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Collaboration for a closed-loop deteriorating inventory supply chain with multi-retailer and price-sensitive demand

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ABSTRACT

In this paper, a closed-loop logistics system with manufacturing and remanufacturing cycle is analyzed using three optimization methods. They are: (i) sequential optimization, (ii) centralized optimization without benefit sharing, and (iii) centralized optimization with benefit sharing. In the first method, the decisions of sequential optimization are made initially by the retailers, and then by the manufacturer. In the second method, the decision of the centralized optimization is made simultaneously by the whole logistics system. The second method is not favorable to the retailers because the retailers' profit will become smaller as a result of collaboration. Therefore a third method with benefit sharing is investigated. The logistics system includes a manufacturer and multi-retailer considering price-sensitive demand and deterioration. Industrial examples of such products are IC chips, computers and mobile phones that usually outdate or decrease in value due to technological innovation. The decrease in value is considered as a form of deterioration. In order to add value, these outdated products can be remanufactured and resold to market. Four key effects are investigated in this study: (i) recycling in supply chain, (ii) deterioration, (iii) collaboration effect between manufacturer and retailers using three optimization methods, and (iv) price sensitive demand.

1. Introduction

One of the keys to successful supply chain management is system integration. Clark and Scarf (1960) presented a concept of serial multi-echelon structures to determine the optimal policy. Banerjee (1986) derived a joint economic lot size model for a single vendor, single buyer system when the vendor has a finite production rate. Goyal (1988) extended Banerjee's model by relaxing the lot-for-lot production assumption. Wee and Jong (1998) studied the integration between parts and finished product with multi-lot size and deterioration. Yang et al. (2007, 2008) derived a collaborative vendor–buyer inventory system with different patterns of purchase cost, products price and market situations.

Wee (1993) considers product deterioration as decay, damage, spoilage, evaporation, obsolescence, pilferage, loss of utility or loss of marginal value of a commodity that results in decreasing usefulness from the original one. Ghare and Shrader (1963) were the first authors to consider on-going deterioration of inventory. Other authors such as Kang and Kim (1983) and Raafat et al. (1991) assumed either instantaneous or finite production with different assumptions on the patterns of deterioration.

Many enterprises have focused their attention on reverse supply chain to meet environmental concerns/regulations and social liability. Product remanufacturing such as transforming used items into marketable products through refurbishment, repair and upgrading can also yield substantial cost benefits. Schrady (1967) was the earliest author to propose a deterministic model with instantaneous production rate for manufacturing and remanufacturing. Schrady (1967) argued that optimal lot sizes for manufacturers and remanufacturers can be determined by the classical EOQ formula. Teunter and Laan (2002) used an average cost approach to derive inventory models with remanufacturing. Chung et al. (2008) developed a closed-loop model with single manufacturing and single remanufacturing cycles. Jaber and Saadany (2009) developed a manufacturing and remanufacturing inventory system under the condition of lost sale. Hsu et al. (2010) considered preservation technology investment for deteriorating inventory. Wee et al. (2011) and Chung and Wee (2011) considered deteriorating green products and supply chains inventory systems. Feng and Viswanathan (2011) derived a new lot-sizing heuristic with remanufacturing. Recently,

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Widyadana and Wee (2012) developed an economic production quantity model for deteriorating items with multiple production setups and rework, and later considered vendor–buyer inventory model with discrete delivery order, random machine unavailability and lost sales (Wee and Widyadana, 2011). Cárdenas-Barrón et al. (2012) developed an improved algorithm and solution on an integrated production-inventory model in a three-layer supply chain. This study extends the paper of Chung et al. (2008) by considering multi-retailer, price-sensitive demand and the effect of deterioration to simulate the real business environment.

This paper is organized as follows. Section 2 shows assumptions, notations and model development. Solution procedure with three cases is derived in Section 3. Numerical analysis and sensitivity analysis are validated in Sections 4–6. Finally, Section 7 concludes this paper.

2. Model development

A closed-loop system of a single manufacturer and multi-retailer is considered to derive the optimal replenishment and pricing policy. Fig. 1 illustrates the material, product and used product flow in the closed-loop manufacturer–retailers system. In Fig. 2, the inventory levels are depleted by demand and constant on-hand-stock deterioration, and there are five inventory levels depicted as follows: (i) total product inventory level, (ii) retailer product inventory level, (iii) manufacturer product inventory level, (iv) manufacturer new material inventory level, and (v) manufacturer used product inventory level. The total product inventory level is the sum of the retailer product inventory level and the manufacturer product inventory level. The following relations hold: (i) $T=T_{R1}+T_{R2}+T_{M1}+T_{M2}$ and (ii) $T=T_{R1}+T_{R2}+I+T_{M1}+II$. The time period T_{M2} is equivalent to the sum of the time periods (I) and (II). The mathematical models in the analysis have the following assumptions:

(1) Single manufacturing and single remanufacturing cycles are considered.
(2) Deterioration is considered and no shortage is allowed.
(3) Constant manufacturing and remanufacturing rates, zero lead-time.
(4) The system contains a single item in an infinite planning horizon.
(5) The product demand rate and return rate are constant, and the return rate is less than demand rate. The price-sensitive demand is within the positive feasible range.
(6) The number of deliveries within the manufacturing cycle is an integer.
(7) The remanufactured products are comparable to newly manufactured products.
(8) Single manufacture and multiple retailers in the closed-loop supply chain inventory system are considered.
(9) All retailers are in a single chain-store group and are located mostly at a metropolitan area (such as IC chips and cellphone's retailers), and their retail prices and replenishment intervals are assumed to be identical due to brand image and risk pooling, though their scale and price-sensitive parameters are distinct.

The following denotes the retailer's variables and parameters:.

P_e	retail price (independent variable)
T_r	ordering cycle time (independent variable)
$I_{rk}(t)$	retailer k's product inventory level
$a_k(b_k)$	demand scale (price-sensitive) parameter for retailer k, $k=1,2,\ldots,K$
d_k	annual demand rate for retailer k, where $dk=ak-bkPe$
D	total demand rate, where $D=\sum_{k=1}^{K} a_k-\sum_{k=1}^{K} b_k P_e$
A_{rk}	ordering cost per time
F_{rk}	annual percentage holding cost per dollar
P_r	wholesale price to retailer
P_r'	new wholesale price to retailer when price discount is considered
ΔP_r	unit discount of selling price to the retailer, where $\Delta P_r=P_r-P_r'$
$TC_r(TP_r)$	annual total cost (total profit)

The following denotes the manufacturer's variables and parameters:

$m(n)$	number of deliveries per manufacturing (remanufacturing) cycle to the retailer (dependent variables from (22) and (23), respectively)
N	number of deliveries to the retailer in this model cycle, where N is an integer and $N=n+m$ (independent variables)
$T_{R1}(T_{R2})$	reproduction (non-production) period in each remanufacturing cycle (T_{R2} is independent variable, T_{R1} is dependent variable from (24))
$T_{M1}(T_{M2})$	production (non-production) period in each manufacturing cycle (T_{M2} is an independent variable, T_{M1} is a dependent variable from (25))
$I_{M1}(t)(I_{M2}(t))$	total product inventory level in production (non-production) period during manufacturing cycle

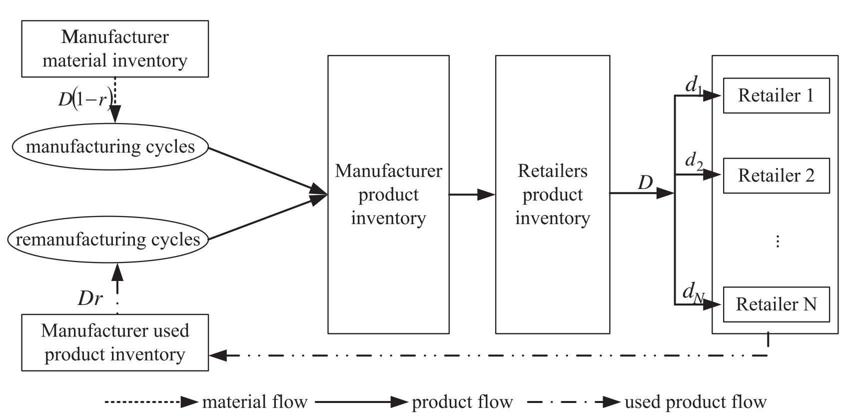

Fig. 1. The material, product and used product flow in the closed-loop manufacturer–retailers system.