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An integrated production and inventory model for a whole manufacturing supply chain involving reverse logistics with finite horizon period

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ABSTRACT

This paper proposes a model and solution method for coordinating integrated production and inventory cycles in a whole manufacturing supply chain involving reverse logistics for multiple items with finite horizon period. A whole manufacturing supply chain involving reverse logistic consists of tier-2 suppliers supplying raw materials to tier-1 suppliers, tier-1 suppliers producing parts, a manufacturer which manufactures and assembles parts from tier-1 suppliers into finished products, distributors distributing finished products to retailers, retailers selling products to end customers and a third party which collects the used finished products from end customers, dissembles collected products into parts, and feed the parts back to the supply chain. In this system, we consider a finite horizon period. A mathematical model for representing the behaviors of the system is developed. Solution methods based on decentralized and a combination of decentralized and centralized decision making process, referred to as the semi-centralized decision making process, are proposed to solve the model while the centralized decision making process is solved by a mixed integer nonlinear programming method. A numerical example is used to demonstrate the model and the solutions based on the three types of the coordination.

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1. Introduction

In today's competitive market, the collaboration between players in the supply chain does not only consist of two-level or three-level supply chain. In addition, in a real problem the supply chain does not manage just a single product. It may consist of more than three-level supply chain and manages more than just a single product. One type of the complex supply chain is named as a whole manufacturing supply chain involving reverse logistics consisting of tier-2 suppliers which produce raw materials to be supplied to tier-1 suppliers, tier-1 suppliers which produce parts for a manufacturer, the manufacturer which manufactures and assembles parts into finished products, distributors which deliver finished products to retailers, retailers selling products to end customers and a third party which collects used finished products and feeds reusable parts to the manufacturer. Because there are many players having their own objectives whilst participating in this chain, a coordination mechanism is needed to manage the effective and efficient flow of raw materials, parts, finished products and returned used products among them ([16,17]).

Integrating production and inventory models of players in a supply chain is therefore needed to achieve the chain objectives with a coordinated decision making process. Coordinating in multi-level production and inventory has been addressed well, not limited to, in Chen and Chen [4], Chung et al. [8], Ganeshan [12], Gou et al. [13], Jaber and Goyal [16], Khouja [17], Munson and Rosenblatt [21], Lee [19], Sarmah et al. [23], Ben-Daya et al. [1], Akanle and Zhang [9], Savaskan [25], and Wang and Hsu [27].

Based on a literature review which has been carried out, researches only considered parts of the whole system studied. Chen and Chen [4] developed joint replenishment and channel coordination between a manufacturer and retailers. For three-level supply chains, Jaber and Goyal [16], Khouja [17] and Munson and Rosenblatt [21] developed three-level supply chain with coordination. Rieksts and Ventura [22] developed two-level inventory model considering two modes of transportation system which are truckload and less than truckload. However, these papers assume that there is no returning of used finished products from end customers.

Concerning returned used products, many papers have also been published (See Srivastava [24]). Choi et al. [5] developed ordering and recovery policy for reusable items. El Saadany and Jaber [11] developed remanufacturing model for subassemblies of used products which are managed differently. Chung et al. [8] developed a closed-loop supply chain inventory system with remanufacturing and Teunter [26] developed EOQ model for

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recoverable item inventory system similarly with work in Koh et al. [18]. These papers considered only a part of the supply chain such as one player in Choi et al. [5] and a two-level supply chain in Chung et al. [8]. Chung and Wee [6] developed integrated production inventory model for deteriorating item with short life-cycles between a supplier and a buyer considering green product design and remanufacturing with re-usage concept whilst Wee et al. [28] developed vendor managed inventory strategy between one supplier and one buyer for deteriorating product and conducted life cycle cost and benefits analysis. Chung and Wee [7] investigated the impact of green product design, deteriorating factor, and information technology application investment on business process with remanufacturing. Later, Mitra [20] developed a two level supply chain with returns considering both deterministic and stochastic demand and return rate.

When constraints of some or all players are considered, few researches had been carried out. Haksever and Moussourakis [14] built a model for optimizing multi-products inventory system with multiple resources constraints. Ishii and Imori [15] developed production ordering system for a two-items (products), two-stages supply chain with production capacity constraints. Both works have a single player and single level (just in the manufacturer).

This paper, therefore, proposes an integrated production and inventory control model in a whole manufacturing supply chain system involving reverse logistics for multiple products, which extends works in Chen and Chen [4] and Jaber and Goyal [16]. The system consists of multiple raw materials suppliers, multiple parts suppliers, a manufacturer, multiple distributors and multiple retailers. Due to limited production capacity of each supplier, it is possible for each type of parts and raw materials to be supplied by more than one supplier. This paper considers reuse option for collecting used finished products from end customers by a third party returning collected parts to a manufacturer to be used into new finished products. This paper also considers the finite horizon period as it is relevant to the real problem. The model developed in this paper can be generalized as integrated production inventory model in multi-level supply chain. The rest of this paper is organized as follows. Section 2 provides an illustration of the system studied, lists the notations, describes the coordinations used, the modeling of the cost functions and constraints and the solution methods proposed for solving the model. In Section 3, a numerical example is used to demonstrate the real problem and some results of analysis are discussed for all types of coordinated decision-making processes. Finally, the paper is summarized and concluded in the Section 4.

2. Mathematical model

First, in this section, we describe the system studied. Fig. 1 shows a system description of the whole green manufacturing supply chain network. Tier-2 suppliers produce and supply multiple-raw materials to tier-1 suppliers producing multiple-parts. Parts from tier-1 suppliers are then supplied to a manufacturer which manufactures and assembles parts into finished products. Then, the finished products will be delivered to distributors distributing them to retailers. A portion of used finished products, the usable parts, will be returned back by a third party to the manufacturer to be used into new finished products.

This paper considers multiple raw materials, multiple parts, multiple finished products with multiple suppliers, distributors and retailers and a remanufacturer. A manufacturer manufacturers and assembles parts from suppliers into the finished products. Production rates for the manufacturer and all suppliers are finite. The paper assumes constant demand rates, zero lead time, and shortages are not allowed. This paper also assumes returned finished products can be perfectly disassembled to become parts. Some of the parts can be used again into new finished products. The quality of the usable parts is considered to be as good as new parts.

2.1. Notations

The input parameters and decision variables for Retailers, Distributors, Manufacturer, Tier-1 Suppliers, Tier-2 Suppliers and the Third Party are as listed comprehensively in Appendix A.

2.2. Retailers' cost components

Retailers clearly incur only two types of costs; ordering cost and finished products holding cost. When there is no coordination among all retailers, retailer r orders $Q_{r,i}^{(r)}$ units of each finished product i from distributor d every cycle time $T_r^{(r)}$. The total cost function for retailer r, TCR_r, is given by

$$TCR_r = \frac{A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}}{T_r^{(r)}} + \frac{T_r^{(r)} \sum_{i=1}^{k^{(i)}} h_{r,i}^{(r)} D_{r,i}^{(r)}}{2} \tag{1}$$

The first term is ordering cost per unit time and the second term is finished products holding cost per unit time.

Based on standard method for calculating economic order interval and quantity, the economic order interval and quantity for each retailer are derived. Differentiating TCR_r with respect to $T_r^{(r)}$ for each retailer r,

$$\frac{\partial TCR_r}{\partial T_r^{(r)}} = -\frac{A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}}{T_r^{(r)^2}} + \frac{\sum_{i=1}^{k^{(i)}} h_{r,i}^{(r)} D_{r,i}^{(r)}}{2}$$

By setting

$\frac{\partial TCR_r}{\partial T_r^{(r)}} = 0$, then

$$T_r^{(r)*} = \sqrt{\frac{2\left(A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}\right)}{\sum_{i=1}^{k^{(i)}} h_{r,i}^{(r)} D_{r,i}^{(r)}}} \tag{2}$$

Based on standard economic order quantity (EOQ) model,

$$Q_{r,i}^{(r)} = T_r^{(r)} D_{r,i}^{(r)} \tag{3}$$

By substituting Eq. (2) in Eq. (3),

$$Q_{r,i}^{(r)*} = \sqrt{\frac{2 D_{r,i}^{(r)^2} \left(A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}\right)}{\sum_{i=1}^{k^{(i)}} h_{r,i}^{(r)} D_{r,i}^{(r)}}} \tag{4}$$

where $T_r^{(r)}*$ and $Q_{r,i}^{(r)}*$ are optimal cycle time and order quantity of finished product i for retailer r.

Eq. (1) is a convex function in $T_r^{(r)}$, where

$$\frac{\partial^2 TCR_r}{\partial T_r^{(r)^2}} = 2\frac{A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}}{T_r^{(r)^3}} > 0$$

Therefore, the optimal solution for Eq. (1) is a global optimum.

For all retailers, the total cost function can be expressed as follows,

$$TCR = \sum_{r=1}^{n^{(r)}} \left(\frac{A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}}{T_r^{(r)}} + \frac{T_r^{(r)} \sum_{i=1}^{k^{(i)}} h_{r,i}^{(r)} D_{r,i}^{(r)}}{2} \right) \tag{5}$$

When there is coordination among all retailers with a common cycle time, T, applied for all retailers, the total cost will be

$$TCR = \frac{\sum_{r=1}^{n^{(r)}} \left(A_r^{(r)} + \sum_{i=1}^{k^{(i)}} a_{r,i}^{(r)}\right)}{T} + \frac{\sum_{r=1}^{n^{(r)}} \left(T \sum_{i=1}^{k^{(i)}} h_{r,i}^{(r)} D_{r,i}^{(r)}\right)}{2} \tag{6}$$

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