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# The impact of demand variability and transshipment on vendor's distribution policies under vendor managed inventory strategy

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ABSTRACT

As demand variability is amplified through supply chains due to the bullwhip effect, the celebrated vendor managed inventory (VMI) strategy, in which the supplier manages the retailer's inventory, allows suppliers and retailers to significantly improve supply chain performance. Under the VMI environment, several appealing questions arise, such as how to determine vendor's optimal distribution policy with transshipment and how the variance of demand affects the optimal policy. These questions are studied in this paper. We explore a two-echelon supply chain with one supplier and two retailers in a planning horizon of two periods. The vendor of the supply chain distributes the product to the retailers at the beginning of the first period, and then adjusts retailers' inventory positions by transshipping the stocks of the retailers based on updated sales figures at the beginning of the second period. By employing transshipment in the supply chain, we prove that a unique optimal distribution policy exists for maximizing the overall expected profit of the supply chain, and that the transshipment deployment increases both retailers' and vendor's optimal expected profit and retailers' service level for customers. We also demonstrate that transshipment can reduce the mismatch between demand and supply. Furthermore, we show that demand variability and correlation among retailers play important roles on the vendor's optimal distribution policy.



## 1. Introduction

As demand variability is amplified from a downstream echelon to upstream echelons through the supply chain due to the bullwhip effect (Lee et al., 2004), it will inevitably lead to excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules (Lee et al., 1997b). Vendor managed inventory (VMI) has been demonstrated to be an effective way of reducing the bullwhip effect in real-world supply chains (Lee et al., 1997a). It becomes a very popular strategy for manufacturers such as Proctor and Gamble and retailers such as Wal-Mart, who have been practicing VMI for some time. In a VMI system, the vendor is responsible for the management of stock at the retailers. The retailers provide the vendor with access to its real-time inventory level. The replenishment decision, namely how much and how often to replenish, are made by the vendor. The retailers may set a certain service level and/or shelf space requirements that are taken into consideration by the vendor. In general, there are two forms of VMI, depending on whether there is a wholesale price between the vendor and the retailers. If the wholesale price exists, under this VMI environment, the vendor and retailers will try to maximize their own profits, which could lead to different or even opposite objectives (Yu et al., 2009a). Another emerging form of VMI is that the retailer's role shifts from managing inventory to simply renting retailing space to the vendor (Birendra and Srinivasan, 2004). The objective of this VMI partnership is to improve co-operatively the aggregate performance of the whole supply chain. The VMI environment studied in this paper belongs to this form. VMI permits the supply chain to exploit the economy of scale in the production and distribution process (Bernstein et al., 2006). Also, by centralizing the replenishment process, inventories can be managed on the basis of actual consumer demands. Indeed, Buzzell and Ortmeyer (1995) reported that the introduction of VMI partnerships at Dillard Department Stores, JCPenney, and Wal-Mart have resulted in sales increases from 20% to 25% and 30%, respectively. VMI is also believed to have resulted in lower retail prices (Nelson and Zimmerman, 2000).

At the same time, with demand uncertainty grows in the marketplace, transshipment is getting more and more popular in

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the supply chain under the VMI environment, especially for perishable goods. Recently, we have visited a diary products distributor in Chengdu which has a lot of difficulty in the dynamic allocation of its products amidst its retailing sites. Boxes of fresh milk are transported from a northern city to Chengdu and sold in a geographical network consisting of several sites, forming a typical co-operative VMI model. The lead-time of the transportation is fixed and is a constant. The milk is selling faster in some sites of Chengdu than others. However, all the fresh milk has a sell-by date indicating the last day milk should be sold by a store. Those unsold boxes of milk will be considered a total loss by the distributor. In view of this potential loss, the distributor monitors closely the sales figures in different sites dynamically during a selling season and will learn the customers' actual demand more precisely using the updated sales figures. Then, the distributor would be able to determine how to transfer the milk in a site with lagging sales to the other site at a cost in the middle of a selling season before the sell-by date so that more boxes of milk could be sold, creating less wastage. Clearly, many companies who sell short life products, such as fresh fruit juices, are facing a similar problem. Another good example is companies selling personal hand set (PHS) to the end-users in China. According to the report released by the Ministry of Information Industry of the People's Republic of China, the quantity sold is more than ninety million till May, 2007. How to distribute and sell the inventory wisely and timely before the end of the product cycle remains to be a difficult problem.

There is a rapid increase in the literature on transshipment models, which has begun with Krishnan and Rao (1965). They studied a general number of retailers with centralized control and independent demands, where transshipment could be made after observing demands. Recently, Dong and Rudi (2004) have extended the model of Krishnan and Rao (1965). They modeled a supply chain consisting of a manufacturer and $n$ retailers, where the retailers made a one-time purchase from the manufacturer before observing demands and could transship inventories among themselves after demands materialization. They studied how the transshipment affects manufacturers and retailers, considering both the manufacturer being a price taker and the manufacturer being a price setter in a single-period setup under multivariate normal demand distribution. Zhang (2005) extended Dong and Rudi's results further to general demand distributions, assuming all retailers have the same marginal demand distribution, where the stochastic comparison approach was adopted in their analysis. Wee and Dada (2005) developed a formal model that focused on the role of transshipment in a system of $n$-retailers and described the optimal transshipment policy. In their paper, it was assumed that some stock might be kept at a warehouse, a retailer who faced a stockout made an attempt to fill backorders by using a transshipment that might come either from the warehouse or from another retailer whose has excess stock. Herer et al. (2006) considered a supply chain which consisted of several retailers and one supplier. They proposed that the supply chain could be coordinated through replenishment strategies and transshipments, and the optimal replenishment policy for each retailer was an order-up-to S policy. Hu et al. (2007) considered a two-location production-inventory model with uncertain capacity, and addressed the question of whether centralized decisions could be achieved by setting linear transshipment prices. Their results indicated that a firm coordinating the production and transshipment between two locations is unlikely to achieve coordination in many instances by setting a linear transshipment price schedule. In previous studies, the role of competition between firms has not received much attention. Zhou et al. (2010) developed a two-location inventory model with transshipments in a competitive environment to investigate the impact of transshipments on their inventory replenishment decisions. Existing studies in the literature discussed transshipment in various aspects, but the effect of demand uncertainty on the vendor's optimal distribution policies together with transshipment under the VMI environment have not been addressed.

As for VMI, there is a rich literature. In recent work, Zhang et al. (2007) presented an integrated VMI model for a single vendor and multiple buyers, where the vendor purchased and processed raw materials and then delivered finished items to multiple buyers. They have developed a joint relevant cost model with constant production and demand rates based on the assumption that the buyers cycle times might be different and the vendor's production cycle was an integer multiple of each buyer's replenishment cycle. Yu et al. (2009a) considered a VMI system which consists of one vendor and multiple retailers, and discussed how the vendor can take advantage of the information that he obtained from his multiple retailers for maximizing his profit by using a Stackelberg game where the VMI partnership has been implemented. Yu et al. (2009b) discussed how a manufacturer and its retailers interacted with each other in order to optimize their individual net profits by adjusting advertising and pricing and inventory policies in an information-asymmetric VMI supply chain. They proposed a computational algorithm to solve this game model based on the theoretical analysis of the best response functions with a generic demand function. Yu and Huang (2010) discussed how a manufacturer and its retailers interact with each other to optimize their product marketing strategies, platform product configuration and inventory policies in a VMI supply chain. They also provided a good survey on the topic of VMI system. Previous researches have mainly studied the VMI supply chain from different views, but transshipment policy and its impacts have not been discussed.

In this paper, we consider a centralized two-echelon supply chain with one vendor and two retailers selling products with a short life cycle and facing stochastic demand. Because of long lead-time and short selling season, the vendor has only one chance to distribute goods to retailers before the demand is realized. The vendor has a chance to adjust the retailers' quantity of products by transshipping between the retailers as they learn more about the market information. For example, the vendor can transship products from the retailer with lagging sales to the retailer facing higher-than-expected demand.

The main contributions of this paper are to provide an explicit treatment and insight into the vendor's optimal distribution policy with transshipment under the VMI environment. We also discuss how transshipment and demand variability interact with the vendor's decision making. As multiple retailers have not been considered so far in the VMI environment, we provide a framework for the study of this supply chain with possibly correlated demands in the analysis, and discuss further the implications of demand distributions of retailers on the vendor's policy. We show that any correlation between demand distributions of retailers will impact on the vendor's optimal distribution policy with transshipment.

The remainder of this paper is organized as follows. The model formulation and assumptions are presented in Section 2. In Section 3, we establish the benchmark case where there is no transshipment between the retailers, and derive the vendor's optimal distribution policies as preliminaries for later discussions. Section 4 is devoted to discuss the case where the vendor has a chance to adjust retailers' inventories by transshipment between retailers during the selling season using the updated sales data. The impact of transshipment on vendor's optimal distribution policies, supply chain's optimal expected profit and retailers' service level with transshipment is compared with the case without transshipment. In Section 5, the effect of demand variability on the vender's optimal distribution policies with transshipment is discussed. Section 6 discusses the impact of demand correlation on the vendor's optimal distribution