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Investigation On The Influence Of Remanufacturing On Production Planning And Control – A Systematic Literature Review

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Abstract

Production planning and control (PPC) is one of the focal operational tasks of a company, and it is used to design logistics services in a target-orientated manner so that individual customer requirements can be fulfilled. However, existing PPC framework models are still based on the prevailing linear economic procedure (take - make - dispose). Due to customers' increasing interest in sustainability and growing regulatory pressure, the Circular Economy (CE) meets these changing conditions by closing material cycles, improving resource efficiency and extending product life cycles. However, for a company to guarantee a high logistics performance, the operational PPC must be adapted to this new economic model. To this end, it needs to be investigated whether and how the adaptation of circular strategies influences existing PPC processes.
This paper focuses on the circular strategy of remanufacturing and its influence on different PPC-main tasks. The latter will be examined using a systematic literature review. Finally, the results of this analysis are compared with the Hanoverian Supply Chain Model as a PPC framework model. This comparison shows which PPC tasks are affected and which existing approaches have already been developed. Ultimately, these results provide the basis for developing a framework model for operational PPC regarding the CE.

Keywords

Circular Economy; Circular Strategies; Remanufacturing; Production Planning and Control; Hanoverian Supply Chain Model

1. Introduction

Increasing regulatory pressure and changing customer requirements are creating new and comprehensive challenges for companies regarding sustainability [1,2]. The concept of the Circular Economy (CE), which enables product life cycles to be extended, is coming into focus, particularly in the manufacturing industry. This concept increases resource efficiency by closing material cycles [3], which influences existing company processes [4]. However, closed material loops mean that used products arrive and must be processed at irregular intervals and with fluctuating quality. The resulting uncertainties of the material return flow make effective operational planning particularly difficult. A comprehensive analysis in this area has not yet been carried out. This lack of knowledge is a key barrier that hinders the comprehensive implementation of the CE [3]. For this reason, this article aims to lay the foundation for a Production Planning and Control (PPC) framework model. This framework model should enable manufacturing companies to carry out targeted PPC within circular strategies and to examine how existing processes may be influenced.

To achieve this goal, a systematic literature review is carried out within this paper, which is intended to provide an overview of the intersection of PPC and a selected circular strategy (R9 Framework [5]). In this

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case, the strategy of `remanufacturing` is examined as an example, as many companies still encounter various difficulties here and, therefore, do not include this strategy in their PPC [6]. By examining the subject area described, an existing framework model of the PPC can be used to derive which processes and PPC main tasks (e.g. *Plan Production Program*, *Plan Secondary Requirements*) are affected and how individual parts may change in terms of content. This procedure addresses the research question `Which PPC main tasks are affected by the circular strategy of remanufacturing? ´.

This article is structured as follows. First, Chapter 2 lays the theoretical foundation for the subject area of remanufacturing and PPC. Chapter 3 then describes the methodology used. This is followed by the results obtained, which are described and discussed in detail in Chapter 4. Chapter 5 concludes with a summary and a critical reflection.

2. Theoretical Background

2.1 Remanufacturing

Within the concept of the CE, which is in line with the widely accepted definition by Kirchherr et al. [7], products must continue to be used after the end of their life cycle. This directly influences the supply chain's design, planning and control, which is why the combination of linear supply chain management and the circular concept is also referred to as circular supply chain management [8]. The form of a company's supply chain depends on the chosen circular strategy or strategies. Potting et al. [5] provided an overview and definition of the possible strategies, which can be found in Figure 1.

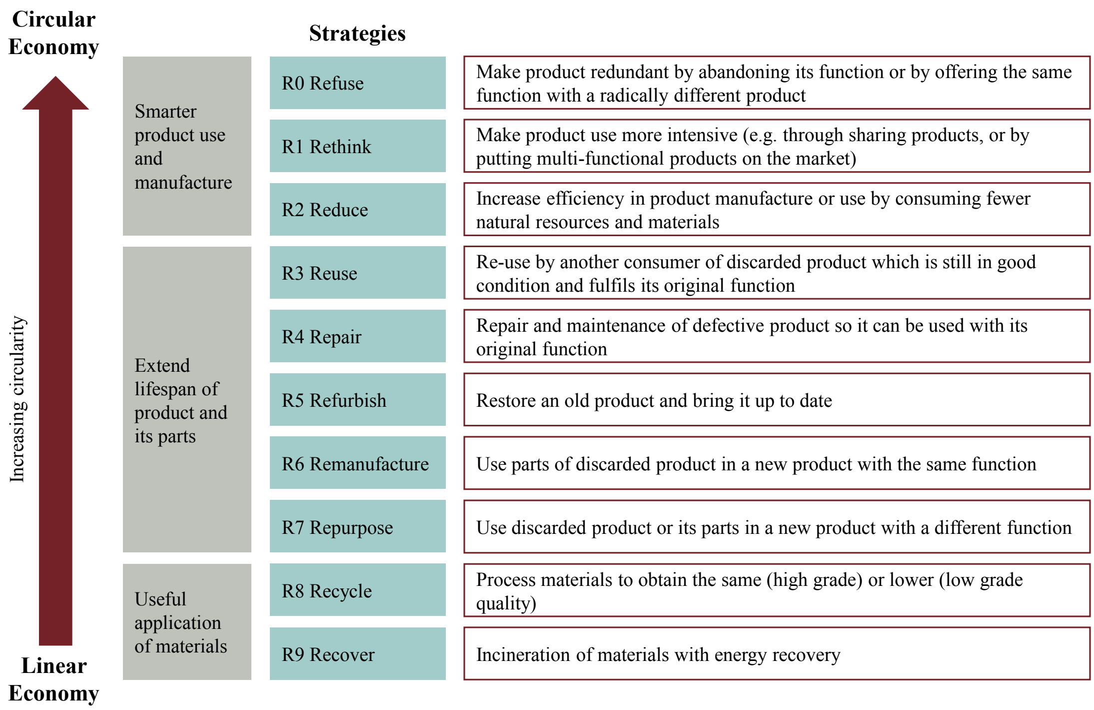

Figure 1: R9 Framework [5]

The figure illustrates the possible circular strategies (blue boxes) and the respective way in which they contribute to increasing circularity (grey boxes). The red-framed boxes provide the corresponding definition. The circular strategies listed are in line with already established concepts such as the 3R concept [9] and the extended 6R concept [10,11]. This paper uses the R9 Framework as the theoretical basis because its clear definition and separation between the circular strategies allows a detailed investigation of the resulting structure of the internal supply chain. In this context, the circular strategies are to be understood as technological elements [12], as they can be used to close material loops. These different forms of circular strategies must be considered so that a supply chain is manageable at system level [13] as each strategy holds its own challenges.

In practice, the remanufacturing strategy confronts companies with significant challenges compared to other strategies, as various factors influence profitability. These include, for example, the complexity of the product itself, fluctuations in demand, the target remanufacturing rate and the question of whether remanufactured products are considered `as good as new` [14,15]. Despite these challenges, companies from all industries increasingly turn to remanufacturing due to its great economic and environmental potential [16], even if it entails higher operational costs than other circular strategies such as refurbishment [17]. This is mainly due to the work steps to be planned that are associated with the characteristics of remanufacturing [5]. This inevitably includes the work steps of disassembly to extract the required parts, an inspection [18], the possible reconditioning of individual components and the final reassembly [19]. The challenge is that some of the work steps mentioned must be carried out with the same work and personnel resources. This means the production and remanufacturing work steps compete for the same resources [20]. If this is the case, it is generally a hybrid system, not a pure remanufacturing system [21].

To make the planning of remanufacturing as efficient as possible, the design of the system, i.e. pure remanufacturing system or hybrid system, must be considered [22,23]. Nevertheless, the planning aspects between conventional production and remanufacturing are very similar, whereby the fluctuations in the quantity and quality of supplies must be considered explicitly within the planning for remanufacturing to ensure efficient planning. Therefore, the initial situation is more complex than for traditional production [24]. For this reason, companies need support in the targeted configuration of their PPC [25].

2.2 Production Planning and Control

PPC is one of the critical tasks for manufacturing companies, the primary aim of which is to plan production and all its sub-areas, such as procurement and manufacturing [26]. Many challenges and conflicting objectives must be dealt with within these tasks, which is why many models and practical solutions have been developed in research to deal with these difficulties [27]. Well-known frameworks include Manufacturing Resource Planning [28], the Aachen PPC Model [29], the Production Control Model [30] and the Hanoverian Supply Chain Model (HaSupMo) [31].

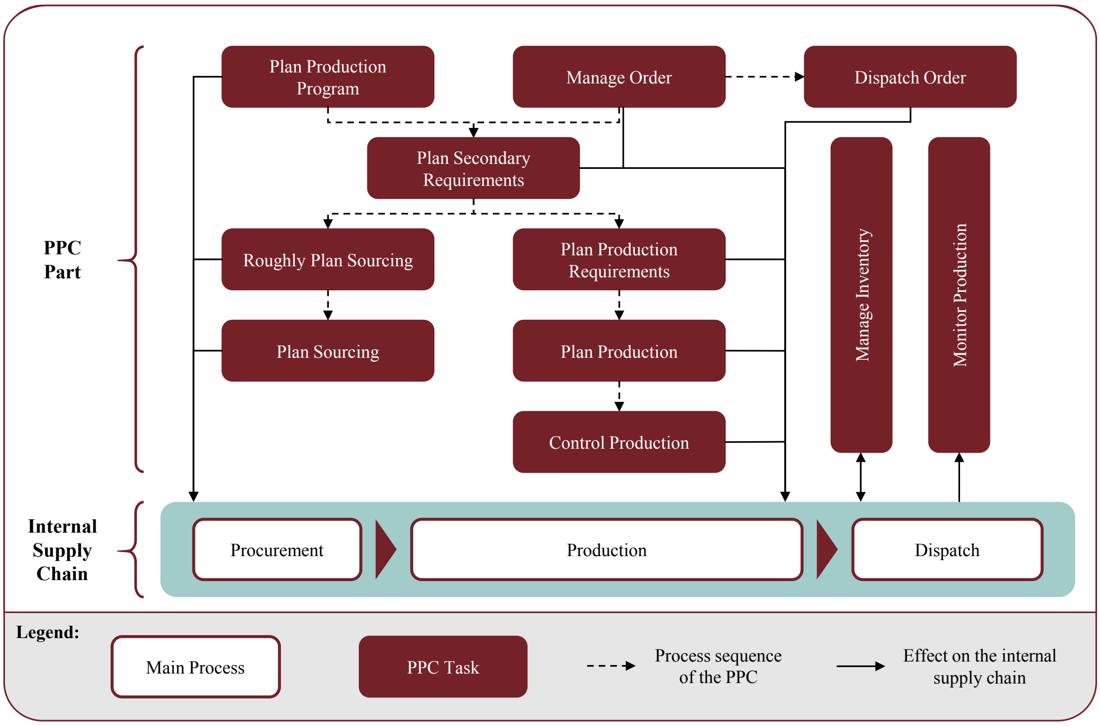

Figure 2: Representation of the PPC in HaSupMo [31]

In particular, the HaSupMo and the associated view of PPC focuses on operational order processing and the resulting interaction with the company's internal supply chain. By illustrating these interrelationships, the HaSupMo represents a framework for companies to align PPC with defined logistical objectives. The following figure shows the PPC main tasks in HaSupMo. Figure 2 shows that *Plan Production Program* and *Manage Order* initiate the process sequence. *Plan Production Program* represents the customer-order-neutral initial point of PPC by analysing the demand from the market and finally creating a customer-order-neutral production plan to cover the primary demand, i.e. the demand for finished products [32], with a long-term planning horizon. In contrast, *Manage Order* can be described as a customer order-specific initial point, as customer orders are coordinated and accepted here. These binding orders are then merged with the customer order-neutral production plan. On this basis, the resulting secondary requirements, i.e. the requirements for components and assemblies that are needed to manufacture the end products [32], can be planned. This includes the time and quantity in which these dependent requirements must be available and the downstream make-or-buy decision. Suppose the dependent requirements are to be covered by external procurement. In that case, these are first coordinated with suppliers in *Roughly Plan Sourcing* with a long-term horizon before the individual orders are planned in *Plan Sourcing*, the suppliers are selected, and the orders are triggered. If the dependent requirements are to be produced in-house, this is planned with a medium-term planning horizon in *Plan Production Requirements* and then with a short-term planning horizon in *Plan Production*. If the scheduled orders have already been released in production, the final sequences are determined in *Control Production* and the corresponding capacities are monitored and controlled. Once an order has been processed or is ready for dispatch, dispatch can be initiated by the PPC main task *Dispatch Order*. In addition to this throughput of orders, the PPC main tasks of *Monitor Production* and *Manage Inventory* have a separate role, as these influence the internal supply chain and thus also all other PPC main tasks [31]. However, PPC within the HaSupMo framework only includes the traditional linear economic model and cannot map circular planning and control processes.

3. Methodology

To finally examine PPC with a particular focus on HaSupMo and remanufacturing, the systematic literature review method, according to Tranfield et al. [33], was chosen to do justice to the exploratory nature of the selected objective and the necessary holistic view. Two different databases (Scopus and Web of Science) were used to search for scientific literature. The search was for conference papers and journal articles that fall within the subject area of PPC and remanufacturing. The search string used for the Scopus database was:

TITLE-ABS-KEY(“remanufactur*“ AND (“production planning“ OR “production control“)) AND (LIMIT-TO (SUBJAREA, ”ENGI”) OR LIMIT-TO (SUBJAREA, ”BUSI”)) AND (LIMIT-TO (DOCTYPE, ”ar”) OR LIMIT-TO (DOCTYPE, “cp”)) AND LIMIT-TO (LANGUAGE, “English”))

The notation of the search string was adapted according to the identical search criteria for the Web of Science database. From the search on January 4th, 2024, 268 publications from Scopus and 168 publications from Web of Science were included in the closer examination. After removing duplicates, the total number of publications considered was 310. These were then examined for relevance to the selected research question by looking at the title and abstract. This resulted in a final number of 222 publications. The selection was then examined for the content orientation of the respective article and assigned to the corresponding PPC main tasks of the HaSupMo, as already carried out by Hillnhagen et al. [34]. Based on the approach used in this paper, it is already possible in the first step to derive which PPC main tasks are affected by the circular strategy of remanufacturing and which have been considered up to this point. In addition to the mere assignment, the affected PPC main tasks and the resulting influence of remanufacturing can be presented.

4. Results

4.1 Identification of Affected PPC Main Tasks

By analysing relevant literature, it became clear that circular strategies, such as remanufacturing, significantly impact the processes within operational PPC [35]. In particular, the uncertainty and fuzziness in planning associated with remanufacturing creates a more complex starting point [36-38]. It was also found that no comprehensive framework for operational PPC addresses the emerging challenges of the circular economy [39]. In order to lay the foundation for this, the affected PPC main tasks of the HaSupMo are now presented with regard to changes.

It should first be noted that not all PPC main tasks are affected by remanufacturing or that some parts of operational PPC have not yet been investigated concerning remanufacturing. *Manage Order*, *Dispatch Order* and *Roughly Plan Sourcing* are among the main tasks of PPC that have not been affected or researched. *Plan Sourcing* and *Monitor Production* were considered to a minor extent. For *Plan Sourcing*, the aspects of optimal order quantity [40] and supplier selection [41] were considered. However, these considerations only include new aspects, such as including new elements in the actual decisions. Similarly, for *Monitor Production*, only aspects such as support from the Internet of Things [42], Industry 4.0 technologies [43], and the general increase in transparency can contribute to minimising uncertainty [44]. However, as these contributions do not entail any changes to operational planning and control processes and have only been mentioned in a few publications, neither *Plan Sourcing* nor *Monitor Production* are directly considered in this paper.

The remaining PPC main tasks have already been examined more extensively concerning the influences of remanufacturing. Figure 3 shows the distribution of the publications analysed with the individual totals for each topic area.

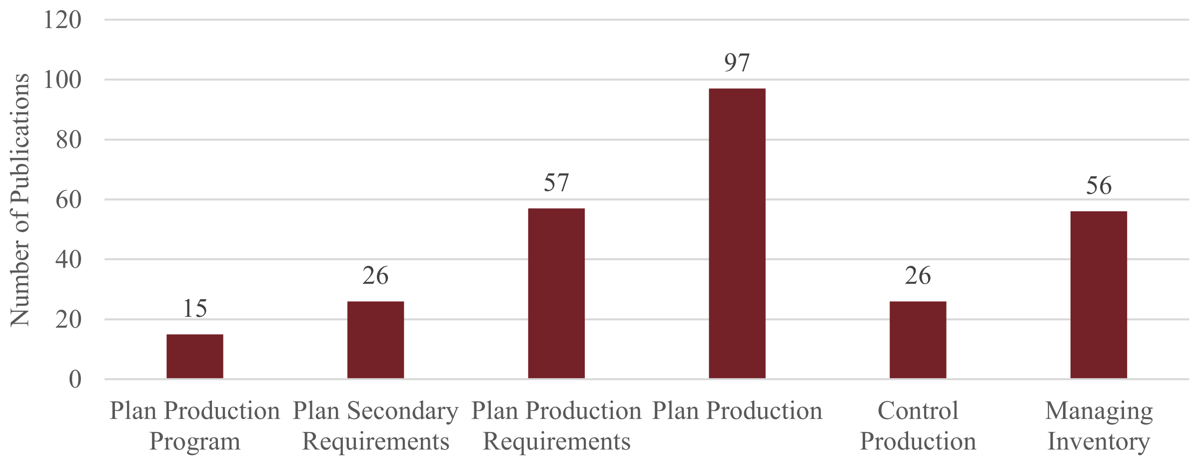

Figure 3: Distribution of Publications regarding PPC-Tasks

It is evident that much of the research currently focuses on the main tasks of *Plan Production*, *Plan Production Requirements*, and *Manage Inventory*. However, *Control Production*, *Plan Secondary Requirements* and *Plan Production Program* have also been addressed and examined in several publications. The influence of remanufacturing on the aforementioned PPC main tasks is presented in the next subchapters.

4.2 Plan Production Program

Within the *Plan Production Program*, it is primarily sales planning where remanufacturing exerts its influence. This influence consists in the fact that the planning of sales of remanufactured products must be integrated into the sales forecast of further primary requirements [4,45]. This goes hand in hand with the critical decision of the respective pricing for the respective products [46-48] since both new and remanufactured products are aimed at a similar target group of buyers. Thus, the pricing influences the individual sales [49,50]. In addition to the traditional functions, the resulting product mix with the forecast sales volumes and the expected useful lives of the respective products now also forms the basis for predicting product returns, which are used in subsequent planning steps [4,46,51]. The corresponding product mix and the expected sales volumes are then used, as in traditional HaSupMo, to initiate long-term production and resource planning in order to be able to map the selected ratio between traditional and remanufacturing production [52-55].

4.3 Plan Secondary Requirements

Subsequently, the required secondary requirements must be derived from the production program created in *Plan Production Program*, which must also react to the fluctuating quantity and quality of the delivered cores, i.e. the used products that are to be reconditioned and reused [56], with regard to the lead time offset [23,51,57]. These fluctuations also influence the planning of Net Secondary Requirements, as some secondary requirements can be covered directly from the dismantling of return deliveries of used products, while others require further processing [23,58]. In addition to these influences of remanufacturing, the most significant influence lies in the procurement type allocation. This is because the innovation here is that secondary requirements can be covered by external procurement of new materials/assemblies and in-house production, and now also by remanufacturing returned products [59]. Much of the research in this area focuses on determining the acquisition price [48,60-65], which is a threshold value for the purchase of used products, as this is also where the profitability of remanufacturing is decided and is therefore used as the primary decision criterion [62]. Based on this, the ideal quantity for take-back and the influence of the quality of the cores [56,66] on this quantity is examined.

4.4 Plan Production Requirements

The key point within *Plan Production Requirements* is to draw up a medium-term resource plan and to check whether the existing resources can cover the planned production requirements. Therefore, this PPC main task must also determine the corresponding production quantities of new and remanufactured products in the medium term [67-73]. The ideal production quantity can be determined by exclusively considering minimising costs [22,74] or by including other objectives, such as $CO2$ emissions [75,76]. The greatest challenge, especially when planning remanufacturing, is the fluctuating quality of the cores, which directly influences the respective processing time and, thus, the maximum output quantity [77,78]. In addition to the uncertain output quantities, the fluctuating quality of the cores also has a negative effect on the availability of the production systems, as increased abrasion occurs here. As a result, maintenance must also be increasingly considered so that plant availability remains high and the respective production quantities can be planned in the best possible way [79,80]. An iterative planning process has proven its worth in this respect, enabling more precise planning [81]. To prevent production facilities from producing new and remanufactured products, some researchers are investigating the influence of a second facility that deals exclusively with remanufacturing, even if this requires investment and is, therefore, not feasible for all companies [82,83].

4.5 Plan Production

Due to the resulting uncertainty, fluctuating throughput times and iteratively determined production quantities, short-term oriented *Plan Production* is affected by remanufacturing at several points, which are necessary to create a binding production plan. On the one hand, this includes lot size calculation, which is considered dynamic in many research papers due to the resulting fluctuations in the availability of the required cores [84-90]. Due to these dynamics, many authors use heuristic approaches to determine the ideal lot size for production orders [87,91,92]. Dynamic lot sizes and fluctuating quality of the cores, in turn, influence the resulting lead time of the production orders and, thus, the scheduling [93]. As with *Plan Production Requirements*, iterative planning processes are necessary to minimise production costs [94-96]. Once the individual orders have been scheduled, the individual work systems must also be planned accordingly. In addition to the dynamic throughput times, the processing times of the orders [97-100], the corresponding setup times and the setup frequency must also be considered [88,101,102]. Numerous algorithms and machine learning methods have been investigated to overcome this challenge [103-107]. Due to the high complexity of these problems, many researchers focus on suboptimal solutions that achieve near-optimal results, as deterministic solutions are usually too computationally complex [108,109].

4.6 Control Production

The innovations that arise in the main task of *Control Production* in the context of remanufacturing focus primarily on sequencing and capacity control. More specifically, numerous control policies that *control production* in a short-term context based on threshold values, such as stock levels or return rates, are being investigated. Many of these control policies aim at mathematically optimal solutions regarding cost minimisation [110-114], whereas other authors use simulations to determine an optimal order sequence [39,115]. In addition to developing new control policies, other authors also deal with the targeted comparison of these policies and consider the influence under a specific use case [110,116,117]. Aspects of order release for order backlog control have been less intensively studied [118].

4.7 Manage Inventory

The PPC main task of *Manage Inventory* becomes more extensive and complex through remanufacturing, although the core task, i.e. the determination of planned inventories, remains unchanged [23]. The increasing complexity is generated by the stock receipts of returns, which arrive at irregular intervals, in fluctuating quantities and of varying quality [51,119-122]. In order to determine optimal planned stock levels, these factors must be included in the corresponding calculation. This challenge has led many researchers to focus on inventory policies that allow optimal stock levels to be determined [123-127]. Some of them are based on threshold values [128] and on the forecast of incoming returns [120,129-131], as is the case with *Control Production*. In operational terms, the inclusion of stock issues and receipts of different products results in overlaps with the purchase order calculation from *Plan Sourcing*. In this context, various ordering policies that represent a further development of traditional ordering policies [132-134] are also examined, for example, to counteract a bullwhip effect [135,136]. Whether the operational planning of such a case is assigned to inventory planning or *Plan Sourcing* depends on the company's business model under consideration. If the used products are returned without being purchased, they will fall under the remit of *Manage Inventory* with regard to operational PPC.

5. Conclusion and Limitations

Within this paper, the topic of remanufacturing was examined concerning its influence on operational PPC. For this purpose, scientific databases were searched for relevant publications, which were then reviewed with regard to the PPC main tasks of HaSupMo. The analysis described above allows the identification of various PPC main tasks that are influenced on the planning side by the circular strategy of remanufacturing and therefore answers the initial research question. Moreover, additional factors must be included in the planning to continue enabling good planning. The exceptions are *Plan Secondary Requirements* and *Manage Inventory*, which are also expanded operationally.

Despite the methodological approach, the described elaboration and the results must deal with limitations. One limitation is that it cannot be clearly stated that all relevant publications were considered due to the search string used in the research. Nevertheless, the number of publications considered made it possible to analyse a comprehensive range of information. The evaluation in Figure 3 also clarifies that only selected PPC main tasks have been addressed in the existing literature to date and that the others have not been addressed in sufficient depth or at all. With the amount of publications considered, it is unlikely that any of the main tasks not listed are comprehensively influenced by remanufacturing. More considerable limitations can only be listed in the manual assignment of the publications to the respective main tasks, as this was not always possible without a doubt. In particular, the distinction between short-term and medium-term planning in *Plan Production*, *Plan Production Requirements* and *Control Production* made a clear assignment difficult and thus possibly prone to error. Nevertheless, this would marginally influence the research intensity described in Figure 3 and not the fact that the PPC main tasks are influenced by remanufacturing.

When interpreting the results, however, it must be noted that only the PPC part of the Hanoverian Supply Chain Model was considered. The company's internal supply chain design and the interaction with the respective PPC main tasks have not yet been examined. Schäfers and Walther [20] provide an initial idea of what such an interaction might look like. In future research, the PPC main tasks must be examined for their influence through circular strategies and extensions of the company's internal supply chain. The Supply Chain Operations Reference model (SCOR) [137] is suitable for this purpose as purposed by Badurdeen et al. [138]. The logical sequence and the different contributions to value retention can be used to draw conclusions about the structure of the company's internal supply chain [139,140] and thus consider all the different life phases of a product [141] and map them at system level [138]. In this way, new PPC main tasks could be identified, and existing PPC main tasks could be defined more precisely in terms of their operational scope to lay the foundation for a circular-applicable PPC framework.

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Biography

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