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Service parts inventory control with lateral transshipment and pipeline stock flexibility

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ABSTRACT

In equipment-intensive industries such as truck, electronics, aircraft and dredging vessel manufacturing, service parts are often slow moving items for which the transshipment time is not negligible. However, this aspect is hardly considered in the existing service logistics literature. In this paper, we consider this aspect and propose a customer-oriented service measure which takes into account pipeline stock and lateral transshipment flexibility. We provide an approximation method for optimizing the stock allocation subject to this service measure. Via extensive numerical experiments, we show that our approximation performs very well with respect to both system performance and costs. Moreover, our numerical experiments indicate that including lateral transshipments and pipeline stock flexibility in inventory decisions is more beneficial than lateral transshipments alone. This effect is larger for high demand rates and high lateral transshipment costs. Results from a case study in the dredging industry confirm our findings. We therefore recommend introduction of pipeline stock information such as the track and trace information from freight carriers in existing ERP systems.

1. Introduction

Research on service parts inventory control with lateral transshipments has been motivated by needs from various industries, including equipment-intensive industries such as truck, electronics, aircraft and dredging vessel manufacturing. Facing stochastic demand of critical service parts, a multi-location inventory control system often allows movement of stock between locations at the same echelon level or even across different levels in order to fulfil customers' demand in time. Many of these critical service parts are slow moving and heavy items for which, in some cases, air transport is impossible or prohibitively expensive. For example, in dredging industry, critical service parts usually weigh more than 1700 kg and therefore are way too costly to transport by air. The lateral transshipment time for these items can be longer than 3 weeks, and is not negligible compared to lead times (around 7 weeks).

Moreover, if transportation is slow, there may be considerable amounts of pipeline stock being transported between a production plant and local bases. In some cases, the average pipeline stock can be up to half of the average stock on hand. In these cases, it may be more profitable to wait till the pipeline stock arrives than to order via lateral transshipments. As a result, the timing of transshipments and normal replenishments becomes an important factor in decision making. To the best of our knowledge, this aspect is not much considered in the existing service parts literature.

Good customer-oriented performance measures are also lacking in the literature. The standard service levels, such as fill rates, are supplier-oriented; whereas customers only observe deliveries with no delays and deliveries within a certain response time in case of delays. Some studies (Kutanoglu and Mahajan, 2009) introduce more customer-oriented service levels by distinguishing the availability of items from different sources with different response times. However, since these studies ignore the fact that the pipeline stocks may arrive and be delivered to customers sooner than other emergency shipments, they still emphasize the operational processes of service suppliers.

Inventory sharing by lateral transshipments between local bases makes stock more valuable as the stock may be used by different bases. The benefits are clear when there is an agreement with a customer on the response time and lateral transshipment times are negligible. On the other hand, if transshipment times are not negligible, lateral transshipments could be detrimental for service levels, as products spend more time in transportation before reaching customers. Hence, the total system cost may be higher in this case due to higher requirements of base stocks.

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1.1. Statement of contribution

The contribution of this paper is as follows: First, we propose a customer-oriented performance measure where both pipeline stock and lateral transshipment flexibility contribute to service performance. Second, we provide an approximation method for optimizing stock levels subject to this measure. The quality of this approximation and the benefits of lateral transshipment and pipeline stock flexibility are assessed via extensive numerical experiments. Based on these experiments, we find that the use of pipeline stock information improves the performance and costs of systems with lateral transshipments. We conclude that including lateral transshipment and pipeline stock flexibility in inventory decisions is more beneficial than lateral transshipments alone. Subsequently, we apply our method in a case study from dredging industry and confirm our findings in practice. Finally, we offer managerial insights on the lateral transshipment decisions when the transshipment time is non-negligible.

The paper is organized as the following. In Section 2, we review the inventory control literature on lateral transshipments. In Section 3 we present the inventory model. In Sections 4 and 5, we give an approximation for the customer-oriented service measure in the context of a single-echelon inventory system with and without lateral transshipments between the local bases. In Section 6 we minimize the average inventory cost subject to service level constraints. We validate our methods and we assess the benefits of lateral transshipment and pipeline stock flexibility via extensive numerical experiments in Section 7. In Section 8, we apply our method in a case study for a global market leader in the dredging industry. In the last part, we draw our conclusion and offer managerial insights.

2. Literature review

In the past decades, a considerable amount of research has been dedicated to service parts inventory control with lateral transshipments. Paterson et al. (2011) provide an extensive literature review on lateral transshipments. Based on the timing of transshipments, they categorize the research into proactive and reactive transshipments. The research on reactive transshipments is divided into two categories: one with centralized systems, the other with decentralized systems. Most models with centralized systems (Lee, 1987; Axsäter, 1990; Alfredsson and Verrijdt, 1999; Diks and De Kok, 1996; Banerjee et al., 2003; Burton and Banerjee, 2005) assume that transshipment times are negligible, and find that lateral transshipments improve the system performance.

In Lee (1987), a two echelon inventory system with continuous review base stock policy, identical bases and negligible transshipment times is analyzed. Demand occurs when there is a failure of a critical part, and is assumed to follow a Poisson process. Failed parts are replaced by stock on hand or lateral transshipments in case of a stock-out. The portion of demand met by stock on hand and the portion of demand met by lateral transshipments are evaluated based on three selection rules for the source base: random selection, maximum stock on hand, and smallest number of outstanding orders. No significant difference in the performance of the three rules is found. The paper concludes that lateral transshipments lead to substantial cost savings because less base stocks are needed at the bases.

Axsäter (1990) relaxes the restrictive assumption of identical bases and presents improved methods for approximating service levels. Alfredsson and Verrijdt (1999) extend Axsäter's model by allowing emergency shipments from a central warehouse and emergency shipments from a manufacturing facility such that no demand is back-ordered. They find that using both lateral transshipment and direct shipment flexibility results in significant cost reductions compared to using no supply flexibility at all. Simulation studies with negligible transshipment time, conducted by Banerjee et al. (2003) and Burton and Banerjee (2005), show that a policy with lateral transshipments is superior to one without lateral transshipments if the benefits of avoiding retail level shortages outweigh the additional delivery costs resulting from transshipments.

On the other hand, some of the relatively few recent studies (Grahovac and Chakravarty, 2001; Tagaras and Vlachos, 2002; Wong et al., 2005; Kutanoglu and Mahajan, 2009) consider non-negligible lateral transshipment times in their models.

Grahovac and Chakravarty (2001) study the benefits of lateral transshipments by comparing overall transportation, inventory holding, and customer waiting time costs in cases with transshipments and without lateral transshipments. They extend the model in Axsäter (1990) by assuming non-negligible transportation times, which are identical for emergency lateral transshipments between retailers and direct emergency orders from the distribution center. They find that, in a centralized supply chain, lateral transshipments often reduce the overall costs. They explain that lateral transshipments make "front-line" inventories more valuable, leading to stock levels larger or equal to the levels without lateral transshipments at retailers. On the other hand, lateral transshipments make inventory at the distribution center less valuable, leading to a stock level smaller or equal to the level without lateral transshipments. These two opposite trends may lead to higher stock levels in the system with lateral transshipments than without lateral transshipments.

To investigate the operational characteristics of lateral transshipments, Tagaras and Vlachos (2002) conduct extensive experiments with 5 demand distributions and non-negligible lateral transshipment times, and conclude that the benefits of risk pooling are substantial only when demand is highly variable. Moreover, they find that the effectiveness of lateral transshipments is superior for identical bases in a pooling group. This is even more pronounced when the lead times are relatively long and the demand is more variable.

Wong et al. (2005) study repairable service parts pooling in a multi-hub system for the airline industry. They include delayed lateral transshipments in their system performance approximation and optimal service parts stocking level determination. Regarding the choice of the source for lateral transshipments, they use the closest neighbour rule as it is more acceptable in practice than the random selection rule used by Axsäter (1990) and Alfredsson and Verrijdt (1999). They find that significant cost savings can be achieved by pooling the service parts inventories via lateral transshipments.

Kutanoglu and Mahajan (2009) point out that the most commonly used service measure, the fill rate, does not capture the time necessary to satisfy the demand. They introduce a time-based service level, i.e., the proportion of total demand satisfied within a specified time window. However, these service levels ignore the pipeline stocks that may arrive and be delivered to customers sooner than lateral transshipment from other local warehouses. The authors find the optimal stock levels subject to the time based service level constraint by enumerating over all possible stock profiles (stock levels across all local warehouses). They also conclude that lateral transshipments improve the inventory system performance.

The use of pipeline stock information has not been studied much in the literature. Axsäter (2003) designed a heuristic decision rule for lateral transshipments that takes into account the remaining delivery time of outstanding orders. He assumes that each base follows an (R, Q) inventory policy and lateral transshipment times are negligible. In this paper, bases follow a