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A heuristic for balancing the inventory level of different locations through lateral shipments

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ABSTRACT

Solving transshipment problems to optimality is difficult, unless several simplifying hypotheses are assumed (such as unit-sized customer demands and replenishments, negligible replenishment lead time, etc.). For this reason, some heuristics have been recently proposed in order to provide rules, which incorporate relevant factors of the problem, to find conditions under which it makes sense to transship a certain number of units from one retailer to another. Most of these studies concern emergency transshipment, which means that shipments between locations can occur only when a shortage happens, and shipments are assumed to be fast enough to satisfy the location in shortage. When this assumption is not feasible, as in many real cases, transshipments between locations have to be performed before a shortage happens. The paper addresses this case, which can be named 'preventive' transshipment, where the inventory level of different locations at the same echelon is balanced through lateral shipments, before a shortage happens. A heuristic for deciding on transshipment policy (when to transship and how much), trying to minimise overall expected costs, is presented. A simulation study considering different scenarios is performed and results confirm the effectiveness of the heuristic.

1. Introduction and literary review

Lateral transshipment has been studied recently as a promising policy for increasing the performances of multi-echelon inventory system (Olsson, 2009; Lee et al., 2007; Wong et al., 2005; Minner and Silver, 2005). By lateral transshipment units can be moved from one location with excess inventory to another location, at the same echelon, in shortage, with the aim of pooling inventory, reducing lost sales and the connected stockout costs.

Numerous researchers have developed analytical models to examine inventory pooling between locations. Their works can be divided into two main streams: those dealing with spare parts and those dealing with final products or consumable items. The great part of the literature about spare parts consists of studies on repairable or recoverable items. The main stream of these studies starts by the well-known METRIC model of Sherbrooke (1968). In this model, one-for-one stock replenishments, i.e. unit-sized customer demands and replenishments, are considered; this assumption is justified when we deal with repairable slow-moving and expensive items, as in Axsäter (1990), Grahovac and Chakravarty (2001), Lee (1987) and Wong et al. (2005).

As far as final products are concerned, transshipment policies are inserted in classical continuous review, order point-order quantity policies, such as Axsäter (2003), Evers (2001), Minner and Silver (2005), Needham and Evers (1998), Olsson (2009) and Xu et al. (2003) and periodic review replenishment policies, such as Archibald et al. (1997), Cohen et al. (1986), Herer et al. (2002), Karmarkar (1987), Robinson (1990), Rudi et al. (2001), Tagaras (1989, 1999) and Tagaras and Cohen (1992). Usually models consider centralized systems in which retailers are coordinated by a central planner and in which individual retailers do not have the ability to make decisions about whether or not to share their inventory. Zhao and Deshpande (2005) consider a decentralized system in which the independent retailers make their own inventory-stocking and inventory-sharing decisions based on their own objectives.

Most of the above mentioned studies concern *emergency* transshipment, which means that shipments between locations can occur only when a shortage happens. In this case shipments are usually assumed to be fast enough to satisfy the location in shortage. From another view, shipments can be used to balance the inventory level of different locations at the same echelon before that a shortage happens (Banerjee et al., 2003; Bertrand and Bookbinder, 1998; Diks and De Kok, 1996; Jönsson and Silver, 1987). We call this latter situation *preventive* transshipment. Thus, emergency transshipment responds to stockout while preventive transshipment reduces the risk of future stockout (Lee et al., 2007).

Costs can decrease and service can improve, if lateral transshipments are used in emergencies (Silver et al., 1998). In effect, because emergency transshipment can be performed after

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a stockout happens, the saving associated to the avoided lost sale is certain, and can be compared to the cost of the emergency shipment. If, on the other hand, transhipments are used in anticipation of stock imbalances among retailers, costs can go up due to excessive unnecessary movement of product (Banerjee et al., 2003; Diks and De Kok, 1996; Jönsson and Silver, 1987; Silver et al., 1998), because it is not certain that an item transhipped from one retailer to another will be utilized to avoid a future stockout.

Solving transshipment problems to optimality is difficult, unless several simplifying hypotheses are assumed (such as, as above mentioned, unit-sized customer demands and replenishments, identical or limited number of retailers, negligible replenishment lead time, etc.). For this reason, some heuristics have been recently proposed in order to provide rules, which incorporate relevant factors of the problem, to find conditions under which it makes sense to transship a certain number of units shortages from one retailer to another. Examples are Banerjee et al. (2003), Burton and Banerjee (2005), Evers (2001), Lee et al. (2007), Minner et al. (2003) and Minner and Silver (2005).

Banerjee et al. (2003) introduce two preventive lateral transshipment policies, namely TBA (transshipment based on availability) and TIE (transshipment based on inventory equalization) in a periodic review policy. For both policies, the transshipment activity in a review cycle can be triggered, at the end of a day, if the inventory position of one retail location falls at or below its "lateral transshipment order point". If this happens, TBA redistributes stocks from locations where the available inventory levels are above their respective expected stock levels to locations with less than expected stock levels; TIE redistributes stocks among retailers such that all locations will have an equal number of days' supply. The lateral transshipment order point is fixed for each location and equal to the average daily demand. The approach does not directly consider costs in order to take decision on when, and how much, to transship. The impact of the two policies on costs can only be analysed ex-post, for example, by conducting a cost-parametric study (Burton and Banerjee, 2005).

In a recent paper Lee et al. (2007) proposed a service level adjustment (SLA) approach that uses both emergency and preventive transshipments to respond to stockout risks. Differently from the TBA policy, retailers with excess inventory (eligible to send items) and in shortage (eligible to receive items) are not selected on the basis of their respective expected stock levels, but on the basis of their service level on the remaining period (SLRP). The SLRP indicates the probability that stockout will not occur before the next arrival from the central depot. The simulation experiments showed that SLA can be more effective than TIE, TBA and NLS (no lateral shipments) policies. However, like every policy based on a service level approach, it does not directly consider costs. Thus, for example, under increasing transportation unit cost between retailers SLA may not be a good policy (Lee et al., 2007).

Heuristics in which costs have been considered to decide when and how much to transship have been proposed by Evers (2001) and Minner et al. (2003). Their studies concern emergency lateral transshipment, continuous review policy, and consider carrying, replenishment and lost sales costs, as well as transportation costs associated to transshipment. Minner et al. (2003) observed that choosing the better of two extreme policies (no lateral shipments, ship all available items) leads to performance that is nearly as good as a more complex analysis that takes account of the future impact of a transshipment on the cost at the location sending the shipment. Minner and Silver (2005) developed, for the case of two stocking points, an analytical approach for approximately estimating the total expected costs of these two policies. This provides a mechanism for choosing between the two policies for any given set of problem characteristics.

In our study, we extend the heuristic presented in Minner et al. (2003) to the preventive transshipment case. The main difference between the two cases is that in the emergency transshipment case the items sent to the receiving retailer are immediately used to meet unsatisfied demand. Thus, the impact of a transshipment on the receiving retailer is straightforwardly represented by a saving equal to the product between the avoided lost sales and the unit stockout cost. On the contrary, in the preventive case, transshipments can be done only before a shortage happens, and the lost sales reduction, due to the receipt of a certain number of items, can only be estimated. This extra complexity makes the investigation on preventive transshipment policies through analytical approaches very hard to perform.

In summary, the aim of the work is to present a new heuristic, named preventive transshipment heuristic (PTH), which, trying to minimise total expected costs by preventing future stockouts, provides rules to decide when and how much to transship among retailers.

The paper is organized as follows. In Section 2 the main assumptions of the model are stated. In Section 3, the replenishment policy through which retailers are supplied by the central depot is discussed, and the design criteria to calculate the parameters of the policy are indicated. In Section 4, the PTH is presented. In Section 5 the simulation study that has been performed to test the heuristic is described and results are also presented. In Section 6 possible extensions to the actual model are proposed. In Section 7 conclusions are drawn.

2. Assumptions and notation

The model consider a supply chain constituted by two retailers which face final customers' demand and one central depot that supplies the two retailers. The following assumptions are made:

i. Each retailer faces a random demand, with average annual value equal to D. Demand process is stationary.
ii. Physical stock is subject to inventory holding costs h per unit and unit of time.
iii. Backorders are not allowed, that is, when demand cannot be satisfied is lost, with an associated cost per stockout unit equal to B.
iv. There is a cost associated to each replenishment order from the central depot equal to A.
v. Each retailer operates through a can order policy (R, s, S), with review period $R=1$ day, reorder point s, order-up-to level S (see Section 3 on how s and S are determined).
vi. The inventory position I is checked at the end of each day: if I is at or below s, the retailer places an order to the central depot for a quantity $Q=S-I$. The ordered quantity arrives to the retailer after a fixed and deterministic lead time equal to L.
vii. We assume that x_L (demand during lead time) is normally distributed. Note that also in case that the daily demand is not normal, the normal will generally be a good approximation for lead time demand if the lead time is at least several days in duration, for the central limit theorem (Silver et al., 1998).
viii. At the end of each day, after each retailer has placed, if necessary, a replenishment order to the central depot, the possibility to transship a quantity q of items from one retailer to the other is evaluated (see Section 4).
ix. The transportation cost associated to the transshipment of q units is expressible as the sum of a fixed component c_1 and a variable component c_2q.