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# Setting the Stage for Research on Aftermarket Production Systems in Operations Management

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**Abstract.** Reduction of resource consumption is essential to the Sustainable Development Goals. One key strategy for achieving this is product life-extension. Products can be maintained or remanufactured to a condition that is better than new. A fragmented literature uses terms such as remanufacturing, maintenance, repair, and overhaul (MRO), or simply service, to refer to various forms of product life-extension. Even though different terms are used, these operations share common characteristics and challenges that are distinctive compared to traditional manufacturing. Addressing the ambiguous use of terms for product life-extending operations and the fragmented body of knowledge, we introduce Aftermarket Production Systems (AmPS) as an umbrella term for industrialized product life-extending operations. The purpose of this paper is to provide an overview of AmPS-related literature and to discuss future directions for research on industrialized product life-extending operations.

**Keywords:** Closed-loop supply chain, Remanufacturing, Product-service systems (PSS), MRO, Circular economy.

## 1 Introduction

One way to reduce global resource consumption is to establish a closed material loop [1]. This can be done by reusing used products or recycling materials [2], often referred to as the circular economy [3]. Closing the material loop and decoupling resource use from economic growth contributes to sustainable development [3].

In reaction to growing public pressure and for economic reasons [4], manufacturing organizations have developed new and more sustainable technologies and business models. One such business model is servitization [5]. Pivotal elements of servitized offerings, such as product-service systems (PSS) [6], are product life-extending operations such as maintenance, refurbishment, and repair [7, 8]. Another example of a business model that supports product life-extending operations is the one of independent third-party remanufacturers. These companies acquire used products (cores), return them through industrial operations to a condition like new, and distribute these products on the aftermarket [9, 10]. Operations management scholars study product life-extending operations most commonly as remanufacturing. Unfortunately, there is no universal definition for remanufacturing. Furthermore, other terms, such as maintenance, repair,

and the abbreviation MRO (maintenance, repair, and overhaul), are often used synonymously when referring to remanufacturing [9, 11]. The related literature focuses on specific functional activities and neglects discussing operational interdependencies in the closed-loop supply chain system [12–14], as well as variation in operational characteristics depending on the industrial setting. The ambiguous use of terms and the focus on isolated operational challenges have led to a fragmented body of research.

To address the ambiguity and fragmentation of the literature, we provide an overview of the scientific literature that discusses product life-extending operations. We introduce the term “Aftermarket Production Systems” (AmPS) to refer to all industrialized product life-extending operations. We position AmPS as a sub-system in the circular economy and closed-loop supply chains. We provide an overview of terms for product life-extending operations, illustrate how the concept of AmPS is linked to the literature, and discuss future directions for research.

## **2 Background**

### **2.1 Circular economy**

The circular economy is discussed in the literature as an alternative to the currently dominating linear economy [15]. The key element of the circular economy is a reduction in resource consumption by means of a closed material loop [2]. The circular economy is seen as an operationalization of sustainable development with the goals of environmental quality, economic prosperity, and social equity [3]. Industrial implementation of the circular economy idea involves the R-principles, or waste hierarchies (ranking based on value retention) [1–3]. In the literature, the R-principles are most often discussed as reduce, reuse, and recycle (3R framework) [2, 3]. However, Reike et al. identified up to 38 different R-principles—remanufacturing being one of them—with differences in the interpretation of their meaning and their ranking in regards to value retention [1].

### **2.2 Servitization and product-service systems**

Operationalization of the circular economy and closed-loop supply chains requires new business models [4]. One business model that fosters industrial sustainability is servitization [5]. Servitization refers to the strategic transition of manufacturers to not only offer a physical product but to provide integrated bundles of products and services [16]. A special manifestation of a servitized offering are PSS. A PSS is defined as a combination of product and service to deliver functionality while reducing impact on the environment [6]. The literature typically distinguishes between three main categories of PSS: product-oriented, use-oriented, and result-oriented [17]. The importance of the service increases from the first to the latter, and the relationship between the provider and the customer shifts from a transaction-based to a relationship-based interaction [8, 17]. As part of this move from product transactions toward the provision of functionality, the ownership structure changes such that the PSS provider remains the owner of

the product [17]. Therefore, the provider is motivated to keep requirements for spare parts low and, as a result, reduce waste [18]. In order to provide services, the provider of PSS often has to establish and manage a network of partnering organizations [19].

Pivotal elements of PSS are refurbishment, repair, and maintenance, either as product-related services for customers owning the product, or as means to keep the provider's assets operational in order to fulfill the promised functionality [7, 8]. There are several good reasons for manufacturing companies to shift their business towards service provision. Competitive advantage is achieved by the higher margins of services and the stable cash flow throughout the product's life [8]. A comprehensive service offering can serve as a barrier to competition if the customer is tied to the organization by a service contract or is simply dependent on the offered services [16]. Manufacturers have certain advantages when offering product-related services, such as existing customer contacts, knowledge about the product, and having the required technology to provide the services [8]. However, the provision of product-related services is not limited to the original equipment manufacturer (OEM). These services are also provided by component manufacturers, independent or subcontracted companies, and end-users (the operator) [8, 13], which are in competition or in a partnership with the manufacturer. Additional challenges faced by manufacturers when providing product-related services and PSS include the increasing integration of products, services, and PSS provider operations with customer operations, the management of reverse logistics, and related data exchange [20–22]. Industry 4.0 technologies, such as the Internet of Things, cloud computing, and big data analytics are considered solutions to overcome these challenges since they facilitate integration of organizations and enable information-based service and value provision [21].

### **2.3 Remanufacturing and product life-extending operations**

Product life-extending operations keep a product in usable condition or return it to a condition that is even better than new. These operations establish a closed material loop by retaining a product's value in the form of the material, energy, and labor involved in the product's creation [12]. These operations are most often studied using the term remanufacturing, which currently has no universal definition [1]. The definition in the automobile industry requires the product to be as new or even better and fully warranted [23]. Other terms for product life-extending operations include repairing, refurbishing, repurposing, reconditioning, reprocessing, restoration, or upgrading [1, 3, 24]. The aviation industry refers to them as MRO [11]. In the operations management literature, the definition of Lund [25] is often used, which considers remanufacturing as an industrial process whereby a product is transformed at its end of life to a condition like new. In this literature, remanufacturing is closely linked with closed-loop supply chain research [9, 12, 14, 26]. The servitization literature refers to product life-extending operations as product-related services or simply as service [7, 8, 22]. The service operations literature considers product life-extending operations a special type of service [27–30]. As addressed in Section 2.2, product life-extending operations are run by different types of organizations. These operations can be part of a PSS-integrated service, offered as a

stand-alone aftermarket service, or they can support other business models, such as the one of an independent third-party remanufacturer.

Product life-extending operations have been studied from different perspectives. These operations include traditional production operations, such as disassembly, inspection, machining, and assembly, but they are also more closely connected with the market and customer [31, 32]. Customer interaction and the processing of a used product lead to uncertainties in the return rate of the products to be processed, the condition of the product, the work scope, and spare part requirements [12, 13, 33–35]. These uncertainties complicate operations and make them very labor-intensive [12, 13]. Most studies focus on these uncertainties and related specific functional activities, such as planning, scheduling, and decision making [12, 13, 32], and investigate rather isolated cases. This research has not considered important operational interdependencies [12, 13]. Guide [12] identified seven operational characteristics of remanufacturing in the literature. These seven characteristics include the condition of the returned products and the disassembly of the products. Taking these two challenges as an example, the disassembly process is dependent on the product quality. Guide stressed the importance of understanding operational interdependencies when developing a planning and control system [12]. Furthermore, product life-extending operations are exposed to the challenges of closed-loop supply chains. By focusing on specific functional activities, the interplay on higher system levels in the closed-loop supply chain is often not considered [14].

On the one hand, product life-extending operations share many characteristics. On the other hand, these characteristics vary depending on the industrial setting. This can be illustrated with another remanufacturing challenge identified by Guide [12]: the need to balance core returns with demand. A company that is remanufacturing consumer goods with high variation in the timing of the product return experiences this challenge differently than a company that remanufactures expensive industrial goods whose return can be forecasted or even scheduled [26]. Categorizations of remanufacturing, and therefore implicitly categorizations of industrial product life-extending operations, have been provided based on customer relations [10], product design and the strategic focus of the manufacturer [9], and production strategy [12]. Despite awareness of these differences, these categorizations are barely used in the available literature.

## 2.4 Proposing a definition of Aftermarket Production Systems

The fragmented research on product life-extending operations and insufficient categorization of studied cases hampers the advancement of this research field. We introduce the term “Aftermarket Production System” (AmPS) as a sub-system within the circular economy and closed-loop supply chains. AmPS is defined as industrialized product life-extending operations taking place at a dedicated facility, and include technology and organizational principles within the system borders of this facility. The position of AmPS in the circular economy and closed-loop supply chains is illustrated in Fig. 1.

AmPS consider all product life-extending operations from major repair to remanufacturing as defined by the automotive industry. The introduction of AmPS as an um-

umbrella term builds on the fact that product life-extending operations share commonalities. However, the term is introduced with an awareness of variations in their characteristics (see Section 2.3). AmPS process a product (core) returning from use, which may have already reached its end of life. After being processed, the product is either returned to the operator for use or sold on the aftermarket. In some cases, parts go partially through the same production process as new products do. The prefix “aftermarket” is used to emphasize that AmPS are part of a product recovery system that provides supply for subsequent secondary market transactions or provides standalone after-sales services. Product recovery and after-sales service both take place in the aftermarket [36]. AmPS can also be part of a PSS delivery system. PSS can include monitoring the product in use and applying Industry 4.0 solutions to provide access to information about its condition [21, 37]. AmPS are part of the circular economy at the micro level [3] and enable a higher value retention than recycling.

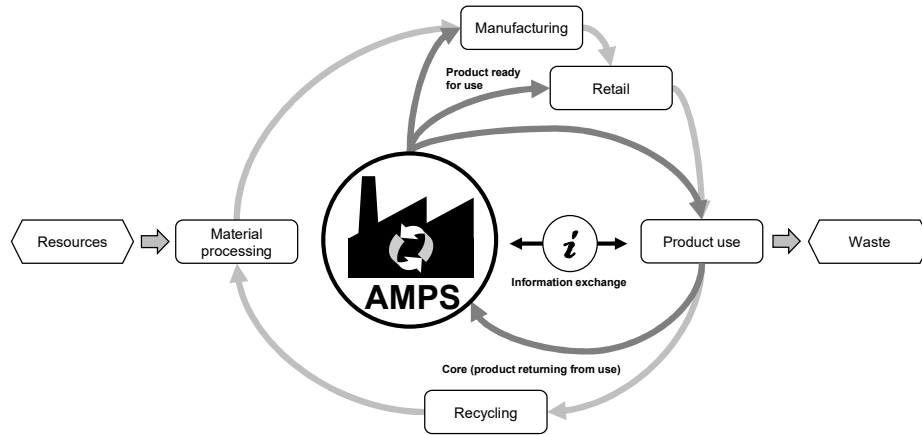


Fig. 1. Aftermarket Production Systems (AmPS) within the circular economy

### 3 Directions for future research

Remanufacturing is considered the backbone of the operationalization of the circular economy [14]. This is applicable to product life-extending operations in general. Even though remanufacturing has received increasing attention among operations management scholars, industry reports show low efficiency and long throughput times compared to manufacturing [13, 32, 35]. This is an indication of the need for more research on industrial product life-extending operations and their improvement.

The literature stresses the importance of considering the operational interdependencies of industrialized product life-extending operations [12] and the importance of understanding them within the context of the supply chain [14] (see Section 2.3). This must be considered when studying AmPS. Different categorization criteria for remanufacturing and industrial product life-extending operations are provided in Section 2.3. As mentioned in that section, these categorizations are barely used. Studying the com-

monalities between AmPS in different industry settings can lead to synergies in research and advancement of the field, which are goals of the introduction of the umbrella term AmPS. However, the distinction is essential when researching AmPS in order to know whether findings are applicable to AmPS in general or only to specific settings. One crucial distinction for future research is the type of company that is running the AmPS, since AmPS are run by different types of companies (see Section 2.2 and Section 2.3). An independent remanufacturer of car parts, for instance, faces a different mix of challenges in its operations than a provider of PSS for aircraft engines, who overhauls them [9, 10]. Much of the literature on servitization, PSS, and remanufacturing approaches operations from the perspective of an OEM [7, 8, 22, 27, 28, 34] or it does not indicate the type of company that was studied.

AmPS can be part of a PSS delivery system. One of the concerns of the community, who does research on servitization, is the PSS delivery system [38]. Related literature examines operations for delivering PSS, which implicitly considers maintenance and repair operations [7, 22]. The integration in the network for PSS delivery [19, 39] must be taken into account in research on AmPS. Additionally, the integration of AmPS in IT infrastructure and the application of Industry 4.0 solutions that support PSS delivery must be considered [21, 37, 40, 41]. However, to advance industrial product life-extending operations, research on operations at the plant level is required. A well designed AmPS can support a business model, as manufacturing can support the corporate strategy [42]. Furthermore, most related research does not take service operations into consideration [22]. The service operations literature studies how variables such as customer interaction, variation in workflow, and fluctuation of processed volumes affect operations [29]. These are characteristics of AmPS. Hence, establishing a link with the service operations literature can contribute to the advancement of AmPS.

## 4 Conclusion

Product life-extending operations play a pivotal role in the operationalization of a circular economy and the support of service-centered business models. They face distinctive challenges compared to conventional manufacturing. Related research has not considered operational interdependencies and studied rather isolated cases. The term remanufacturing is used broadly in the field of operations management to refer to product life-extending operations. Many other terms are used synonymously. Furthermore, little attention is paid to the respective industrial setting of the operations, such as the type of organization performing the work. Research is fragmented, and the operations that have been studied are insufficiently categorized. Taking a systems perspective, we defined AmPS and positioned them within the circular economy and closed-loop supply chains. AmPS collectively refers to all industrialized product life-extending operations, including applied technology and organizational principles at the dedicated facility. The definition of AmPS serves as a basis for future research. It aims to reduce ambiguity when referring to product life-extending operations, and it emphasizes the importance of operations at the plant level that support the respective business model in use. We linked AmPS to related research streams in operations management—which include



remanufacturing, closed-loop supply chain, servitization, PSS, and service operations—and highlighted important considerations for future research. The future research we outlined is particularly relevant for an OEM on its journey toward a servitized product offering, independent organizations that are running product life-extending operations, and operators who are maintaining their assets.

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