Int. J. Production Economics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Manufacturing-remanufacturing policies for a centralized two stage supply chain under consignment stock partnership

Moncer Hariga *, Rami As'ad, Zeinab Khan

Department of Industrial Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates

ARTICLE INFO

Article history:
Received 15 September 2015
Received in revised form
14 April 2016
Accepted 19 July 2016

Keywords:
Supply chain management
Integrated vendor-buyer
Consignment stock
Remanufacturing

ABSTRACT

This paper addresses a centralized closed loop supply chain comprised of a single vendor and a single buyer operating under a consignment stock (CS) strategy. Following this sort of partnership, the buyer agrees to store the product at its premises where, in return, the payment of those products is made only after being sold to the end customer. We develop a mixed integer non-linear program that seeks to minimize the chain-wide total cost by jointly optimizing the length of the production cycle, the number and the sequence of the newly manufactured and the remanufactured batches, as well as the inventory levels of the finished and recovered products at the beginning of the cycle. The special case of the production sequence (R,M), in which R consecutive remanufacturing batches are produced first followed by M manufacturing batches, along with the production sequences (M,R), (R,1), and (1,M) are also derived from the general model. Extensive numerical experiments are also conducted in order to assess the impact of key problem parameters on the behavior of the developed models. The results confirm that, under the consignment stock agreement, the (R,M) and (M,R) production sequences are the dominant ones as they yield the optimal solution in roughly 87% and 10% of the reported problem instances, respectively. It is also found that intermittent schedules, in which the vendor alternates between the production of newly and remanufactured batches more than once, would only result in marginal savings under extreme values of the setup costs. In contrast to the reported results in the literature, the simplified cases of (R,1) and (1,M) did not perform well under several settings of the problem parameters with an average increase in the total cost as high as 19% and 25%, respectively.

1. Introduction

With customer satisfaction being the primary driver for success, organizations are constantly turning towards initiatives that would lower their supply chain costs, enabling them to pass on the savings to their customers in the form of more affordable products. Examples of recent supply chain initiatives are Vendor Managed Inventory (VMI), Consignment Stock (CS) and the environmentally friendly approach of green supply chain.

In CS systems, although the products are stocked at the buyer's storage facility, the products belong to the vendor until they are used by the buyer. The ownership of products will be transferred from vendor to buyer when the products leave buyer's warehouse or are sold to the end customer. Consignment stock policies are gaining more popularity and are now being studied more frequently than ever (Sarker, 2014). Valentini and Zavanella (2003) presented a real life example of an Italian auto parts manufacturer who stocks the items at the buyer's site under a CS partnership. The advantages of the CS policy to both the vendor and the buyer are provided in Sarker et al. (2012), where they also noted that such policy has been widely adopted in Italy, Japan and the United States. Battini et al. (2010a) noted that consumer items, small parts, tools packaging parts, and personal protection equipment are specific examples as to when CS policy is most attractive. More applications are also highlighted by Sarker (2014) including clothing, antiques, furniture, sports equipment, musical instruments and books. Examples of consignment purchasing in various sectors of the healthcare industry were also identified in the latter work.

Nowadays, environmental concerns is becoming a serious threat as greenhouse gas emissions are increasing, and critical resources such as food, water, minerals, are diminishing. As a result, several companies are now integrating environmental concerns into their supply chain practices and are shifting towards green or sustainable supply chain. In addition, the emerging field of closed-loop supply chain (CLSC) management seeks to efficiently manage the activities related to the retrieval of products

* Corresponding author.
E-mail address: mhariga@aus.edu (M. Hariga).

http://dx.doi.org/10.1016/j.ijpe.2016.07.015
0925-5273/© 2016 Elsevier B.V. All rights reserved.

from end customers as well as the proper reuse of those returned products. Closed-loop supply chain is rampant in theory as well as in practice with numerous successful applications drawn from diverse industries. The value of returned products in the U.S. is estimated to be $100 billion per annum (Blackburn et al., 2004). Many electronic companies such as HP, Cannon and NEC Corporation are taking advantage of reverse supply chain. Xerox Corporation saves 40–65% in manufacturing costs through a prepaid mailbox service which allows customers to return used cartridges (Gou et al., 2008). Another successful implementation is Kodak which reported a return rate of greater than 70% in the United States and almost 60% globally for their disposed cameras (Guide et al., 2003). A favorable product for recycling is battery as 35 kg of lead and 7.5 kg of plastic can be recovered from 100 kg of used batteries (Daniel et al., 2003).

Given the above successful practical applications of CS and CSLC, their integration will have great potential to lead to substantial improvements in the supply chain economic and environmental performance. This paper addresses the problem of optimizing a centralized closed loop supply chain comprised of a single-vendor and a single-buyer operating under CS partnership. In particular, we present a mathematical model that optimizes inventory levels and replenishment decisions as well as the sequencing of the newly manufactured and remanufactured batches at the vendor stage such that the chain wide total cost is minimized. Therefore, the practical relevance of the work presented in this paper is attributed to the fact that it integrates two practical and widely adopted supply chain initiatives with higher potential for greater benefits from both environmental and economic perspectives.

The remainder of this paper is structured as follows. Section 2 reviews the literature related to the problem at hand. In Section 3, the problem description along with the stipulated assumptions, the derivations of the optimization model as well as the solution algorithm are provided. Section 4 highlights the derivation for special cases of the generalized model developed in Section 3. Extensive computational experiments are presented in Section 5 followed by concluding remarks and proposed future research directions in Section 6.

2. Relevant literature

The integrated approach for optimizing production and inventory related decisions in the context of multi-layer supply chains has received a great deal of interest from academic researchers. An example of such approach is the Joint Economic Lot-sizing (JELS) models, which stands out as the foundation of integrated supply chain models. In the JELS model, the objective is to determine the production and shipping policy that minimize the overall costs of all supply chain players. Several contributions to the JELS problem have also been made since the first paper by Goyal (1977). Interested readers are referred to the review papers by Ben-Daya et al. (2008) and Glock (2012) for a detailed discussion of these contributions.

Due to its many potential benefits, several researchers have extended JELS models to account for CS partnership. Braglia and Zavanella (2003) developed a mathematical model for a centralized two stage single-vendor single-buyer supply chain operating under CS strategy and showed the conditions under which such strategy is beneficial. However, their model considered only forward supply chain where the end customer demand is fully satisfied from newly purchased material, a policy that we refer to in this paper as the “Manufacturing only policy”. Valentini and Zavanella (2003) showed numerically that supply chain models adopting CS partnership are economically better than classical independent inventory models. In a related work, Gumus et al. (2008) determined the operational benefits of CS under deterministic demand for a single item, and integrated vendor-buyer system.

The CS partnership for a single-vendor multi-buyer supply chain was addressed by Zavanella and Zanoni (2009) where they handled a special case in which a buyer receives one shipment per cycle or consecutive shipments in case of more than one shipment per cycle. In addition, the sequence of deliveries to the buyers was assumed to be known in advance. As noted by the same authors in a follow up paper (Zavanella and Zanoni, 2010), the sequencing of the shipments from the vendor to the various buyers is a complicated problem. Accounting for demand variability and assuming that different buyers face the same demand distribution, Battini et al. (2010b) presented a model for the single-vendor multi-buyer supply chain under CS partnership which also incorporated space constraints, obsolescence risk, and shortage risk. Ben-Daya et al. (2013) considered another shipment policy where the buyers receive equal shipments in each cycle. The generalized version of the single-vendor multi-buyer problem was tackled by Hariga et al. (2013). They presented a mixed integer non-linear programming (MINLP) formulation of the problem and proposed a heuristic that allows for the attainment of near optimal solutions. A recent thorough review and classification of the literature pertaining to JELS models under CS partnership is given by Sarker (2014).

Another line of research has taken into account the environmental concerns through analyzing green or closed loop supply chain systems. In that spirit, researchers have developed integrated models for forward and reverse supply chains simultaneously, in both single and multi-echelon systems as detailed below. In general, once compared to forward supply chains, the simultaneous optimization of forward and backward supply chain is more complex since there is additional tradeoff in the selection between the supply modes: procured items and economically valuable returned items. Also, a decision has to be made whether to dispose the returned items or store them in serviceable or recoverable inventory for a later use.

For single echelon systems, Schrady (1967) was the first to develop an economic order quantity (EOQ) model for a repair-inventory system. He proposed a solution where one manufacturing batch succeeds R remanufacturing batches, denoted as the $(R, 1)$ policy, and assumed that none of the returned materials is disposed. Later, Tuenter (2001) proposed the alternative $(1, M)$ policy in which a single remanufacturing batch precedes M manufacturing batches. Similarly, Schulz and Voigt (2014) developed a better approach to determine the total cost, and the optimal R and M values for the above $(R, 1)$ and $(1, M)$ policies, respectively. They then proposed a more general policy that considers non-equal sized remanufacturing batches and that also optimizes the production sequence of both type of batches. Koh et al. (2002) determined optimum inventory level of recoverable items and procured items simultaneously, based on joint EOQ and economic production quantity (EPQ) models. Moreover, their model takes into account the time it takes to transform products from recoverable to serviceable, and a finite repair capacity. In a related work, Minner and Lindner (2004) determined the optimum batch sizes and number of recovered and newly procured items simultaneously, as well as the production sequence of batches under the assumptions of infinite manufacturing and remanufacturing rates, and a return rate that is less than the deterministic demand rate. El-Saadany and Jaber (2010) developed optimization models that account for waste disposal cost, while assuming the return rate of the item to be dependent on its price and quality level. Other authors have also addressed the single echelon closed loop supply chain problem under deterministic time varying demand (Pan et al., 2009) as well as stochastic demand (Shi et al., 2011).