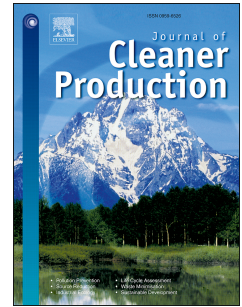


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## Price optimization of multi-stage remanufacturing in a Closed Loop Supply Chain

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**ABSTRACT:** In a remanufacturing process within the closed loop supply chain (CLSC) the manufacturers collect the end of life or used products from the customers and repair/refurbish them to sell it along with newly manufactured products. This phenomenon is common for products which are mechanical in nature and contains more reuse value. The reverse supply chain part of acquiring the used products incurs acquisition cost and remanufacturing cost, which depends on the quality or grade of returned product. Generally, the remanufacturers pay higher acquisition prices for good quality returned products and lower acquisition prices for poor quality returned products. Also, the remanufacturing cost is a decreasing function of the quality of the returned products.

But if the returned product can be refurbished and remanufactured in the corresponding stage of supply chain, it can be sold along with newly manufactured product. Inclusion of remanufactured products will reduce the demand of raw materials or sub components required from suppliers. This reduction in this cost may be transferred in the form of price of the product charged to the customer in forward supply chain. With this backdrop, a non-linear unconstrained model is proposed with the objective of maximizing closed-loop supply chain (including remanufactured products) profitability considering a price dependent demand. The decision variables to be determined are sale price, acquisition prices for stages, total return percentage to be accepted and their distribution. Some interesting insights can be drawn to analyze whether there will be price difference in CLSC arrangements compared to only forward supply chain without considering remanufactured products. A numerical example along with sensitivity analyses at the end gives the insights regarding circumstances under which CLSC operation is really profitable vis-à-vis FSC operation only.

Keywords: Remanufacturing, acquisition price, reverse supply chain, quality grade, separation of decision variables, closed loop supply chain.

### 1. INTRODUCTION

Closed Loop Supply Chain (CLSC) is defined as the design, control, and operation of a system to maximize value and dynamic value recovery throughout the life cycle of the returns of different types and quantities (Guide and Wassenhove, 2009). CLSC may be looked upon as a system which integrates Forward Supply Chain (FSC) and Reverse Supply Chain (RSC). FSC is involved in the activities like sourcing, manufacturing, distribution and delivery of new products/parts to the customers. Whereas, in the RSC products flow in the opposite direction of FSC. RSC comprises of activities involving acquisition/collection, distribution, delivery back to remanufacturers, reprocessing and delivery of products along with new parts/products to new or same customers. The idea is to recover left over market value or dispose it off (Pochampally et al., 2009). After acquiring used products or end of life products, they might undergo one of the following processes (Radhi, 2012).

- Reuse is the process of directly reusing the product with minor repair apart from cleaning and checking

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