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Review

# The integration of core cleaning and product serviceability into product modularization for the creation of an improved remanufacturing-product service system

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ABSTRACT

Remanufacturing has been identified as the most viable product end-of-life (EOL) management strategy. However, about 80% of manufactured products currently end up as waste. Meanwhile, some of the bottlenecks in product remanufacturing could be remedied by Product Service System (PSS). Therefore, the integration of remanufacturing and PSS as an improved product offering has been increasingly recommended. However, an integration that is informed by mathematical analysis is still missing. Meanwhile, product life cycle performance is largely influenced by the decisions made at the early phase of product development (PD). Therefore, an effective remanufacturing-PSS synergy is mainly dependent on the PD decisions. Among the PD strategies, modular architecture has been identified as a technique that significantly enhances product life cycle management including ease of product disassembly, thereby improving product serviceability and cleaning processes. Consequently, modular product design is a suitable PD strategy for improved remanufacturing-PSS integration. This research identifies two factors that are critical for the success of remanufacturing and PSS: core cleaning and product serviceability. Module variants are assessed in pairs, and the modular pair compatibility indices are obtained via fuzzy system. These indices are the coefficients in the objective functions of an optimization model. The essential criteria are optimized and integrated at the modular product development phase, and the viable product configuration(s) are determined from among several product alternatives. The study provides decision guides to the original equipment manufacturers (OEMs) in making product configuration choice(s) that will enhance product serviceability and core cleaning so as to boost remanufacturing-PSS business offering.



**Contents**



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## 1. Introduction

In order to address the sustainability concerns that result from increasing demand for higher quality products as well as population growth, significant efforts have been made with regard to product end-of-life (EOL) management. EOL management strategies include, recycling, reuse, refurbishment, remanufacturing, reconditioning, repurposing, repair, composting, incineration, and disposals in landfill (Ma and Kremer, 2014). Remanufacturing is widely reported to be the most economically and environmentally beneficial among product EOL management strategies (Ma and Kremer, 2014). However, despite the various EOL management strategies, about 80% of manufactured products currently end up as waste (Commission, 2012). Among other challenges, remanufacturing is influenced by uncertainty with regard to the time in which a used product is returned, and also by the quality and quantity of the used product that is returned. Product service system (PSS) is a business strategy that emphasizes the functions of the product rather than the product itself, while the OEMs retains the ownership of the product. This enables the OEM to have some control over the time, quality and the volume of products that are returned from use. (Meier et al., 2011). Consequently, PSS provides a remedy to some of the challenges of remanufacturing. Govindan et al. (2016) evaluate twenty common barriers to remanufacturing and conclude that low customer acceptance of remanufactured product is a substantial impediment. Meanwhile, PSS remedies this problem as well because customers do not take ownership of the product, and a remanufactured product that provides the functions that the customers desires is well acceptable. In a study on the level of customers' satisfaction with regard to a product that is offered in PSS, Lee et al. (2015) identify measures of customers' values and provide their priority indices. The newness or otherwise of the product is not listed as important among the prioritized eight measures of customers' satisfaction. As a result, the integration of remanufacturing and PSS is considered to be a potent remedy to the sustainability issues associated with manufacturing. Some theoretical attempts to links remanufacturing and PSS have been reported. The work of Sundin and Lindahl (2008) is the earliest that provides such theoretical connection. Due to the potential benefits, the need to conduct further studies on remanufacturing and PSS synergy was emphasized by Hatcher et al. (2011). Nevertheless, analytical-based integration of remanufacturing and PSS at the early phase of product development is still missing. The aim of this study is to fill this lacuna by providing a mathematical approach to modular product development in order to enhance remanufacturing and PSS. PSS is characterized by heavy product usage, which requires higher product serviceability. Therefore, serviceability must be built into the product at the product development phase. Meanwhile, research has shown that over 70% of product life cycle costs are associated with the product design and development decisions (Nepal et al., 2007). By implication, the integration of both PSS and remanufacturing rests heavily on product development decisions. It has also been shown in the literature that modular architecture significantly enhances product development (Nepal et al., 2008). With modular architecture, complex products are decomposed into simpler units while sustaining product integrity (Nepal et al., 2007). Among other benefits, architecture strategy enhances product disassembly, thus improving product serviceability and core cleaning for both PSS and remanufacturing. This paper considers two factors that are essential for both PSS and remanufacturing: serviceability, a major criterion at product use phase, and core cleaning during remanufacturing at the product end-of-use (EOU) phase. These criteria are optimized, and most viable product configurations are obtained from among several product alternatives that are potentially available to the OEM. The outcomes will help product development decision makers to make better informed decisions regarding product modularity at the early stage of product development.

## 2. Review of previous research

### 2.1. Overview of remanufacturing

Remanufacturing refers to the process of restoring product at the end-of-life/end-of-use phase into products that are at least as good as the original product (Aksoy and Gupta, 2005) This definition is common to most of the research on remanufacturing. To make this description more encompassing, Ijomah et al. (2007) includes the importance of similar customers' perception of both the remanufactured and new product. Remanufacturing is considered to be the most viable option among product EOL options (Lund and Hauser, 2003). Remanufactured products save landfills, prevent air pollution associated with recycling, mitigate extraction of raw materials, and retain other value added to the materials when the product was initially produced, such as energy and machinery (Gray and Charter, 2007). Numerous studies have focused on product remanufacturing. Remanufacturing saves about 85% of the energy required to manufacture a new product, the energy equivalent of about 10.744 million barrels of crude (Giutini and Gaudette, 2003). It prevents yearly production of around 28 million tons of $CO_2$ globally (Gray and Charter, 2007). Remanufacturing also avoids huge manufacturing costs (Lund and Hauser, 2003), creates jobs, and lowers the price of remanufactured products to about 40%–65% of a similar product when new (Commission, 2012). As a result of the benefits of remanufacturing, several works have studied how it could be improved, while identifying the factors that are required for its success. Among these factors, core cleaning is considered essential. While developing metrics for a generic remanufacturing process, Sundin (2004) reiterates the importance of core cleaning operation. Sundin et al. (2008) study the product properties that are essential so as to improve remanufacturing. The study develops a remanufacturing process matrix called RemPro, which includes cleaning operations as being critical for effective remanufacturing. Gallo et al. (2012) found that in the remanufacturing industries,