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Optimizing inventory policy for products with time-sensitive deteriorating rates in a multi-echelon supply chain

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ABSTRACT

Many industries with multiple-echelon supply chains suffer inventory management with costly deteriorating rates changed along with the time, such as TFT-LCD panel manufacturing industry, IC manufacturing industry, and agricultural industry, to name a few. In addition, highly competitive pressures in business force firms to develop their partnership through strategic alliances. This study assumes that product deterioration is time-sensitive and develops an optimal integrated inventory policy for time-sensitive deteriorating products by taking into account a strategic alliance for a three-echelon supply chain (one producer, one distributor, and one retailer). This study empirically investigates how different deterioration rates in each echelon affect performances of individuals and integrated inventory policies. Sensitivity analysis is given to justify that the impact of changes in deterioration rates of each echelon is significant and the joint cost of the proposed integrated inventory policy is found to be much less than the individual policies. In addition, a compensation policy is applied to evaluate cost reduction and benefit losses under different individual policies. Through the proposed coordination mechanism, the timing and quantities of deliveries can be determined optimally in cooperation with up-/down-stream members to achieve a minimum overall cost. Furthermore, the proposed integrated inventory policy can contribute to a significant cost reduction of such supply chains, and facilitate strategic alliance among the parties in the supply chain.

1. Introduction

Coordination-based supply chains have been advocated in past decades to respond quickly to customer needs and reduce the cost of carrying inventory for a multi-echelon supply chain. Through coordination, the timing and quantities of deliveries is derived in cooperation with up-/down-stream members to achieve a minimum overall cost.

Inventory policy describes how to stock inventory and when to replenish. It determines: (1) How much product is stored at a site, (2) when replenishment orders are generated, and (3) what quantity is replenished. In their study, Yu et al. (2008) have classified inventory policies as a 2×2 matrix as shown in Fig. 1. Individual models include Policy I, II, and III. Partners in a supply chain apply individual inventory policies from myopic viewpoints. Policy I is an isolated policy which is often used in a two-head supply chain management (SCM) that consists of both powerful producer and retailer. Policy II is from the retailer's perspective and is often used in a power-retailer SCM. Wal-Mart is a typical example. Policy III is from the producer's perspective and is commonly used in a power-producer SCM. Intel is a typical example. Policy IV deals with two partners with equal power and apt to increase collaboration. This study focuses on a supply chain of Policy IV which is used commonly in a cooperative SCM with close partnership relationship. An integrated inventory policy is formed and all parties follow the resulting decision to minimize total cost.

In practice, products in a multiple-echelon supply chain have distinct deteriorating rates and the rates can change along with the time. Because members in a supply chain suffer from different deteriorating costs, they would come up with self-centered decisions on inventory policies which may hurt other members and the overall cost of the supply chain. This study thus focuses on investigating how distinct deterioration rates of products will affect individuals as well as system performances under a three-echelon supply chain.

To name a few, the TFT-LCD panel manufacturing industry forms a typical three-echelon supply chain with different time-sensitive deterioration rates of products: material producers, panel manufacturers, and assemblers. The main materials of TFT-LCD provided by producers are color filter, backlight unit and driver IC. Taiwan is one of the leading economic bodies in the TFT-LCD panel manufacturing industry. Some typical firms in the economic body are Sintek, Radiant and Forhouse co. For color filter, its major technological source is obtained mainly from Japan, being expensive and of long lead time, thus the deteriorating cost of color filter related materials are significantly high due to technology phase-out of

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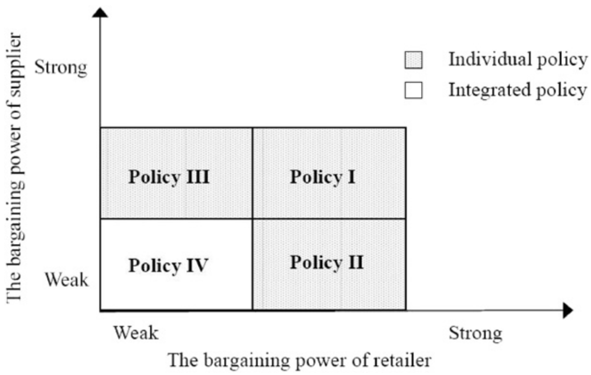

Fig. 1. Inventory policies characterized by the bargaining power of producer and retailer (Yu et al., 2008).

material loss in process. The member in the middle echelon of the TFT-LCD supply chain is the panel manufacturers, such as AUO Co. (AU Optronics Corporation) and CMO Co. (Chi Mei Optoelectronics). Their material cost is very high (almost attributes to 60% of the total cost) for the panel manufacturers. Their inventory items are the most complicated among all the supply chain units. In order to take advantage of utilization of facilities which investment of equipment is huge, the inventory level is usually high also. The deteriorating cost of materials, in terms of manufacturing defects and material loss, has threatened their competiveness. The down-stream unit of the supply chain is the TFT-LCD assemblers, such as Innolux Co. and TPV Co. The firms in this stage are labor intensive, has low deteriorating rate of products.

It is worthy to note that in the TFT-LCD supply chain, the producers give a panel manufacturer their material by a large batch with a long lead time. A panel manufacturer in the middle echelon of the supply chain produces panels and divides them into small batches and ships individual batches to retailers as required by retail. The panel manufacturers need to pay attention to panel wholesales price and make responsive decisions on timing of production duration and shipment cycle to guarantee the lowest manufacturing cost as well as the commitment to market.

The other example that distinct deteriorating rate of materials occurs in a supply chain is IC manufacturing industry. This industry also forms a three-echelon supply chain: IC design houses, IC manufacturers, and IC package/testing service companies. IC design houses are the producers of such a supply chain. Some typical IC design firms in Taiwan are Mediatek, GUC (Global Unichip Corp.) and Novatek. The majority of cost of the firms attributes to R&D, and they have very low deteriorating rate of materials because only very few "defective goods" are made at this stage. IC manufacturers constitute the middle player of the supply chain. Typical firms are TSMC (Taiwan Semiconductor Manufacturing Co.), UMC (United Microelectronics Corporation), and MVI (Mosel Vitelic Inc.). Their machines are expensive and the corresponding investment is huge. The process of IC manufacturing is long and complex, while deteriorating items are generated in each process due to break, shaving, manufacturing defects and technology phase-out deterioration. Deteriorating cost is fairly high, partially because of fine manufacturing quality requirement by end customers/IC design houses. Work-in-process inventory accumulates heavily at this stage because of long process and large batches. For instance, the deteriorating rate, even for the worldwide leading semiconductor manufacturing firm, TSMC, reaches 30% in the most precise 0.13 μm production process. IC package/testing service companies is the most down-stream player in this chain. Some typical companies are ASE (Advanced Semiconductor Engineering Inc.) and SPIL (Siliconware Precision Industries Co., Ltd.). The deteriorating cost of materials in this stage is fairly low.

It is worthy to note that, IC manufacturing industry, the IC design company gives IC manufacturers their design in a large batch (in quarters). IC Manufacturers then produce them by smaller batches (in weeks) and forward them to IC package/test companies. Finally IC package/test firms directly deliver the final ICs to customers.

Another example that distinct deteriorating rate of materials occurs in a supply chain is agricultural industry. This industry forms a three-echelon supply chain: farmers, product distributers, and retailers. Agricultural products are gathered every certain period of time, and collected in the warehouse after being purchased by distributors, and then transported to retailers in turn. Farmers are the producers of such a supply chain. When agricultural products are not gathered yet, deteriorating rate and cost is low. Product distributers constitute the middle player of the supply chain. Inventory and WIP accumulate at this stage but ship to retailers rapidly, hence its deteriorating cost is fairly low. Product retailer is the most down-stream player in this chain. Since agricultural products have been gathered for a long time, and have already presented in the market without throughout protection facilities as in the distributors, the deteriorating rate is very high in this stage.

To take into account a vertical integration of supply chain by applying Lee and Moon's (2006) and Yu et al.'s (2008) methods, we focus on the investigation of performances in a three-echelon supply chain with distinct deteriorating rates of products. We examine how the performances of the integrated model to be affected by the products with different deteriorating rates.

The rest of this article is organized as follows. Section 2 presents related literatures. In Section 3 we retrospect the models for individual and integrated inventory replenishment policies in a three-echelon supply chain and the corresponding solution procedure. Section 4 is a sensitivity analysis. We conclude the study by Section 5.

2. Literature review

Decision-making for inventory in a supply chain is very challenging. Clark and Scarf (1960) were the first to consider multi-echelon stock in inventory research. Wee (1998) derived an integration model of deteriorating products between a buyer and a seller. Viswanathan and Piplani (2001) proposed a one-vendor, multi-buyer supply chain model and analyzed the benefit of coordinating inventories through the use of common replenishment epochs. A cooperative approach for a vendor–buyer inventory system to minimize the joint inventory cost was studied by Yang et al. (2007). Jong and Wee (2008) developed a JIT single-buyer single-supplier integrated deteriorating model with multiple deliveries. Note that many researchers have investigated inventory issues in a supply chain system; most of them considered two-echelon models with two roles (vender and buyer), while few studied models have dealt with three-echelon models including distributors.

Joint Economic Lot Size (JELS) Models is a promising replenishment policy in SCM. JELS generates lower total inventory relevant cost allowing the net benefit to be shared by both parties. Goyal (1976) was the first to introduce an integrated inventory policy for a single-producer single-customer problem. His research showed that an integrated inventory policy results in a minimum joint variable cost for the producer and the customer. In the meanwhile, Donaldson (1977) introduced the inventory replenishment problem with a linear trend in demand. But his approach was developed by a complicated computation using tabular and interpolation to solve this problem. Banerjee (1985) developed a joint JELS with lot-for-lot policy for a single-buyer single-vendor system by combining two economic order quantity (EOQ) models from the buyer and the vendor. By considering both the buyer and the vendor at the same time, he also showed the JELS model has minimum joint total relevant cost. Later Goyal (1988) generalized