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A fractal echelon approach for inventory management in supply chain networks

Kwangyeol Ryu [a,*], Ilkyeong Moon [a], Seungjin Oh [b], Mooyoung Jung [c]

[a] Department of Industrial Engineering, Seoul National University, Seoul 151-744, Korea
[b] Department of Industrial and Management Engineering, Pohang University of Science and Technology, San31 Hyoja-dong, Nam-gu, Pohang 790-784, South Korea
[c] School of Technology Management, Ulsan National Institute of Science and Technology, 100 Banyeon-ri, Eonyang-eup, Uljin-gun, Ulsan 689-798, South Korea

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ABSTRACT

A major issue in supply chain inventory management is the coordination of inventory policies adopted by different members in a supply chain including suppliers, manufacturers, distributors, etc. This paper presents a fractal-based approach for inventory management in order to minimize inventory costs and smooth material flows between supply chain members while responsively meeting customer demand. Within this framework, each member in the supply chain is defined as a self-similar structure, referred to as a fractal. A fractal-based echelon does not indicate a functional level or composition of supply chain members but indicates a group of multi- or hetero-functional fractals. The basic fractal unit (BFU) consists of five functional modules including an observer, an analyzer, a resolver, an organizer, and a reporter. The application of the fractal concept into inventory management makes it easy to intuitively understand and manage supply chain inventories because similar functional modules can be iteratively applied to an inventory management system. More specifically, we apply the fractal concept to a vendor managed inventory (VMI) model, referred to as fractal-based VMI (fVMI), where a vendor assumes responsibility for maintaining inventory levels and determining order quantities for his buyers. In this paper, we develop mathematical models for the analyzer and resolver to effectively manage supply chain inventories. For validating the proposed approach, a comprehensive simulation model, representing two VMI initiatives including traditional VMI and fVMI, is constructed and used for comparative analyses of case studies.

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1. Introduction

A supply chain is a complex network consisting of several organizations with different objectives for the production and distribution of products according to customer demand. Especially, supply chain management (SCM) is concerned with finding the best strategy for the entire supply chain (SC) by coordinating different enterprises along the logistics network or establishing business partnerships (Simchi-Levi et al., 2003). Many researchers have studied ways to optimize SCs so that manufacturers, distributers, and suppliers can maximize their profits. In order to find the best strategy in this complex network, intensive communication, and coordination between trading partners is required so that material and information flow along the SC can be optimized (Sari, 2008).

Among various SCM issues, inventory management is to a greater extent relevant when the entire supply chain, namely a network of procurement, transformation or production, and delivery firms, is considered. According to the literature, inventory usually represents from 20% to 60% of the total assets of manufacturing firms (Giannoccaro et al., 2003). Supply chain inventory management (SCIM) is focused on end-customer demand and aims at improving customer service while lowering relevant costs (Verwijmeren et al., 1996). Inventory management policies prove critical in determining the profit of each supply chain members. The main considerations regarding SCIM policies include (i) nature of optimization (e.g., local, global), (ii) control type (e.g., centralized, distributed), (iii) nature of review of inventory levels (e.g., periodic, continuous, hybrid), (iv) type of demand function (e.g., linear, distribution), and (v) responsibility for inventory control (e.g., self-managed, vendor-managed), as illustrated in Table 1.

An inventory policy can possess local or global goals (Axsäter and Juntti, 1996). Regarding the pursuit of local goals, the SC inventory policy results from a collection of local policies in which every SC member tends to make decisions on its own inventory individually based on local performance criteria. Several effective incentive mechanisms including quantity discounts, profit sharing, buybacks,

* Corresponding author. Tel.: +82 51 510 2473; fax: +82 51 512 7603.
E-mail addresses: kyryu@pusan.ac.kr (K. Ryu), ikmoon@pusan.ac.kr (I. Moon), halmea@postech.ac.kr (S. Oh), myjung@unist.ac.kr (M. Jung).

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etc., can be applied to align members' goals or profits in the supply chain. On the contrary, regarding the pursuit of global goals, the SC inventory policy tends to make decisions to optimize the entire inventory based on global performance criteria.

There are two different strategies for managing SC inventory including centralized and distributed (or decentralized) inventory control (Petrovic et al., 1999). Under centralized control, a central decision-maker determines the policy that minimizes the entire SC cost using a high degree of coordination and communication between the SC members. However, under distributed control, each SC member monitors the status of their own local inventory and places orders to their predecessors based on their own performance criteria. With the help of several incentive mechanisms, distributed inventory policies, which are adopted in most cases in SCs, can achieve performance levels almost as high as those realized through centralized policies.

Inventory management policies can also differ in terms of the manner of reviewing inventory levels. Under a periodic-review control policy, the inventory status is reviewed at every stage at a constant time interval. At each review, a replenishment order can be issued in order that the inventory status should meet the target level. In this case, the optimal quantity for replenishment, Q^*, has to be calculated. Under a continuous-review control policy, a replenishment order is issued when the inventory position at the considered stage falls below a predetermined level, i.e., the reorder point. In that case, a fixed quantity, Q, is ordered. A hybrid control policy may also be applied for inventory management. The most common is the (s, S) policy. Under this policy, if the inventory position falls below the reorder point s, an order is issued to raise the stock up to the target level S.

Inventory management policies are characterized based on the demand functions used. Most of the literature assumes that demand follows a certain probability distribution such as normal, Poisson, gamma, and so on. Some researchers use a linear demand function to simplify their models (Dong and Xu, 2002; Nachiappan and Jawahar, 2007). Even though demand is the most important factor for inventory control, it is very difficult to forecast the exact demand in advance. The lack of visibility of real demand can and does cause a number of problems in a SC if it is not properly designed; even then fluctuations cannot be completely eliminated. One of the easiest ways to prepare for such problems is to apply probability distributions or linear functions for demand expectation. However, progressively shorter product life cycles as well as growing innovation rates make demand extremely variable and the collection of statistics, that are required by stochastic models, less and less reliable (Blackburn, 1991).

Table 1
Main considerations affecting SCIM policies.

Considerations for SCIM	Exemplary choices
Nature of optimization	Local; global
Control type	Centralized; distributed
Nature of review of inventory levels	Periodic; continuous; hybrid
Type of demand function	Probability distribution; linear
Responsibility of inventory control	Self-managed; vendor-managed

Finally, inventory policies can be characterized based on the responsibility for inventory control. In traditional inventory control policies, each member is responsible for his own inventory control and production or distribution ordering activities. One fundamental characteristic and problem that all members in a traditional SC including retailers, distributors, and manufacturers must solve is just "how much to order the production system to make (or the suppliers to supply) to enable a SC echelon to satisfy its customers' demands." Each member strives to develop local strategies for optimizing her own organizational goals without considering the impact of her strategies on the performance of other members. Upstream members do not know actual demand information from the market place because no information is shared between members (see Fig. 1(a)). SC members use only replenishment orders placed by their immediate downstream member to create demand forecasts and inventory plans. In other words, each echelon in the SC has information only about what their immediate customers want and not on what the end customer wants. Each member of SC, therefore, replenishes her own inventory by considering her local inventory position.

In contrast to the traditional inventory control, many companies have been compelled to improve their SC operations by sharing demand and inventory information with their upstream and downstream members including customers (Disney and Towill, 2003a). Vendor managed inventory (VMI), also known as continuous replenishment, supplier-managed inventory, or consignment inventory, is a SC strategy where the vendor or supplier is given the responsibility of managing the customer's stock. VMI is one of the most widely discussed partnering initiatives for encouraging collaboration and information sharing between trading partners (Angulo et al., 2004). Under the VMI program, the retailer provides the vendor with access to its real-time inventory level through for instance POS (point of sale) data. The retailer may set a certain service level or spatial capacity for stocks, which are then taken into consideration by the vendor. Based on the information on retailers through POS systems for example, the vendor decides on the appropriate inventory level of each of the products and appropriate inventory policies to maintain those levels (see Fig. 1(b)). As a consequence, the retailer's role shifts from managing inventory to simply renting retail space (Simchi-Levi et al., 2003; Mishra and Raghunathan, 2004).

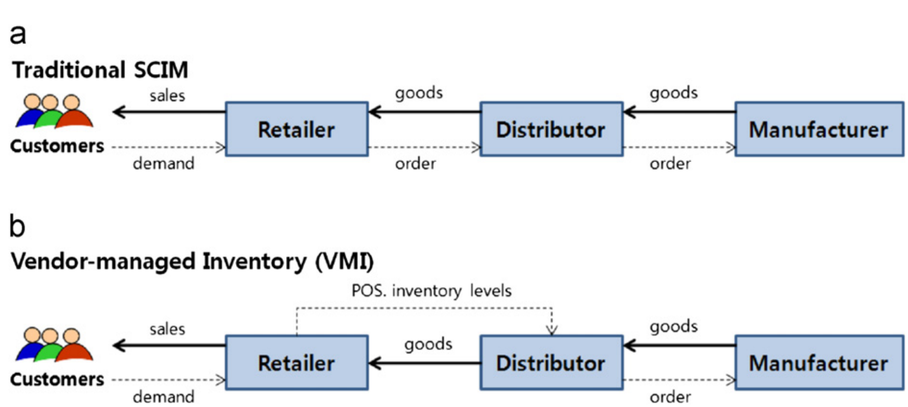

Fig. 1. SC structure under SCIM and VMI. (a) Material and information flow under traditional SCIM policy and (b) material and information flow under VMI policy.

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