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Preventive transshipment decisions in a multi-location inventory system with dynamic approach

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ABSTRACT

This paper addresses the preventive transshipment problem in a multi-location inventory system. Decisions are made before demands are observed to prevent future stock out. Both lateral transshipments (LT) and emergency orders (EO) are available in this system. The objective is to figure out the timing and quantity of preventive transshipment decisions. A Markov decision process is formulated to describe the problem. First a decomposition method is used to divide the multi-location problem into different pairs of two-location problems. Then a sorting heuristics combined with backward dynamic programming (BDP) approach and approximate dynamic programming (ADP) approach is developed to solve this problem. Extensive numerical examples are used to demonstrate the effectiveness of this method. Results show that demand distribution at the retailer affects the way transshipment performs. In addition, product's perishability has obvious effects on transshipment decisions.

1. Introduction

Inventory management is a classical research area that devotes to reducing supply chain cost. Lots of efforts have been made by academics and practitioners to optimize the inventory system so as to reduce stock imbalance caused by unpredictable event. Traditionally, the design of inventory system is hierarchical, assuming material flows from one echelon to another, i.e. from supplier to retailer. What happens if horizontal material flow exists, i.e. from retailer to retailer? This leads to the field of *lateral transshipment* (*LT*). It refers to stock movement in the same echelon of an inventory system. The merit of LT lies in improving the performance of the inventory system by reallocating the procured stock. LT has competitive advantage over no pooling case, and it is proved to be an effective way to improve customer service level (Gao, Niu, & Wang, 2011; Paterson, Kiesmüller, Teunter, & Glazebrook, 2011; Tagaras, 1989). The main constraints of LT are the associated transportation and administration costs for re-distributing items. Potential benefits and extra expenses should be trade off by managers to improve system performance.

The development of information technology has made the access to real time data easier and information sharing more realistic. Therefore, lateral transshipment is increasingly prevalent as an approach to effectively manage inventory in realistic industry. Scenarios of particular interest to this research include sporting goods and cosmetics where customer satisfaction is a principal element. Retailers have to decide when and how much to transfer stock to bring more benefit for the system. For example, Foot Locker (a shoes retailer) has been encouraging inventory sharing among retailers in the company (Özdemir, Yücesan, & Herer, 2006). Due to the availability of real time data, this research devotes to solving a preventive transshipment problem in a centralized multi-location system.

Substantial literatures are available on LT in academic world. Two main types can be identified based on the timing of LT: *emergency transshipment* and *preventive transshipment*. Emergency transshipment is performed after a stock out is observed when demands are fully realized. A common assumption in this type of research is instantaneous transshipment or unsatisfied demands are backlogged. On the other hand, preventive transshipment relaxes these constraints and decisions are made before demands are fully realized. Preventive transshipment decisions are more complicated due to the interrelationships between transshipment quantity and uncertain residual demands. There are fewer literatures on preventive transshipment than on emergency transshipment. Since this research focuses on preventive transshipment, only the most related literatures are reviewed. Readers could refer to Paterson et al. (2011) for a comprehensive review on LT.

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Preventive lateral transshipment is first introduced by Gross (1963). He optimizes both ordering and redistribution decisions at the beginning of the review period in a two location system. Transshipment lead time is assumed to be negligible. Das (1975) further extends this idea by allowing the redistribution decisions to take place at predetermined times within the replenishment cycle. Jönsson and Silver (1987) allow complete redistribution of all branch warehouse inventories one period before the end of the order cycle. They consider transshipment lead time in the model. The objective is to obtain the best service level in the remaining order cycle. Tagaras and Vlachos (2002) concentrate on understanding the performance of pooling groups with nonnegligible transshipment times. Transshipment is arranged once at a predetermined time near the end of the review cycle. It is concluded that the shape and variability of demand distribution are key parameters for an appropriate transshipment policy.

Banerjee, Burton, and Banerjee (2003) propose two lateral transshipment policies in a two-echelon network: Lateral transshipments based on availability (TBA) policy and lateral transshipments for inventory equalization (TIE) policy. For both policies, the transshipment activity can be triggered if the inventory position falls at or below "the lateral transshipment order point". But they do not consider costs when making transshipment decisions. Based on results of this study, Burton and Banerjee (2005) examine the relative effectiveness of these two transshipment approaches with different cost structures. They conclude that the inventory system with transshipment is always superior to that of no transshipment case. Lee, Jung, and Jeon (2007) propose a new lateral transshipment policy denoted as service level adjustment (SLA) that integrates emergency lateral transshipment and preventive lateral transshipment. The service level in the remaining period (SLRP) is used in the SLA policy. The simulation experiments show that SLA is more effective than TBA, TIE policies when the transportation unit cost is low.

Some other researchers propose effective strategies to achieve coordination in decentralized system with transshipment. Li, Sun, and Gao (2013) analyze a two stage inventory model with preventive transshipment in a decentralized system. They present a bidirectional revenue sharing contract that coordinate the system. The authors also investigate the effects of preventive transshipment on ordering quantities. Dan, He, Zheng, and Liu (2016) develop a framework on preventive transshipment for an inventory system consisting of one manufacture and two retailers. A two-period ordering and pricing model with preventive transshipment and conditional return is formulated. Given a simple transshipment policy, the optimal ordering and pricing policy are identified.

Most former researches apply simulation approaches to overcome complexity of inventory problems with preventive transshipment. Various preventive transshipment policies have been designed for different inventory systems. However, these researches consider relatively simple problem structures and do not capture the full complexity of transshipment decisions. This has limited the practical usefulness of these researches. This research tries to make up for the deficiency of existing researches to some extent. It devotes to solving a preventive transshipment problem in a multi-location inventory system. Rather than giving out some simple rules, this paper applies a dynamic programming approach that could take advantage of real time data in making decisions. We are unaware of any paper dealing with preventive transshipment problems in a multi-location inventory system with dynamic programming approach. Moreover, both emergency order (EO) from suppliers of the upper echelon and lateral transshipment (LT) from retailers of the same echelon are considered as an approach to prevent future stock out. Decisions are made dynamically in each decision period to maximize the profit in remaining periods. To better reflect realistic cost structure, implementation of EO/LT will incur a fixed cost and unit variable cost. At the end of the decision cycle, there will be a goodwill loss for unsatisfied demands and a salvage value for unsold products.

In this problem, transshipment decisions are made before demands in the remaining periods are observed. Retailers need to decide the optimal quantity and timing for transshipment to maximize total profit. A Markov decision process is formulated to describe the problem. This research first develops a decomposition method to decompose the multi-location problem into pairs of two-location problems to reduce computational complexity. Then a sorting heuristic combined with dynamic programming approach is proposed to solve the two-location problem. Numerical instances are executed to give some management insights and implications for practical industry.

The paper is organized as follows. Section 2 presents problem description and model formulation. Section 3 is devoted to developing solution methods for the proposed model. In Section 4, numerical examples are presented to illustrate the advantage of the dynamic transshipment approach. The effectiveness of the proposed algorithm for solving large sized problems is also illustrated. Section 5 gives out the concluding remarks.

2. Model development

2.1. Problem description and notations

This research is conducted based on a centralized inventory system composed of one central warehouse and multiple retailers. The centralized decision maker has full access to the stock status over the system. The inventory framework is illustrated in Fig. 1. Solid lines represent normal replenishment at the beginning of the review period while dashed lines refer to LT within the same echelon or EO from warehouse to retailer.

This system applies a base stock replenishment policy without fixed replenishment cost (Archibald, Black, & Glazebrook, 2009; Tagaras & Cohen, 1992). Each retailer places an order to bring their inventory to a base stock level ord_i at the beginning of each replenishment cycle. The length of the review cycle is predetermined by fully considering the system characteristics. Demands are identically and independently distributed (iid) in each location. Unsatisfied demands are assumed to be lost due to product homogeneity in the market. Generally, retail stores are not open 24 h per day, so that the replenishment and transshipment could be completed during the time when they are closed. Thus replenishment lead time as well as the EO/LT lead time is negligible.

To facilitate decision-making, one review cycle is sub-divided into T decision-making time periods. To avoid confusion, the notation "cycle" is used to denote the time span between two

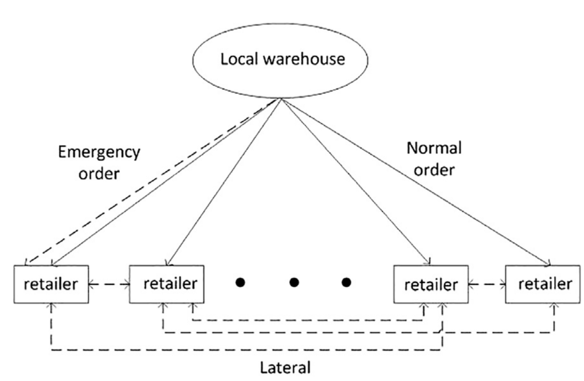

Fig. 1. The inventory system with transshipment.