 2025; Karabağ et al., 2025; Naumov et al., 2025).
Process uncertainty	Variability in time, routing, resource requirements, and yield of remanufacturing operations.	(Guide, 2000; Ferrer & Whybark, 2001; DePuy et al., 2007; Jonsson & Mattsson, 2009; Goltsos, Ponte, et al., 2019; Goltsos, Syntetos, et al., 2019; Kamper et al., 2019; Hoffmann et al., 2025).
Control uncertainty	Variability in the control of remanufacturing operations due to incomplete information or use of incorrect managerial policies, analytical methods, and assumptions.	(Wei et al., 2015; Goltsos, Ponte, et al., 2019; Naumov et al., 2025).

Developed by the author (derived from existing literature)

2.3 PPC for remanufacturing

This section defines PPC in the context of remanufacturing and discusses the planning challenges that arise from the unique characteristics of remanufacturing systems. It concludes by presenting the analytical framework used in this thesis.

2.3.1 Defining PPC for remanufacturing

As discussed earlier, remanufacturing consists of three core processes: disassembly, reprocessing, and reassembly. Consequently, the PPC system must coordinate and manage activities across all three processes. Guide et al. (1999) describe this role as follows:
"The basic problem for production planning and control is to determine how much and when for a number of inter-related decision variables. Any coordinated production planning and control system must assist a manager, at a minimum, in planning how much and when to disassemble, how much and when to remanufacture, how much to produce and/or order for new materials, and coordinate disassembly and reassembly. The production planning and control system should also be capable of coordinating a mix of remanufacture and new production" Guide et al. (1999, p. 3).

This conceptualization has informed much of the subsequent research on PPC in remanufacturing (Fang et al., 2017; Ferrer & Whybark, 2001; Guide, 2000; Hoffmann et al., 2025; Junior & Filho, 2017). While these studies differ in their specific focus, there is a consensus among them that PPC needs to coordinate material flows, information flows, and planning activities. Several studies have extended this perspective by emphasizing the integration of demand, supply, and operational information. For example, Ferrer & Whybark (2001) highlight the importance of incorporating demand, return, and shop-floor information into MRP. Although originally identified more than two decades ago, the need to integrate information on demand, returns, and production times continues to influence PPC decisions in remanufacturing (Karabağ et al., 2025) . Junior & Filho (2017) suggest maintaining inventories of disassembled cores to reduce the impact of uncertainty in demand and core quality. Similarly, Guide et al. (2003) propose different planning approaches, including remanufacture-to-stock (RMTS), reassemble-to-order (RATO), and remanufacture-to-order (RMTO), depending on return rates, return quality, and other planning parameters. More recently, Karabağ et al. (2026) examined the use of real-time product usage data to support planning decisions in RMTS environments. Although these researchers disagree regarding the most appropriate planning practice, they generally view uncertainty in demand, return rates, return quality, and related information flows as the key challenges of remanufacturing PPC.

Closely related to this thesis is the framework developed by Ferrer & Whybark (2001). The framework has two comparable elements with the general definition of PPC proposed by Jonsson & Mattsson (2009). First, it uses formal planning methods (e.g., MRP) to support planning decision-making. Second, it incorporates information from multiple organizational functions, including sales, product return management, procurement, and production operations. Demand information originates from sales activities, return information from core management processes, material availability from procurement, and operational data from disassembly, reprocessing, and reassembly activities (Mutha et al., 2022). These information flows support the coordination of planning and control activities in the remanufacturing production. Based on Guide et al. (1999), Ferrer & Whybark (2001), and Jonsson & Mattsson (2009), PPC for remanufacturing in this thesis is understood as:

"The planning, development, coordination, organization, management, and control of decisions regarding how much and when to disassemble, how much and when to remanufacture, how much to produce and/or order for new materials, and the coordination of disassembly, reassembly, and related information flows to meet market demand"

2.3.2 Framework for analyzing PPC for remanufacturing

As discussed in Section 2.2.2, remanufacturing is susceptible by a number of sources of uncertainties. These uncertainties create considerable challenges in PPC activities. Seminal work of Guide (2000) identified seven characteristics that complicate PPC activities in remanufacturing. These include uncertainty in the timing and the quantity of returns, balancing returns with demands, disassembly, uncertainty in materials recovery, reverse logistics, materials matching requirements, routing uncertainty and processing time uncertainty. A review by Junior & Filho (2012) found that much of the literature examined these characteristics individually rather than as an interconnected set of challenges. More recent studies continue to show that PPC for remanufacturing is complicated because of firms face one or several of these characteristics (Gong et al., 2020; Hoffmann et al., 2025; Huster et al., 2023; Kamper et al., 2019; Karabağ et al., 2026).

To examine how firms plan and control remanufacturing production in such uncertainty, this thesis adopts the framework presented in Figure B. Similar to Figure A, the framework shows the key PPC activities and the associated flows of materials and information. It also highlights key sources of uncertainty that distinguish remanufacturing from manufacturing and therefore require specific planning and control considerations.

PPC for remanufacturing must coordinate disassembly, reprocessing, and reassembly activities, processes that are generally absent from manufacturing. The inventory structure is also more complex. Rather than managing only raw materials, work-in-process inventory, and finished goods, remanufacturing operations typically involve several other inventory categories, including returned products (cores), recovered materials and components, new replacement parts, and remanufactured products. These have important implications for PPC. The planning and control therefore must manage both forward and reverse flows of materials and information while coordinating activities across demand management, return management, procurement, and production operations. The framework provides the foundation for the analysis in this thesis by showing the key activities, flows, and inventory types involved in PPC for remanufacturing.

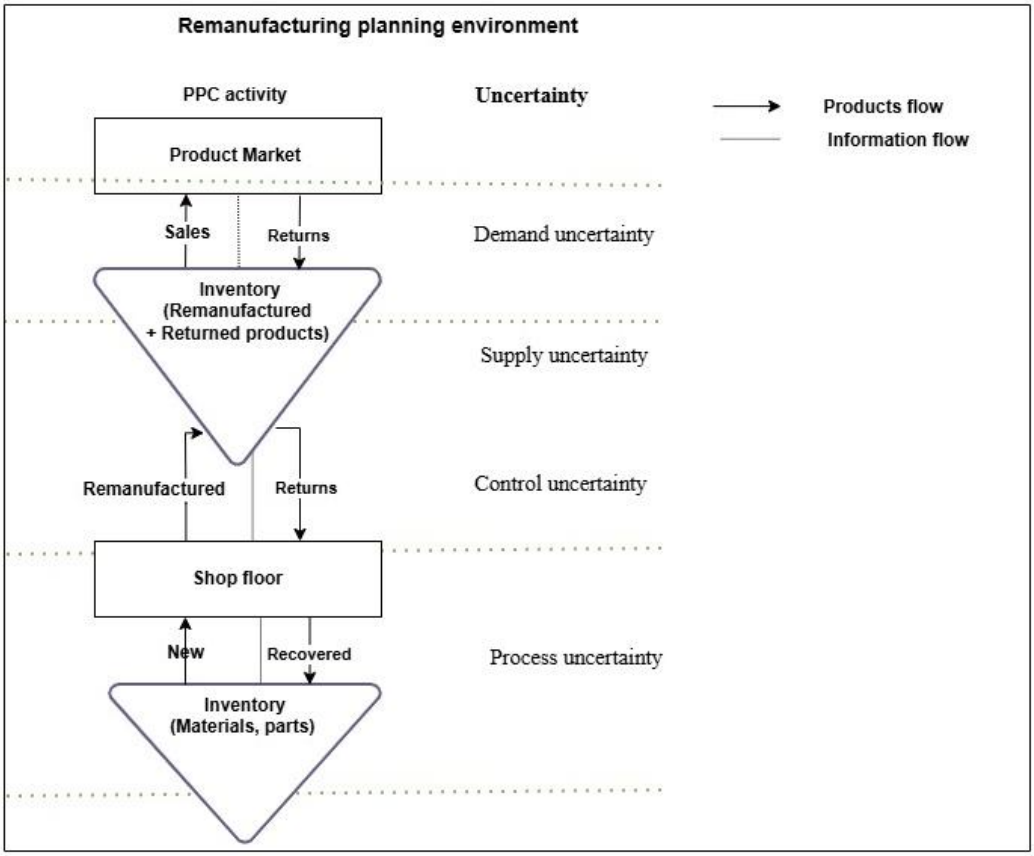

Figure B: Framework for analysing PPC for remanufacturing
Adapted from Jonsson & Mattsson (2009), Ferrer & Whybark (2001), and Goltsos, Ponte, et al. (2019)

3 Research methodology

This chapter presents and justifies the research design used to address the three research questions and achieve the overall objective of the thesis. It begins by describing the research process, followed by research design, including data collection and analysis methods and techniques. The chapter concludes with a reflection on methodological choices and research quality.

3.1 Research process

This thesis forms part of the author's five-year doctoral project, which commenced in February 2024 and is scheduled to conclude in February 2029. The research reported in this thesis covers work conducted between February 2024 and October 2026.

The research process began with a review of the literature on PPC for remanufacturing, discussed in Chapter 2. This provided the theoretical foundation and guided the development of the three research questions addressed in the thesis. The three research questions are investigated through two studies resulted in three Papers I, II, and III. Paper I addresses RQ1, Paper II addresses RQ2, and Paper III addresses RQ3. Throughout the research process, preliminary findings were presented at academic conferences and workshops, providing opportunities for feedback and refinement. The initial results of Paper I were presented at the Paris Circular Operations Workshop 2025 in Paris and later at the EurOMA Sustainable Operations and Supply Chains Forum 2025 in Porto. Findings from Paper II were presented at the ESDI Conference 2025 in Gothenburg, and a revised version was presented at the Production and Operations Management Society (POMS) Conference 2026 in Stockholm. Preliminary findings from Paper III were presented at EurOMA 2026 in Vienna. Table B summarizes the overall research process (highlighted in gray color), the associated papers, and their timelines.

Table B: Research process, papers, and timeline

Process	2024				2025				2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
RP												
Paper I					Paris+EurOMA							Ongoing
Paper II						EDSI				POMS		Submitted
Paper III										EurOMA		Ongoing
Lic												

RP = Research proposal; Lic = Licentiate.

3.2 Research design

PPC for remanufacturing is recognized as a complex research area because of the uncertainty in product returns, material availability, and production processes (DePuy et al., 2007; Junior & Filho, 2016; Karabağ et al., 2026). Despite growing interest in the field, limited empirical evidence exists on how firms design and coordinate PPC activities in remanufacturing environments. Investigating such a complex phenomenon requires a research design capable of linking empirical observations to the research questions and, ultimately, to the study's conclusions.

According to Yin (2018), research design refers to the logical sequence that connects empirical data to research questions and conclusions. Given the nature of the research questions and the need to draw on both quantitative and qualitative evidence, this thesis adopts a sequential multi-study research design combining quantitative and qualitative methods (Creswell & Creswell, 2017). This design is particularly suitable for addressing complex research problems because it combines the strengths of quantitative and qualitative approaches, thereby providing a more comprehensive understanding of the investigation problem (idem). The design begins with the collection and analysis of quantitative data, followed by qualitative inquiry to explain, elaborate, and contextualize selected findings from the quantitative analysis. The approach is well suited to this research because it allows a broad understanding of PPC in remanufacturing to be developed through quantitative methods and subsequently deepened through qualitative investigation.

That said, the quantitative findings of Paper I guided the focus of the qualitative investigations conducted in Papers II and III. Specifically, the uncertainties identified in Paper I as making PPC in remanufacturing challenging informed the selection of contextual factors examined in Paper II and the exploration of managerial decision-making processes in Paper III. The qualitative studies therefore served to understand the patterns identified in the survey phase.

3.2.1 Data collection and analysis methods

Each paper adopted data collection and analysis methods that were appropriate for addressing its research aims and objectives.

Paper I

Paper I used a survey method to collect quantitative data. Surveys have a long history of being employed to collect quantitative data from a sample of a population to describe and explore trends and patterns of phenomenon of interest (Creswell & Creswell, 2017). The aim of Paper I was to explore challenges faced (i.e., seek to identify challenges that can provide a basis for more focused investigation) in PPC for remanufacturing across several industries (e.g., aerospace, automotive, and electronics and electrical equipment) in multiple European countries and the United States of America (USA). Therefore, the survey method fits Paper I's research aim and question (Montabon et al., 2018).

Although remanufacturing is practiced in many countries worldwide (e.g., China and India), the European and USA contexts offer similarities and differences that closely relate to the thesis aim, scope, practical considerations, and time frame. One similarity between Europe and the USA is their advancement in remanufacturing (Östlin et al., 2008). In contrast, a key difference is in government regulations regarding product take-back (Esenduran et al., 2017; European Commission, 2020; US International Trade Commission, 2012), which may influence some aspects of remanufacturing operations (e.g., core acquisition), and thus how PPC is practiced.

Drawing on existing literature, an initial conceptual framework was developed to describe the key remanufacturing source uncertainties and PPC activities. This initial framework was discussed with scholars knowledgeable in remanufacturing and PPC. Their feedback led to a refined framework, which informed the survey questionnaire design. The survey questionnaire was developed using Qualtrics software (qualtrics.com) and administered to remanufacturing

managers or similar roles. These managers possessed the knowledge and experience required to provide informed responses on remanufacturing PPC practices (Bell et al., 2022). They were contacted directly via email addresses obtained from their company websites, LinkedIn, and business directories. Directly contacting managers for online surveys has a long tradition and is an established practice in operations management (Montabon et al., 2018).

Data collection started on November 7, 2024, and is ongoing. During this period, the managers were reminded once to complete the survey, with a notice to disregard if they had already responded. Twenty complete and valid responses were received; resulting in 7 % response rate with participation across five industry sectors: Aerospace, automative, EEE, furniture and home appliances, and heavy-duty. The level of analysis was plant because remanufacturing PPC is a plant-level phenomenon (Guide, 2000). The remanufacturing plant defined in paper I (and in papers II and III and the thesis) as an industrial facility that acquires used products, disassembles, processes, and reassembles them into final remanufactured products to meet market specific demand (Thierry et al., 1995). In an instance where a plant operates both manufacturing and remanufacturing, known as hybrid system (van der Laan et al., 1999), the focus was on the remanufacturing activity. Brokers, dealers, and other organizations related to remanufacturing but not having plants performing remanufacturing were excluded. While the author acknowledges implications of relatively small number of responses, however, compared to similar remanufacturing studies (cf. Guide, 2000; Kamper et al., 2019; Parker et al., 2015), the sample appears comparable to the population over several dimensions (e.g., sales volume, type of remanufacturer, and product category), and thus, the findings provide a useful basis for understanding PPC in remanufacturing and for guiding more detailed future investigations. The author plans to collect more data before writing the final paper.

The collected data were analyzed using descriptive statistics, including frequencies, means, and standard deviations. Such techniques are well suited for exploratory studies that seek to identify patterns and trends (Bell et al., 2022). While the findings describe the characteristics of the sampled remanufacturing plants, a sufficiently representative sample would have enhanced the potential to generalize the results to the broader population from which the sample was drawn (idem).

Paper II

Paper II was informed by the findings of Paper I and the literature on PPC in remanufacturing. Drawing on contingency theory (CT) (Sousa & Voss, 2008), the paper examines how contextual factors shape PPC approaches in remanufacturing environments. More specifically, it investigates how variations in demand, return rates, return quality, and product variety influence planning decisions, including the choice of planning methods, inventory buffer, and customer order fulfilment strategies. Given the need to understand these relationships within their organizational context, a case study research design was adopted (Meredith, 1998).

The case study design allows for a contextualized understanding of the phenomena of interest (Yin, 2018). A multiple-case design was selected because it facilitates cross-case comparisons, reduces the risk of drawing conclusions from isolated observations, and strengthens both theory development and external validity (Eisenhardt, 2021). Cases were purposefully selected to include remanufacturing plants exhibiting variation in key characteristics relevant to the study, such as demand variability, return volume variability, and product variety. At the same time, several control criteria were applied to ensure comparability

across cases (Harrigan, 1983). These criteria included firm size (e.g., annual remanufacturing sales exceeding USD 2 million), the use of established planning processes (e.g., MRP and inventory management systems), and organizational maturity in remanufacturing (e.g., ISO 9001 certification and recognition in industry reports).

The final sample consisted of six remanufacturing plants, three operating in the electrical and electronic equipment (EEE) sector and three in the automotive sector. This number of cases is considered appropriate for theory building while remaining manageable for qualitative analysis (Eisenhardt, 1989). Furthermore, both sectors have well-established remanufacturing activities and have been through significant developments, making them suitable contexts for studying PPC in remanufacturing (Eisenhardt, 1989; Esenduran et al., 2016).

Data were collected primarily through semi-structured interviews with remanufacturing managers and other individuals with direct responsibility for, or knowledge of, PPC activities. This method enables a detailed exploration of PPC practices while remaining open to new insights during the interviews (Brinkmann, 2014). Interviews were conducted in person and online via Microsoft Teams. Interviews were audio-recorded, with informed consent, and transcribed. All informants, except one, agreed to be recorded. Each interview lasted between 45 to 75 minutes and in total (16) interviews were conducted. In addition to interviews, data from field notes, internal company reports, documents, and presentations were also collected and appropriately documented (Yin, 2018).

The data were analysed iteratively, moving between the empirical material and the relevant literature (Yin, 2018). The analysis began with a within-case analysis to develop a detailed understanding of each firm's planning environment and PPC approach. This was followed by a cross-case analysis aimed at identifying patterns, differences, and relationships across cases. These analyses enabled the development of an understanding of how contextual factors shape PPC approaches in remanufacturing environments.

Paper III

Paper III adopted the same overall research design as Paper II, namely a multiple-case study design. However, because Paper III aimed to examine PPC-related decisions across managerial decision-making levels, additional case-selection criteria were applied. Specifically, participating firms were required to have well-defined organizational structures to account for how decision-making responsibilities are distributed and coordinated across strategic, tactical, and operational levels (Siggelkow & Levinthal, 2003).

All selected firms have more than 20 years of remanufacturing experience and organizational structures with hierarchical levels: operational, tactical, and strategic. To reduce the influence of structural differences on managerial decision-making, only firms with centralized organizational structures were included (Siggelkow & Levinthal, 2003). In a centralized structure, key decisions are made at the organizational level rather than being delegated to individual business units or departments. This contrasts with decentralized structures, where decision-making authority is distributed across organizational subunits. The final sample comprised five European remanufacturers. To capture some variation in organizational and operational contexts, three cases were selected from the electrical and electronic equipment (EEE) industry and two from the automotive industry.

Data collected through semi-structured interviews and on-site visits conducted from March 2025 and ongoing. Interviews were carried out either face-to-face or online via Microsoft Teams. To capture PPC-related decision-making across the firm, interviewees were selected from strategic (e.g., chief executive officer), tactical (e.g., department or unit manager), and operational (e.g., supervisor) levels. The interviews explored participants' roles and responsibilities, professional experience, and how decisions were made and communicated within the firm. Interviewees' experience in their current positions ranged from 4 to 15 years. Each manager was interviewed individually and assured of confidentiality to encourage open and candid discussions. Interviews lasted between 45 and 75 minutes. In total, 16 interviews were conducted, yielding about 18 hours of interview material. Papers II and III partially overlap. Both used data from the same case firms. Paper II included 6 case firms and Paper III. 5. Data from 2 firms were partially used in the analysis of both papers.

All interviews were transcribed verbatim. Interview data were complemented by observations from site visits and relevant company documents and records. Data was analyzed using within-case and cross-case analysis methods. The within-case analysis was used to understand decision-making processes within each firm, while the cross-case analysis identified common patterns and differences across cases. The unit of analysis was decision-making process. Table C summarizes the methodological aspects including research design, data collection methods, and data analysis techniques used in each of the three papers.

3.3 Data analysis in the thesis

To address the research questions, the findings from the three papers were synthesized and used as the primary source of evidence. Each paper contributed directly to answering one of the thesis research questions.

The findings from Paper I were used to answer RQ1: What challenges do remanufacturing firms face today in production planning and control? By identifying the characteristics and sources of uncertainty that complicate PPC. Paper I established the empirical foundation for the thesis. The findings from Paper II were used to answer RQ2: How do remanufacturing planning environments shape production planning and control approaches? Paper II applied contingency theory and investigated how variations in contextual factors, such as demand, product returns, and product characteristics, influence firms' PPC practices and planning choices. Finally, the findings from Paper III were used to answer RQ3: How do managers in remanufacturing firms make and communicate production planning and control decisions? Paper III applied the bounded rationality perspective and investigated how PPC-related decisions are made and communicated across managerial levels. The findings from the three papers provide a comprehensive understanding of PPC in remanufacturing by addressing its challenges, contextual influences, and managerial decision-making processes.

Table C: Research design, data collection methods, and data analysis techniques used in each of the three papers

Methodological aspect	**Paper I**	**Paper II**	**Paper III**
Research purpose	Explore challenges faced in PPC for remanufacturing across industries and countries	Explain how contextual factors shape PPC approaches in remanufacturing environments	Explain how PPC-related decisions are made and communicated across managerial levels
Research design	Quantitative survey study	Qualitative multiple-case study	Qualitative multiple-case study
Role in overall thesis	Exploratory phase providing broad empirical understanding and identifying key PPC challenges	Explanatory phase building on Paper I findings to understand PPC approaches	Explanatory phase examining decision-making processes linked to PPC across managerial levels
Unit of analysis	Remanufacturing plant	Remanufacturing plant	Decision-making process across managerial levels
Sampling strategy	Purposive identification of remanufacturing managers or similar roles	Purposeful case selection based on variation and control criteria	Purposeful case selection with additional organizational structure criteria
Population/context	Remanufacturing firms/plants in Europe and USA	Automotive and Electrical & Electronic Equipment (EEE) remanufacturers	European remanufacturers in Automotive and EEE sectors
Respondent type	Remanufacturing managers or equivalent positions	Remanufacturing managers and personnel responsible for PPC activities	Strategic (e.g., CEOs) tactical (e.g., department managers), and operational managers (e.g., team supervisors).
Sample size	20 complete survey responses.	6 remanufacturing plants; 18 interviews.	5 remanufacturing plants; 16 interviews
Case selection criteria	Not case-based; managers involved in PPC-related activities.	Established planning processes, remanufacturing maturity	>20 years' remanufacturing experience, centralized organizational structure, established planning processes
Data collection method	Online survey	Semi-structured interviews, site visits, and documentary evidence	Semi-structured interviews and site visits
Data analysis technique/s	Descriptive statistics	Within-case and cross-case analysis	Within-case and cross-case analysis
Data collection period	Began November 2024 and ongoing	March 2024 to June 2026	March 2025 and ongoing
Theoretical foundation	Conceptual framework developed from PPC and remanufacturing literature.	Contingency theory (CT)	Judgment and decision-making (JDM)

Developed by the author

3.4 Reflection on methodological choices and research quality

The methodological choices made in this thesis are rooted in the recognition that PPC for remanufacturing is a complex phenomenon characterized by uncertainty and context-specific managerial practices. Such phenomena are difficult to capture through a single method because they involve both observable operational characteristics and socially constructed managerial interpretations (Creswell & Creswell, 2017). Therefore, this thesis combined quantitative and qualitative methods across sequential studies to generate complementary insights into PPC in remanufacturing. While the individual studies were analyzed separately, their findings are integrated in the synthesis of the thesis to develop an overall understanding of PPC.

From a philosophical perspective, the thesis is broadly aligned with a pragmatic worldview. Pragmatism emphasizes the research question as the primary driver of methodological choices and advocates the combination of methods when this contributes to a more comprehensive understanding of the phenomenon under investigation (Saunders et al., 2009). RQ1 was formulated as a "what" question and was addressed using a quantitative method, whereas RQ2 and RQ3 were formulated as "how" questions and addressed using qualitative methods. Given the exploratory nature of the research questions and the limited empirical evidence concerning PPC for remanufacturing, the use of both quantitative and qualitative methods was considered appropriate (Creswell & Creswell, 2017). Rather than viewing methodological approaches as competing paradigms, the thesis treats them as complementary means of developing knowledge about PPC practices and decision-making processes.

Sequential multi-study research design is valuable when investigating complex phenomena (such as PPC for remanufacturing) because it combines the breadth of quantitative approaches and the contextual depth of qualitative inquiry (Creswell & Creswell, 2017). In this thesis, the survey study (Paper I) provided an exploratory overview of PPC-related challenges, while the two qualitative case studies (Papers II and III) enabled a deeper understanding of how firms respond to these challenges. The sequential design, therefore, reflects methodological complementarity, whereby the weaknesses in one method are complemented by the strengths of another. However, the adoption of sequential multi-study research design also raises a number of methodological issues.

A key issue relates to the claim of methodological integration while presenting separate quantitative and qualitative investigations (Tashakkori & Teddlie, 2010). A critical question, therefore, concerns the extent to which findings from Paper I genuinely informed the design and execution of Papers II and III. Although the survey results influenced the development of subsequent research phases (Papers II and III), the strength of the overall contribution lies in integration between the studies rather than treating them as independent empirical observations. Thus, key criterion for evaluating the quality of the thesis is the extent to which knowledge generated in one phase contributes to explanation and theory development in later phases.

3.4.1 Reflection on Paper I

To assess the quality of the research in Paper I, an evaluation of the survey design, respondent selection, instrument development, and sample characteristics was conducted. Paper I employed a survey design to explore challenges in PPC for remanufacturing. Surveys are known for enabling data collection from multiple firms and facilitate the identification of

patterns across industrial settings (Forza, 2002). Given the aim of generating an exploratory overview of PPC challenges across industries and geographical contexts, the survey method was deemed an appropriate choice.

A notable strength of the survey was participation of key informants occupying managerial positions responsible for PPC activities. Previous operations management research highlights the importance of selecting informants who possess sufficient knowledge about the studied phenomena (Forza, 2002). Furthermore, the questionnaire was developed from existing literature and refined through expert feedback, thereby strengthening content validity and reducing the likelihood of measurement errors (idem). Nevertheless, several limitations deserve attention. The most obvious concern relates to the final sample size and response rate. Although low response rates are not uncommon in industrial surveys, particularly in niche fields such as remanufacturing (cf. Guide, 2000; Kamper et al., 2019; Nasr et al., 1998), a sample of 20 responses inevitably limits statistical power and the ability to perform inferential analyses. This means that strong population-level conclusions cannot be drawn. Therefore, the findings should be interpreted as exploratory rather than representative. The author plans to add more responses.

A related concern is the possibility of non-response bias. Firms that chose to participate may differ from those that did not, potentially affecting the validity of the findings (Wagner & Kemmerling, 2010). While efforts were made to reach knowledgeable respondents and the sample appears broadly consistent with characteristics reported in previous remanufacturing studies, uncertainty regarding representativeness remains. These limitations highlight the importance of viewing Paper I as an exploratory foundation for subsequent qualitative investigation rather than as a standalone source of generalizable conclusions.

3.4.2 Reflection on Papers II and III

Papers II and III adopted multiple-case study designs to investigate PPC approaches and managerial decision-making in remanufacturing environments. The choice of case study methodology is consistent with recommendations within operations management research (Eisenhardt, 1989; Yin, 2018), where case studies are regarded as valuable for examining complex processes and elaborate theory (Ketokivi & Choi, 2014).

A key strength of both papers is their ability to capture contextual complexity (Yin, 2018). PPC practices do not exist independently of firm but are influenced by factors such as uncertainty, organizational structure, product characteristics, and managerial capabilities. Such interactions are difficult to isolate through purely quantitative approaches. As Yin (2018) and Stake (1995) argue, case studies allow researchers to examine phenomena within their natural settings while maintaining sensitivity to contextual factors.

The use of multiple cases further strengthens the research design. According to Eisenhardt, (1989), theory-building case research benefits from replication logic, where patterns observed across multiple cases increase confidence in emerging explanations. Multiple-case designs also reduce the risk that conclusions reflect idiosyncratic characteristics of individual firms (Eisenhardt, 2021). The inclusion of firms from different industrial sectors therefore enhanced variation while maintaining sufficient comparability to support analytical generalization.

The quality of Papers II and III are assessed using the criteria of credibility, transferability, dependability, and confirmability (Lincoln et al., 1985).

Credibility refers to the extent to which the findings accurately represent the phenomenon being investigated (Lincoln et al., 1985). A potential weakness of Papers II and III is their reliance on interview data. Interviewees may unintentionally reconstruct events in ways that appear more coherent and rational than they were at the time (Miller et al., 1997). To reduce these risks, several measures were taken. First, data triangulation was employed by combining interview data with site visits, field observations, company documents, reports, and presentations. Comparing information across multiple sources helped verify participants' accounts and identify inconsistencies (Lincoln et al., 1985; Yin, 2018). Second, interviewees were encouraged to provide examples and describe specific situations rather than general opinions. This helped anchor discussions in actual managerial practices and reduced the likelihood of purely retrospective explanations (Miller et al., 1997). For Paper III, the author acknowledges that in some firms insights from certain managerial levels are missing (although data collection ongoing) and that might impact the findings of Paper III, however, the use of multiple case firms allowed recurring patterns to be assessed across different contexts, thereby increasing confidence that the findings reflect broader phenomena rather than isolated individual accounts (Eisenhardt, 1989; Yin, 2018). Moreover, in Paper III, additional case selection criteria were introduced to focus on firms with centralized structures and mature remanufacturing operations. While these criteria increased comparability and theoretical consistency (Eisenhardt, 1989; Voss et al., 2002), they also narrowed the empirical scope of the study. PPC-related decision-making in decentralized firms may differ substantially from that observed in the selected organizations. Hence, the findings should be interpreted within the specific context of mature and centralized remanufacturing firms.

Transferability concerns the extent to which findings are applicable beyond the studied cases (Lincoln et al., 1985). The inclusion of firms from different industrial sectors increased variation in the empirical material and strengthened the broader relevance of the findings. Detailed descriptions of case characteristics, organizational contexts, and PPC practices further enable readers to assess the applicability of the findings to other settings (Stake, 1995). Nevertheless, transferability remains limited by the purposeful selection of cases. The firms were selected because they were theoretically relevant rather than statistically representative (Eisenhardt, 1989). In particular, Paper III focused on mature remanufacturing firms with centralized organizational structures. As a result, the findings may not fully reflect PPC practices and decision-making processes in smaller firms, less mature remanufacturers, or firms with decentralized decision-making structures.

Dependability refers to the consistency and transparency of the research process (Lincoln et al., 1985). Throughout the research process, the author ensured documentation, development of criteria for case selection, interview protocols, and data collection and analysis procedures. Both studies followed established case study procedures recommended by (Yin, 2018) and (Eisenhardt, 1989), providing a clear audit trail from data collection to conclusions. Furthermore, data analysis involved iterative within-case and cross-case comparisons, allowing emerging interpretations to be continuously assessed against empirical evidence.

Confirmability concerns the extent to which findings are grounded in empirical evidence rather than researcher preferences or assumptions (Lincoln et al., 1985). Qualitative research is interpretive (Lim, 2025). The author played an active role in selecting cases, conducting interviews, coding data, and developing explanations. While such involvement was necessary

to generate contextual understanding, it also introduces the possibility of subjective interpretation and confirmation bias (idem). To reduce these risks, the author used multiple data sources, documentation, and iteratively moved between empirical observations and theory to strengthen confirmability.

Throughout the research process, efforts were made to ensure that conclusions were supported by evidence from the cases rather than preconceived expectations. Figure C summarizes the overall structure of the thesis, including the research objective, research questions, the papers through which they are addressed, and studies conducted. Two studies were conducted: Study I employed a quantitative research design, whereas Study II employed a qualitative research design.

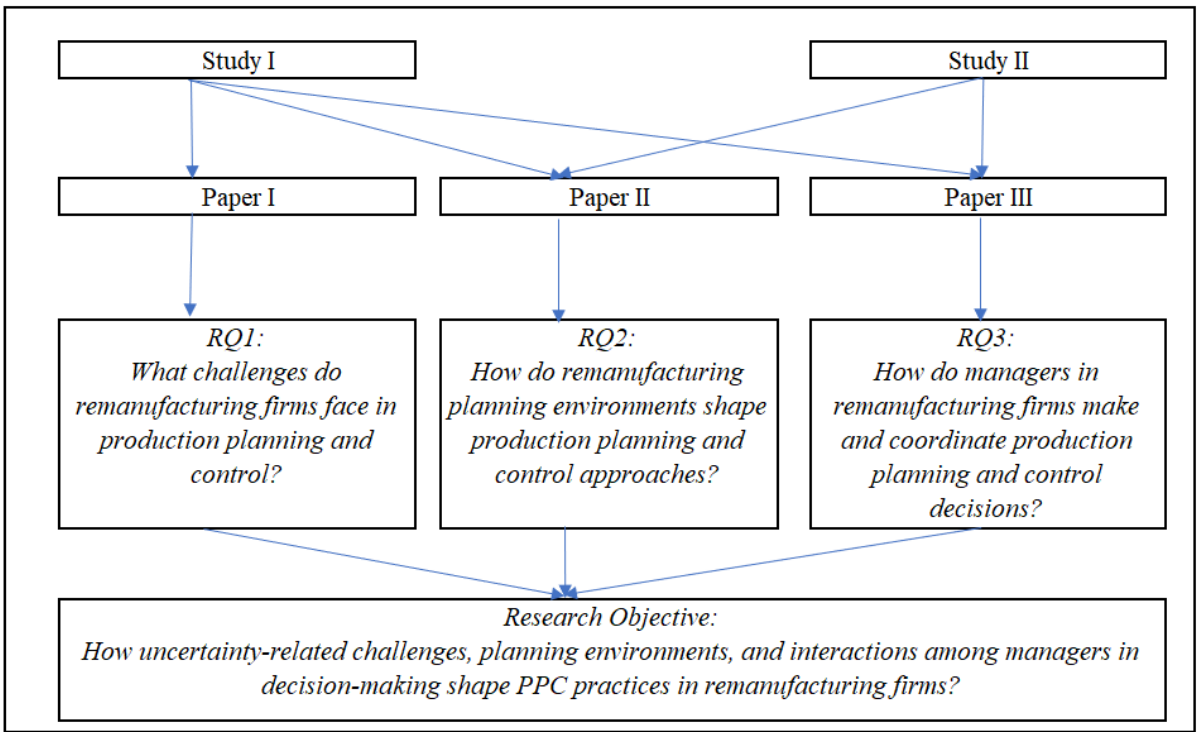

Figure C: Research objective, questions, and related papers. Developed by the author

4 Summary of papers

This chapter summarizes the three appended papers on which the analysis in this thesis is based. The chapter focuses on each paper's purpose, methodology, theoretical framework or lens, and key findings. More details can be found in the appended papers.

4.1 Paper I: Production planning and control for remanufacturing: A state-of-the-art practice and challenges

The purpose of Paper I was to examine the current state of PPC practices in remanufacturing and to revisit the seven PPC characteristics and challenges originally identified by Guide (2000), namely, uncertainty in the quantity and the timing of returns, balancing returns with demands, disassembly, uncertainty in materials recovery, reverse logistics, materials matching requirements, and routing uncertainty and processing time uncertainty. The paper investigates whether these characteristics and challenges are still relevant and how firms have developed planning processes and capabilities to manage them. The paper uses survey data from 20 remanufacturing firms located in Europe and the United States and compares the findings with those of Guide's (2000) seminal survey. It was found that remanufacturing firm still face challenges in PPC albeit they are starting to develop planning processes and capabilities, among many other.

4.2 Paper 2 Exploring production planning and control approaches in remanufacturing: A multiple-case study

The purpose of Paper II was to investigate how different planning environments shape PPC approaches in remanufacturing. The paper adopts contingency theory as a lens to explain why firms use different planning methods, inventory strategies, and customer order fulfillment strategies. It employs multiple-case study design to collect qualitative and quantitative data on planning processes, inventory, and customers' order fulfillment from six remanufacturing firms, three from automative and three from EEE, in Europe. The within-case analysis identified the planning environment in each case that shapes the planning approaches. The cross-case analysis revealed similarities and differences that explain how planning approaches are shaped. The paper synthesized these similarities and differences into high-order planning dimensions: requirement predictability and planning complexity.

4.3 Paper 3 Managerial decision-making interactions in remanufacturing production planning and control

The purpose of Paper III was to investigate how managers make PPC-related decisions and how strategic, tactical, and operational decisions interact in remanufacturing environments. The paper adopts judgment decision making as a theoretical lens to explore how managers at different managerial decision-making levels make and communicate PPC-related decisions under uncertainty due to lack or incomplete planning information. It employs multiple-case study design to collect qualitative and quantitative data on managerial decision-making processes across the managerial levels (strategic, tactical, and operational) from five remanufacturing firms, two from automative and three from EEE, in Europe. The cross-case analysis revealed three dimensions of managerial decision-making: overlapping, interaction,

and alignment/misalignment. Furthermore, it was found that uncertainty (coming from lack or incomplete planning information) leads high-level managers to intervene in low-level managers' decisions and tasks.

5 Findings

This chapter presents the main findings of the three papers included in this thesis. Each section focuses on one paper and addresses a specific research question (e.g., Paper I addresses RQ1, Paper II addresses RQ2, and Paper III addresses RQ3). The sections begin by describing the paper's relationship to the thesis, followed by a presentation of its main findings and its primary contribution to the literature. Table D provides the summary of individual papers.

5.1 Paper I Production planning and control for remanufacturing: A state-of-the-art practice and challenges

Paper I contributes to answering the thesis's first research question (RQ1): What challenges do remanufacturing firms face today in production planning and control? To address this question, the findings are compared with those reported by Guide (2000). The analysis identified five key findings.

First, core-related uncertainty remains a major challenge in PPC for remanufacturing. Despite decades of research, uncertainty regarding the quantity, timing, and quality of returned cores continues to challenge many planning and control activities. Firms still struggle to predict when cores will be returned, in what quantities, and in what condition. The availability of a sufficient quantity of cores, with acceptable quality and at the required time, is essential for meeting customer demand. When return rates and core quality are difficult to predict, PPC activities such as material requirements planning, production scheduling, and inventory control become increasingly challenging. However, the findings also indicate that firms have begun to develop planning processes and capabilities to better manage these challenges and mitigate the effects of core-related uncertainty (further details of these processes and capabilities are provided in Paper I).

Second, firms are shifting to a diversified sourcing portfolio, that is, diversifying sources of supply. Many remanufacturers start to use multiple return channels, such as leasing contracts, exchange programs, partnerships, brokers, and buy-back programs, rather than depending on one or only a few sources of core supply. This diversification improves core availability and enhances supply flexibility.

Third, the findings suggest that planning maturity matters. Firms with more mature planning processes reported high performance in customer order delivery, demand-supply balancing, and control over return flows than firms with less developed planning processes.

Fourth, and finally, digital technologies are enabling rather than replacing planning. Technologies such as the Internet of Things (IoT), artificial intelligence (AI), radio-frequency identification (RFID), and advanced analytics improve visibility and forecasting capabilities. However, these technologies create value only when combined with mature planning processes.

The paper contributes to the PPC for remanufacturing literature by showing that uncertainty remains a fundamental challenge. However, rather than attempting to eliminate uncertainty, remanufacturing firms increasingly address it through the development of planning processes and capabilities, high levels of planning maturity, and use of emerging digital technologies.

5.2 Paper 2 Exploring production planning and control approaches in remanufacturing: A multiple-case study

Paper II contributes to answering the thesis's second research question (RQ2): How do planning environments shape production planning and control approaches? More specifically, it examines how planning environment characteristics, such as variability in demand, return volume, return timing, and return quality, influence planning methods, inventory buffering, and customer order fulfillment strategies. Drawing on CT, the paper identifies two higher-order dimensions that explain variations in PPC approaches across remanufacturing firms.

The first dimension is requirement predictability, which refers to the degree to which managers can reliably estimate future requirements for cores and replacement materials. The findings show that requirement predictability shapes the choice of planning methods. When future requirements can be estimated with reasonable accuracy, firms tend to employ material requirements planning (MRP)-based methods. In contrast, when predictability is low, firms rely more on re-order point (ROP) and inventory-driven planning methods.

The second dimension is planning complexity, which refers to the degree of effort required to coordinate planning information, inventories, materials, and production activities. The findings indicate that planning complexity influences inventory buffering. Higher levels of planning complexity are associated with larger inventory buffers, particularly core inventories, which serve as flexibility buffers. Core inventories play a strategic role in managing variability in returns, recovery rates, and customer demand.

The paper contributes to the remanufacturing PPC literature by showing that planning approaches are not shaped directly by environmental uncertainty itself, but rather by how managers interpret and respond to that uncertainty through the dimensions of requirement predictability and planning complexity. In other words, PPC approaches are contingent upon the level of requirement predictability and the degree of planning complexity faced by the firm.

5.3 Paper 3 Managerial decision-making interactions in remanufacturing production planning and control

Paper III contributes to answering the thesis's third research question (RQ3): How do managers in remanufacturing firms make and communicate production planning and control decisions? Specifically, how managers at strategic, tactical, and operational decision-making levels make PPC-related decisions and how do they communicate these decisions. Drawing on the JDM perspective, the study explores how managers at different decision-making levels address uncertainty in PPC decisions arising from limited or incomplete planning information. The paper reveals four key findings.

First, managerial decision-making levels overlap. Managers do not necessarily remain within the boundaries of their formally assigned decision responsibilities. In particular, higher-level managers may temporarily participate in PPC-related decisions typically made at lower managerial levels when the information required for those decisions is incomplete, changing, or distributed across managerial levels.

Second, the paper identifies three interaction mechanisms through which managers address informational limitations across managerial levels: guiding, informing, and coordinating. Guiding communicates priorities from higher to lower managerial levels while preserving discretion over implementation. Informing makes locally held decision-relevant information accessible across managerial levels. Coordinating brings together managers and information across functional units to jointly consider interdependent PPC-related decisions and trade-offs.

Third, managerial decision alignment cannot be assumed to follow automatically from formal organizational structures or managerial interaction. Managers at different levels operate with different information, responsibilities, and interpretations. Guiding, informing, and coordinating can create conditions supporting alignment, but these mechanisms do not guarantee that interdependent managerial decisions and responses will be mutually consistent.

Fourth, interaction and decision overlapping are distinct managerial responses to informational limitations. Interaction allows information and influence on cross managerial levels while decision participation remains differentiated. Overlapping, by contrast, occurs when participation itself crosses established decision boundaries. Worth noting, neither interaction nor overlapping inherently produces decision alignment because managers may continue to interpret information, priorities, and interdependencies differently.

The paper contributes to remanufacturing PPC research by showing that formally differentiated strategic, tactical, and operational decision responsibilities do not necessarily delimit managerial participation. Under information limitations, managers interact across managerial levels and may temporarily participate in decisions beyond their usual responsibilities, revealing remanufacturing PPC as a cross-level managerial decision-making process.

Table D: Summary of individual papers

Paper	Research Question	Purpose	Main findings	Contribution to thesis
Paper I	RQ1: What challenges do remanufacturing firms face today in PPC?	Revisit the PPC challenges identified by Guide (2000) and examine how firms currently manage these challenges.	Return quantity, timing, and quality remain major uncertainties that make PPC challenging. Firms started to develop planning processes and capabilities, diversify supply sources, and adopt emerging digital technologies. Digital technologies support but do not replace planning processes.	Provides updates on PPC challenges and shows efforts on developing planning process and capability.
Paper II	RQ2: How do planning environments shape PPC approaches?	Examine how planning environments shape planning approaches (i.e., planning methods, inventory buffering, and order fulfillment strategies).	Two higher-order planning dimensions that explain differences in planning approaches: requirement predictability and planning complexity.	Extends contingency-planning research by identifying planning dimensions that explain differences in PPC approaches.
Paper III	RQ3: How do managers make and communicate PPC decisions?	Examine decision-making and interactions across strategic, tactical, and operational levels.	Decision-making levels overlap and interact through guiding, informing, and coordinating mechanisms. Decision alignment requires active managerial engagement, while misalignment occurs due to role ambiguity and informality.	Contributes to managerial decision-making under uncertainty literature by identifying dimensions that explain managerial decision-making and communication.

Developed by the author

6 Discussion

This chapter discusses how the main findings of the individual papers contribute to the existing literature on PPC for remanufacturing. The objective of the thesis was to understand how uncertainty-related challenges, planning environments, and interactions among managers in decision-making shape PPC practices in remanufacturing firms. Accordingly, three research questions were formulated (RQ1, RQ2, and RQ3; see Section 1.4), each addressed in a separate paper. Each paper draws on empirical research. Paper I draws on Study I, while Papers II and III draw on Studies I and II. Each study was guided by a theoretical framework developed from the existing literature. Further details on these frameworks are provided in the respective appended papers.

5.1 Addressing RQ1: What challenges do remanufacturing firms face today in production planning and control?

Previous research investigated the characteristics that make PPC for remanufacturing a difficult managerial task (e.g., Hoffmann et al., 2025; Junior & Filho, 2016; Kamper et al., 2019). The seminal work of Guide (2000) identified seven of those characteristics providing the foundation for much of the subsequent PPC and remanufacturing literature (Junior & Filho, 2017; Karabağ et al., 2025, 2026). The findings from Paper I support this body of literature by confirming that PPC for remanufacturing continues to be challenging because of these characteristics. The paper extends existing research by providing empirical insights into the practices firms employ to deal with these challenges.

A key finding of Paper I is the growing tendency among remanufacturers to diversify core supply sources rather than rely on a limited number of return channels (e.g., core exchange programs). This practice may increase supply flexibility and improve the availability of cores, thereby reducing the risk of cores shortages and supporting inventory build-up when demand increases. However, while supply source diversification could enhance resilience, it also adds coordination and managerial complexity across the supply network, consistent with broader supply chain research (Cohen et al., 2022). Existing remanufacturing literature has primarily focused on maintaining larger inventories of cores with varying quality levels (Gunasekara et al., 2023; Karabağ et al., 2025), core grading and sorting practices (X. Li et al., 2016; Ponte et al., 2021; Yanıkoğlu & Denizel, 2021), and the role of supplier relationships and return acquisition channels (Östlin et al., 2008). However, explicit empirical evidence regarding diversification of core supply sources has remained limited. By reporting this practice and its implications for PPC, Paper I contributes to current understanding of supply-side uncertainty management in remanufacturing.

A second contribution relates to the development of planning processes and capabilities to deal with challenges in PPC for remanufacturing. Building on the work of Cañas et al. (2022) and Kasper et al. (2024), who emphasis the importance of formalized planning processes and digital technologies. The findings indicate that remanufacturing firms are making efforts in developing planning processes. Examples include the establishment of recurring material requirements planning, inventory management policies, and clear metrics of measuring supply chain performance. These findings suggest that firms are moving beyond ad hoc decision-making toward more proactive planning and managing uncertainty. While earlier studies by

Ferrer & Whybark (2001), DePuy et al. (2007), and Hoffmann et al. (2025) proposed formalized planning processes, their contributions were conceptual or mathematical models tested within specific contexts. Paper I provides empirical evidence of how such planning processes and capabilities are being developed and implemented in practice.

Furthermore, the paper highlights efforts by firms to leverage emerging digital technologies, including IoT and RFID, to improve the visibility of return flows and enhance the availability of information regarding return quality, quantity, and timing. Accurate information availability has the potential to reduce uncertainty and improve planning accuracy throughout the remanufacturing process. The findings also reveal that such technologies often require substantial investments and are most effective when supported by established and mature planning processes. These observations provide empirical support for recent calls to investigate the role of digital technologies in remanufacturing and closed-loop supply chain (Bansal et al., 2024). More broadly, the results suggest that technological solutions alone are insufficient; their effectiveness depends on the simultaneous development of \planning capabilities and process maturity.

5.2 Addressing RQ2: How do remanufacturing planning environments shape PPC approaches?

Paper II shows that planning environments shape PPC approaches through two higher-order dimensions: requirements predictability and planning complexity. Requirement predictability refers to managers' ability to predict future core and new parts/materials requirements using available planning information. The concept of requirements predictability is similar to that of Shurrab & Jonsson (2026), who addressed the issue of how firms cope with uncertainty arising from limited information regarding customer demand, product technical specifications, inbound inventory, and other factors in the planning processes. Planning complexity refers to the effort a manager makes to coordinate material flows, inventories, planning information, and planning activities. This definition aligns with Naumov's et al. (2025), who emphasize the managerial effort involved in coordinating multiple interdependent and uncertain tasks.

Figures 1 and 3 (see Figures 1 and 3 in Paper II) illustrate the development of the contingency. Figure 1 presents the initial framework, including the contextual and response variables. Figure 3 presents the revised framework, which introduces the higher-order dimensions of requirements predictability and planning complexity and shows how they relate to both the contextual variables and PPC responses. The contextual variables were guided by Paper I and prior research (e.g., Goltsos, Ponte, et al., 2019; Guide et al., 2003; Huang & Su, 2013), and include variability in demand, core return volume, core return timing, core return quality, product complexity, and product variety. The response variables were adopted from Olhager & Selldin (2007), Kaipia & Holmström (2007), and (Thürer et al., 2022) comprising planning methods, inventory buffering practices, and order fulfillment and production strategies.

A key contribution of Paper II is the revised contingency framework presented in Figure 3. The findings indicate that managers are concerned with two questions: whether future requirements for cores and new parts/materials can be predicted, and how difficult it is to coordinate the planning process. This extends prior contingency-based planning research (e.g., Guide et al., 2003) by suggesting that requirements predictability and planning complexity

provide a more direct explanation of PPC approaches than individual contextual characteristics such as demand variability, return uncertainty, or product variety. Rather than influencing PPC decisions independently, these contextual factors shape planning approaches through their effects on the two higher-order dimensions.

A second key contribution concerns the use of multiple planning methods within the same planning environment. Previous PPC research has examined planning methods individually, focusing on methods such as MRP and ROP (Berry & Hill, 1992; Huttunen & Helo, 2026; Jonsson & Mattsson, 2003; Olhager & Selldin, 2007; Thürer et al., 2022). Paper II shows that multiple planning methods can coexist within the same materials planning system. This occurs because different planning objects, such as cores and new parts/materials may have different levels of requirements predictability. As a result, firms may combine planning methods to match the specific characteristics of different materials and information flows within the remanufacturing process.

5.3 Addressing RQ3: How do managers make and communicate PPC decisions?

Building on the managerial decision-making levels proposed by Subramoniam et al. (2009), Souza (2013), and Rizova et al. (2020), Paper III investigates key PPC-related decisions at the strategic, tactical, and operational levels. Strategic decisions include core acquisition and supply strategies, production and customer order fulfilment strategies (e.g., RMTS, RMTO, and RATO), and marketing strategies. At the tactical level, decisions relate to master production planning and demand planning. Operational decisions include planning material requirements, purchasing these requirements, production process planning and scheduling, and customer order delivery/ fulfilment. Figure 1 (see Figure 1 in Paper III) shows the different managerial decision-making levels (left-hand side) and the PPC-related key activities (comparable with Figure B in Chapter 2 of this thesis) associated with each level (right-hand side). The bidirectional arrows indicate both vertical relationships between decision-making levels (top-down and bottom-up) and horizontal relationships among managers operating at the same level.

While Naumov's et al. (2025) findings provide valuable insights into PPC-related decision-making by demonstrating that the effectiveness of managerial decisions can be constrained by the amount of planning information available, their study focuses on the individual managerial level (i.e., the tactical level). Similarly, the studies by Subramoniam et al. (2009) , Souza (2013), and Rizova et al. (2020) either focus on one or two managerial levels or are limited to literature reviews. Paper III emphasizes the challenges of managerial decision-making in uncertain planning environments created by a lack of, or incomplete, planning information. This finding supports the work of Naumov et al. (2025) while also extending the discussion by addressing strategic, tactical, and operational decision-making simultaneously.

One contribution of Paper III is to show that informational limitations can lead to managerial decision overlapping across managerial levels. Rather than remaining confined to formally assigned responsibilities, higher-level managers may temporarily participate in PPC-related decisions typically made by lower managerial levels when PPC-related information is incomplete, changing, or distributed across the firm. From a bounded rationality perspective (Simon, 1979), such informational limitations constrain managers' ability to evaluate decision alternatives using only the information available within their immediate responsibilities. Managerial decision overlapping can therefore be understood as a response to these informational bounds, whereby higher-level managers extend their participation across

established decision boundaries to access locally held information, develop a more direct understanding of PPC-related issues, and contribute to decisions that would ordinarily be made at lower managerial levels.

The second contribution is to identify three mechanisms through which managers interact across managerial levels: guiding, informing, and coordinating. Guiding involves downward interaction through which higher-level managers communicate priorities and direction while lower-level managers retain discretion over implementation. Informing involves upward interaction that makes locally held, decision-relevant information accessible to higher-level managers. Coordinating involves horizontal interaction through which managers at similar levels exchange information and jointly consider interdependent PPC-related decisions. These mechanisms reflect concepts examined separately in previous research, including top-down direction (e.g., Li et al., 2018), bottom-up involvement and information flows (e.g., Heyden et al., 2017), and cross-functional coordination (e.g., Oliva & Watson, 2011). Paper III integrates these mechanisms to explain managerial interaction across managerial levels while making and communicating PPC-related decisions when information is incomplete or distributed. Worth noting, such interaction does not necessarily produce managerial decision alignment, because managers may interpret available information, PPC priorities, and decision interdependencies differently.

5.4 Putting the three papers together

The findings from the three appended papers suggest that uncertainty in remanufacturing planning environment (e.g., variability in demand, return rates, and return quality) continue to challenge PPC (Paper I). At the same time, some firms started to develop planning processes and capabilities that help them manage the uncertainty in planning environment (Paper I).

Interestingly, firms operating in comparable planning environments may adopt different PPC planning practices. Examples include the use of different planning methods, inventory buffering decisions, and production/customer order fulfillment strategies. These differences depend largely on the degree of requirement predictability and planning complexity that firms face in PPC (Paper II). Therefore, PPC practices in remanufacturing may not fully be explained by uncertainty in the planning environment alone. They can also be influenced by how firms develop and apply planning processes and capabilities to respond to that uncertainty.

Furthermore, managerial decision-making processes and communication of decisions are especially important to appropriately respond to uncertainty in PPC remanufacturing. Managers can support planning activities and share planning information through guiding, informing, and coordinating. When planning information is incomplete or unavailable, higher-level managers may become involved in low-level managers' decisions. This involvement sometimes helps firms cope with uncertainty, improve decision-making, and maintain alignment across managerial levels.

These findings provide empirical insights into how PPC is carried out in uncertain planning environment. They show how firms respond to uncertainty through the availability and use of planning information and managerial decision-making and communication across managerial levels. The study therefore extends the predominantly technical treatment of PPC in the remanufacturing literature by providing empirical evidence of how managerial decision-making processes complement, for example, planning methods in practice.

7 Conclusion

This thesis aimed to explore how remanufacturing firms plan and control production. Drawing on the existing literature and perspectives from contingency theory and judgment and decision-making theory, the thesis investigated the challenges firms face, the planning environments in which they operate and its effect on planning practices, and the managerial processes through which planning decisions are made and communicated.

7.1 Theoretical implications

This thesis contributes to remanufacturing and PPC literature in three main ways. First, it extends the remanufacturing literature by providing an updated understanding of the uncertainty-related characteristics that complicate PPC and by showing how firms are developing capabilities to manage them. Previous remanufacturing research has established that uncertainty regarding product returns, demand, and core availability creates planning challenges. The findings of this thesis confirm that these challenges remain relevant but also show that firms develop planning processes and capabilities that enable them to cope with these uncertainties. The contribution is therefore not only to reaffirm established remanufacturing challenges, but also to shift attention toward how remanufacturing firms respond to and manage these challenges today.

Second, the thesis contributes to PPC literature by developing two conceptual constructs, requirement predictability and planning complexity, that characterize the conditions under which PPC decisions are made. Requirement predictability captures the extent to which future production requirements can be anticipated, whereas planning complexity reflects the difficulty of translating these requirements into feasible production plans. By considering these constructs together, the thesis provides a basis for explaining why firms facing apparently similar remanufacturing characteristics may nevertheless use different PPC approaches. This extends the discussion beyond identifying uncertainty as a general characteristic of remanufacturing toward explaining how different planning conditions shape PPC practices. In this way, the findings also contribute to PPC literature by emphasizing that planning approaches should be understood in relation to the specific planning environment in which they are applied.

Third, the thesis extends PPC research by shedding the light on managerial decision-making dimension. PPC is commonly concerned with decisions at strategic, tactical, and operational levels, yet the findings show that the boundaries between these decision-making levels may become less distinct when relevant planning information is incomplete. In such situations, managers at higher managerial levels may become involved in decisions that would normally be handled at lower levels. The thesis conceptualizes this as managerial decision overlapping and shows that it can function as a response to information constraints rather than simply representing a deviation from established managerial responsibilities. When appropriately balanced, such involvement can reduce uncertainty and facilitate decision-making and communication across managerial levels. This contribution broadens the understanding of PPC from primarily a planning and control problem to one that also involves managerial decision-making, information limitations, and interactions across managerial levels.

7.2 Practical implications

From a practical perspective, the findings provide several implications for managers responsible for PPC in remanufacturing. First, managers should not rely solely on planning

models and tools, such as those for core acquisition, inventory management, and production planning, but should also develop planning processes and capabilities that enable them to respond to uncertainty. Because information about demand, core availability, and core quality may be incomplete or change, managers need planning processes that can be adjusted as new information becomes available. This includes regularly updating plans, maintaining appropriate buffers, and developing the capability to respond to deviations between planned and actual conditions.

Second, the findings suggest that managers should consider the characteristics of their planning environment when selecting and developing PPC approaches. In particular, requirement predictability and planning complexity can help managers assess whether existing planning practices are appropriate for their operational conditions. When requirements are relatively predictable and planning complexity is low, more standardized planning processes may be sufficient. In contrast, environments characterized by low requirement predictability or high planning complexity may require flexibility, frequent replanning, and closer monitoring of operations and interactions between managers. Rather than searching for a universally applicable PPC approach, managers should consider planning practices that address specific challenges in their planning environments.

Third, managers should recognize that PPC depends not only on planning systems and processes but also on how information and decisions are made and communicated across managerial levels. When planning information is incomplete, managers at different hierarchical levels may need to become involved in decisions outside their usual areas of responsibility. Such involvement can be beneficial when it provides missing information, guidance, or coordination, but excessive involvement may also undermine established responsibilities. Managers should therefore maintain clear decision responsibilities while allowing sufficient flexibility for cross-level involvement when uncertainty makes it necessary. Communication through guiding, informing, and coordinating can further help managers combine information distributed across managerial levels and support PPC decisions when conditions change.

7.3 Limitation and future research

The empirical work in this thesis focused on remanufacturing firms in selected industries (automotive and EEE) and geographical contexts (Europe and the USA). The findings should therefore be interpreted within these settings. Future research could look into whether the uncertainty-related challenges, planning environments, and PPC practices identified in this thesis also apply to remanufacturing firms in other industries and geographical contexts. Such studies could assess the transferability of the findings and identify whether different product characteristics, market conditions, or institutional contexts give rise to different PPC challenges and responses.

A second avenue for future research concerns the organizational context of managerial decision-making. The qualitative study focused on firms in which strategic, tactical, and operational decision-making levels could be identified. The findings show that PPC-related decisions and interactions can extend across these levels, particularly when managers face incomplete information. Future research could investigate whether similar patterns occur in smaller firms, flatter organizations, or other organizational structures in which these decision-making levels are less clearly differentiated. This could further clarify how organizational structure influences the distribution of PPC decision-making responsibilities and interactions among managers.

Third, the thesis investigated PPC mainly from the perspective of the focal remanufacturing firm. However, some of the uncertainties confronting remanufacturers, particularly those concerning core availability, quality, and demand, may originate beyond the focal firm's boundaries. Future studies could therefore extend the unit of analysis from individual firms to remanufacturing supply chains or networks. Examining the perspectives of suppliers, customers, logistics providers, and other relevant actors could provide a more comprehensive understanding of how information is generated and shared across remanufacturing supply chains or networks and how such information influences PPC decisions.

A fourth avenue concerns the relationship between planning environments and PPC approaches. This thesis shows that firms operate under different combinations of requirement predictability and planning complexity and that these conditions are associated with different approaches to planning and control. Future research could examine these relationships across larger samples and investigate whether firms move between planning environments as demand, product characteristics, or core availability change. Longitudinal studies would be particularly useful for understanding how PPC approaches evolve in response to changes in the planning environment rather than treating the planning environment as a relatively static condition.

Finally, future research could investigate how digital technologies affect PPC and managerial decision-making in remanufacturing. Because the findings of this thesis highlight the importance of information availability and communication across managerial levels, technologies that improve collection, visibility, and sharing of information may shape planning processes and managerial decisions. Future studies could examine whether digital technologies (e.g., IoT) reduce information constraints, improve the predictability of requirements, support the management of planning complexity, or change how PPC-related decisions are distributed across strategic, tactical, and operational levels. This would extend the findings of the thesis by examining how technological developments may reshape the relationship between uncertainty, planning environments, and managerial decision-making.

In conclusion, this thesis argues that understanding PPC in remanufacturing requires attention to three interconnected dimensions: the uncertainties firms face, the planning environments in which they operate, and the managerial processes through which planning decisions are made and communicated. By bringing these dimensions together, the thesis provides a foundation for understanding how remanufacturing firms plan and control production and identifies several opportunities for further developing PPC research in remanufacturing.

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