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Evaluation of two transshipment policies in a two-location decentralized inventory system under partial backordering

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ABSTRACT

This research investigates the replenishment and transshipment decisions in a two-retailer inventory system with a single selling season. Both emergency lateral transshipment (ELT) and preventive lateral transshipment (PLT) are investigated. ELT satisfies partial backordering. We prove the existence of unique Nash equilibrium for the system under each policy. The results show that the ELT solution is independent of the transshipment price while the PLT solution converges to the newsvendor solution as the transshipment price increases. Numerical analysis is presented to illustrate the advantage of each policy. This study assists retailers in deciding which transshipment policy should be preferred.

1. Introduction

Uncertainty in supply chain has posed a great challenge for managers. Many researchers have focused on inventory management to reduce risks and decrease system cost (Sarkar, 2013; Sarkar, 2016). Traditional design of inventory system is hierarchical, i.e. from the upper echelon to the lower echelon. On the contrary, lateral transshipment refers to the horizontal material flow within the same echelon of an inventory system (Zhao et al., 2016). It can rebalance the system inventory to improve customer service while reduce total cost. Lateral transshipment has received and continues to receive significant attention as an effective method to obtain more flexibility and responsiveness.

Lateral transshipment has been extensively applied in retail industries such as the apparel, sporting goods, and toys. Managers in the retail industry have been encouraging inventory sharing within a company to achieve better performances, for instance, Foot Locker (a shoe retailer) (Özdemir et al., 2006). On the other hand, owing to the availability of real-time data, transshipments also occur when retailers are not owned by a single firm or cannot be coordinated through a central agency. For instance, Rudi et al. (2001) carried out their research based on the transshipment problem between independent Norwegian distributors of Bosch. Many leading enterprises have been trying to participate in transshipment programs to improve competition.

Transshipment is classified into two types based on the execution time (Paterson et al., 2011, 2012), that is, *emergency lateral transshipment* (*ELT*) and *preventive lateral transshipment* (*PLT*). ELT is triggered at the end of the selling season when stock outs are observed. On the contrary, PLT is used to redistribute inventory at some point within the selling season to anticipate inventory imbalance. Traditionally, the studies on ELT and PLT are conducted separately within different inventory systems. For instance, Archibald et al. (2009, 1997) and Torabi et al. (2015) studied ELT problems while Banerjee et al. (2003, 2005) and Dan et al. (2016)

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focused on PLT problems in each inventory system. Due to the technology development, many firms have access to both transshipment policies. Multiple transshipments might perform better in certain circumstances. However, it needs more communication between retailers and higher handling cost. Since the transportation cost should be included in the total cost (Sarkar et al., 2016; Sarkar et al., 2017), multiple transshipments may lead to decrease in profit. Retailers in the industry prefer a single transshipment within one selling season to take advantage of operational simplicity (Tagaras and Vlachos, 2002). In this case, the manager should wisely weigh the advantages and disadvantages of each policy and choose the most economic one. For an inventory system with ELT, transshipment decisions are made after demand realization to fulfill unsatisfied demands. The handling costs for ELT are relatively high because a faster transportation mode is preferred to reduce customer-waiting time. On the other hand, for an inventory system with PLT, decisions are made before full demand realization to prevent future shortage. It faces the risk of deteriorating system performance because of demand uncertainty.

This research is motivated by observations in fashion industry, i.e. Shaanxi Lihe Trade Co. Ltd, a company that sells products of different brands, for instance Nike. As time becomes one of the crucial elements in competition, customers become impatient and less tolerant to backorders. Partial backordering is a common phenomenon in retail industry (Kim and Sarkar, 2017). It has an obvious effect on the performance of ELT because ELT is executed at the end of the selling season when stock outs are observed. The consideration of partial backordering provides a reasonable approach to evaluate the performance of ELT. On the contrary, partial backordering has little effect on the performance of PLT, which is executed within the selling season. PLT is applied primarily to prevent future stock out. The selling season is divided into two periods by the time when PLT occurs. The possibility of shortage is relatively small during and right after the first period. Therefore, it is acceptable not to consider partial backordering in the system with PLT to simplify the analytical derivation.

These two transshipment policies discussed above lead to some interesting questions. For instance, how should transshipment decisions be made under each policy? What is the optimal order choice if transshipment is considered? How should an appropriate transshipment policy be chosen for systems with different characteristics? This research devotes to answering these questions. We focus on a decentralized system with two retailers between which lateral transshipment may occur in order to improve the system performance. The model is cast in a newsvendor setting. Specifically, this research develops a model for two retailers placing their orders to cover stochastic demands over a single selling season. Both ELT and PLT are studied. We try to evaluate these two transshipment policies within a comparable framework. To the best of our knowledge, this is the first time to consider partial backordering in the system with ELT. The existence of a unique Nash equilibrium of the order quantity is shown for the system under each policy. Extensive numerical examples are provided to illustrate the advantages of each policy. The results show that the system with either policy is superior to that without transshipment. The ELT solution is independent of the transshipment price if it is set within a reasonable interval. The PLT solution converges to the newsvendor solution as the transshipment price increases. This work provides managers an analytical method to figure out a preferable transshipment policy for a specific system. The performance of each policy depends on the interrelationship of demand distribution, transfer point, customer patience and backorder cost.

The remainder of this paper is organized as follows: Section 2 reviews related studies on the field of transshipment. Section 3 provides the problem definition and notations. Section 4 develops three models and derives the optimal policy under each policy. Section 5 reports the computational results for each policy, compares their performances and provides the managerial insights. Section 6 presents some concluding remarks and extensions for future research.

2. Literature review

A significant number of studies have been conducted on transshipment models, beginning with Krishnan and Rao (1977), who studied a single-period multi-location inventory system with ELT. This study constructed a basic model framework for many following research, including the work by Tagaras (1989) and Herer and Rashit (1999). Archibald et al. (1997) analyzed a multi-period, periodic review model for a two-location inventory system. In this system, transshipment was allowed at any time when a shortage occurs. The problem was modeled as a Markov decision process to characterize the optimal transshipment policy. Archibald et al. (2009) extended this study to a multi-location case and developed an index heuristic for determining the optimal transshipment policies. A pairwise decomposition was applied to reduce the multi-location inventory system into different pairs of two-location problems. Wang and Ma (2015) developed an age-based model with preference-selection methods for blood transshipment decisions. The proposed policy was compared with a quantity-based policy. The sensitivity of the parameters was analyzed under operating scenarios with time-varying supply and demand. Olsson (2015) proposed a transshipment policy for a two-location inventory system with a positive transshipment lead time. A more sophisticated transshipment policy was constructed, the results of which show that it is worth the effort to reduce the transshipment lead time. Torabi et al. (2015) formulated an inventory problem in an e-tailing environment with complete pooling. A mixed-integer programming model was formulated and solved to minimize the logistical costs. Chou et al. (2014) studied a pickup and delivery routing problem with hub transshipment. Distinguished from other research, the objective of this study was to reduce both the workload and customer waiting time. Karsten et al. (2017) addressed a time constrained liner shipping network design problem allowing for an arbitrary number of transshipments.

The above research focuses on inventory systems with ELT under centralized control. Owing to the development of information technology, ELT has also been applied and investigated in decentralized systems. Rudi et al. (2001) examined the transshipment between two independent locations aiming to maximize their own profits. A unique set of transshipment prices exist that can lead to coordination. Hu et al. (2007) generalized the work of Rudi et al. by considering uncertain capacity during production. They proved that price coordination only exists for a specific range of problem parameters. Zhao et al. (2016) studied the inventory transshipment problem in an online-to-offline (OTO) supply chain. A unique Nash equilibrium of the order quantity was proven to exist in a