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Warehouse capacity sharing via transshipment for an integrated two-echelon supply chain

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A B S T R A C T

Warehouse capacity constraint has been one obstacle to achieving the channel-wide optimal decision in inventory management. We studied an integrated inventory model consisting of a single vendor and multiple buyers with warehouse capacity sharing via transshipment. We proposed an optimal transshipment policy by developing nonlinear programming models and genetic algorithms as well as obtaining Karush-Kuhn-Tucker points. This inventory policy can significantly reduce the channel-wide cost and the performance is influenced by the consideration of fixed transshipment costs. Sensitivity analyses show that parameters have different impacts on the channel-wide cost and the performances of the algorithms.

1. Introduction

Warehouse capacity has been an important consideration that managers need to take into account to make optimal decisions in many industries. On one hand, extending warehouse capacity usually involves a long-run investment that is a strategic decision. Such investment would require a certain or predictable increment in demand for a long period. On the other hand, many supply chains have some certain peak time of demand in a short period due to short-term sales promotions or emergencies. Therefore, it would not be economical for those managers to invest for higher warehouse capacities which cannot be fully utilized in the long run. Moreover, it is usually not easy to rent warehouses for a short time, such as one month. There exist many studies on inventory system with tight warehouse capacity (refer to Wang et al., 2012; Fiestras-Janeiro et al., 2015), and delayed replenishment is considered as a solution to the single buyer case (refer to Lee and Wang, 2008; Yi and Sarker, 2013). For multi-buyer cases, we show that transshipment between warehouses of buyers could be an efficient approach to improving the supply chain performance. The following examples in China motivate our research.

Chinese on-line business companies conduct sales promotions under several periods in each year, such as the first week in October, the second week in November, and the month corresponding to spring festival, which are related to new or conventional festivals in China. Because demands during those periods are much higher than those at other time, warehouse capacities at many retailers are not sufficient. However, it is not easy for them to expand their warehouse capacities. First, building new warehouses may fail to be beneficial because each peak time may last for two or three weeks. Second, warehouse owners prefer long-term contracts (longer than one year) that make leasing warehouse capacity for a short time usually unavailable in

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China. Although some retailers may sell multiple types of products, it is still difficult for them to smooth out the utilization of the warehouses by scheduling the arrival of products because the demands are much higher than the warehouse capacities. In this case, the companies replenish products to retailers simultaneously in every cycle, and transship products between them to fully utilize warehouse capacities during the demand peaks which can reduce the ordering and replenishment costs.

The second example is from the medicine supply chains during the Severe Acute Respiratory Syndromes (SARS) disaster in China in 2003. The SARS lasted for about half a year when citizens generated high and specific demand for some Chinese traditional medicines. Because this demand was caused by emergency, supply chains could not extend warehouse capacities of retailers to satisfy the high demand. Therefore, transshipment between retailers was implemented to increase the utilization ratio of warehouse capacities of supply chains. In addition, the suppliers replenished retailers simultaneously in every cycle, to satisfy the constraints for long-distance transportation, including limited number of trucks and drivers.

In an integrated inventory system, the vendor can arbitrarily move the products from one buyer to another, which is known as transshipment between buyers. Transshipment can also be achieved under the vendor managed inventory (VMI) system, in which the vendor has the authority to conduct transshipment between buyers. The advantage of transshipment is twofold. First, under uncertain demands, transshipment between buyers can improve the customer service level, and it is popular in many industries, such as automobile and consumer goods (refer to Anupindi et al., 2001). In this case, transshipments transpire between a buyer with excess inventory and another with excess demand. To the best of our knowledge, most of existing studies on transshipment are motivated by this consideration. Second, under the transshipment policy, the vendor may improve the utilization ratio of the buyers' warehouse capacities by keeping products that exceed one buyer's warehouse capacity at other buyers' warehouses for a time. In this way, the vendor can move those products to that buyer at appropriate time points and benefit from this type of warehouse capacity sharing strategy. The above two examples reveal that this strategy has been implemented in the real world to improve the supply chain performance under some short-term selling seasons.

In this paper, we study a continuous review inventory model under integrated control and transshipment between buyers who have limited warehouse capacity. The vendor simultaneously replenishes buyer inventories by using ordinary deliveries with relatively long lead times; however, in a relatively short time, inventories can be moved from one buyer to another when inventory levels prompt buyers to reorder. Fig. 1 illustrates a supply chain model with transshipment between buyers.

In this paper, we propose a nonlinear programming model for a supply chain with warehouse capacity constraints under transshipment policies. We attempt to address the following three questions:

(a) Can warehouse capacity sharing with lateral transshipment (TRAN) lead to a lower channel-wide average cost than the integrated inventory model without transshipment (INT)?
(b) If it can, what is the reason for this advantage and how do channel parameters affect it?
(c) How do the fix transshipment costs affect the performance of the TRAN model?

Because the three research questions have been addressed rarely, we explain the contribution of our study to the existing literature by revealing the advantages of the TRAN model and the necessity for considering fixed transshipment costs during decision making. In addition, with respect to methodology, we develop an efficient algorithm to find the channel-wide optimal solution under any assignment of buyers for transshipment. For the algorithm, we propose an optimal transshipment

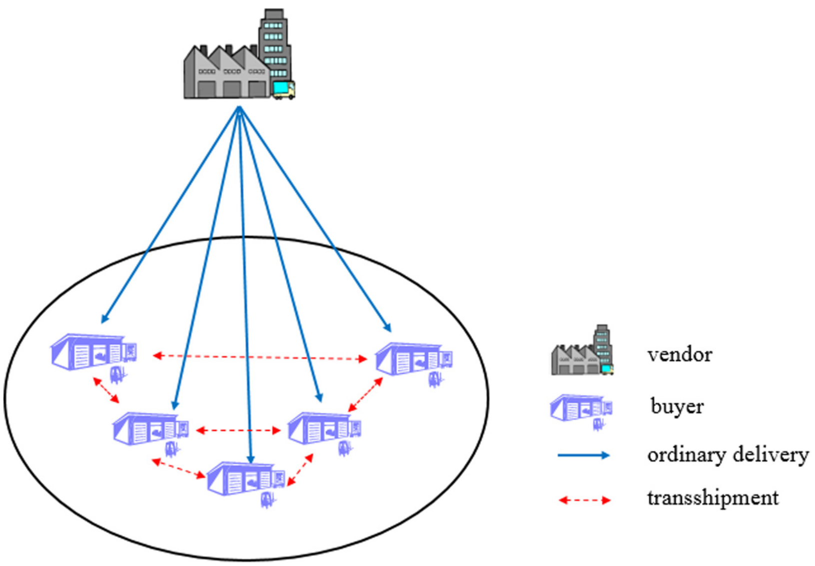

Fig. 1. Supply chain model with transshipment.