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Invited Review

Inventory models with lateral transshipments: A review

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ABSTRACT

Lateral transshipments within an inventory system are stock movements between locations of the same echelon. These transshipments can be conducted periodically at predetermined points in time to proactively redistribute stock, or they can be used reactively as a method of meeting demand which cannot be satisfied from stock on hand. The elements of an inventory system considered, e.g. size, cost structures and service level definition, all influence the best method of transshipping. Models of many different systems have been considered. This paper provides a literature review which categorizes the research to date on lateral transshipments, so that these differences can be understood and gaps within the literature can be identified.

1. Introduction

Inventory systems often account for a large proportion of a business' costs. This makes it crucial to manage them efficiently. The 'traditional' design of an inventory system is hierarchical, with transportation flows from one echelon to the next, i.e. from manufacturers to wholesalers and from wholesalers to retailers. More flexible systems also allow *lateral transshipments* within an echelon, i.e. between wholesalers or retailers. In this way, members of the same echelon *pool* their inventories, which can allow them to lower inventory levels and costs whilst still achieving the required service levels.

Two main strands of literature on lateral transshipments can be identified that differ in the timing of transshipments. Lateral transshipments can either be restricted to take place at predetermined times before all demand is realized, or they can take place at any time to respond to stockouts or potential stockouts. We will refer to these two types as *proactive transshipment* and *reactive transshipment*. In proactive transshipment models, lateral transshipments are used to redistribute stock amongst all stocking points in an echelon at predetermined moments in time. This can be arranged in advance and organized such that the handling costs are as low as possible. Since handling costs are often dominant in the retail sector, this type of lateral transshipment is most useful in that environment. Reactive transshipments respond to situations where one of the stocking points faces a stock out (or the risk of a stock out) while another has sufficient stock on hand. This kind of lateral transshipment is suitable in an environment where the transshipment costs are relatively low compared to the costs associated with holding large amounts of stock and with failing to meet demands immediately. This is often the case in a spare parts environment. For example, Kranenburg (2006) discusses a semi-conductor company ASML with such a cost profile, and shows that using lateral transshipments can save the company up to 50% of annual inventory related costs for spare parts.

Lateral transshipments are graphically illustrated in Fig. 1 for a simple inventory system with a single central warehouse (echelon 1) that supplies a number of stock points (echelon 2) between which lateral transshipments are allowed. Each bold arrow represents a possible transshipment route.

Note from Fig. 1 that lateral transshipments must take place between stock points of the same echelon. Both the transshipment of actual products and the transshipment of demand, where demand is directly satisfied from a different location, are considered in the literature and included in this review. Literature on multi-echelon distribution networks where items in the replenishment pipeline are reallocated before the items physically arrive at the location are excluded from this review. Contributions on emergency shipments from a different echelon or outside supplier are also excluded, unless there are lateral transshipments as well. We remark that these excluded types are sometimes referred to as transshipments in the literature. Also, many alternative terms have been used to describe lateral transshipments, such as lateral resupply, reallocation of stock, substitutions and stock transfers.

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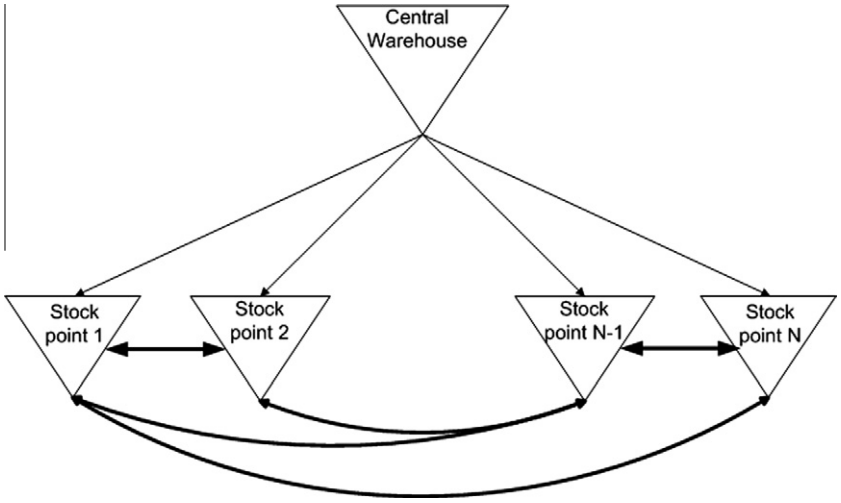

Fig. 1. Lateral transshipments.

Obviously, the added flexibility of allowing lateral transshipments implies that an inventory system is more difficult to control and optimize. Besides deciding when and how much to order from the 'regular' supplier, decisions on when, how much, and from where to transship are needed. Because of this added complexity, the literature is mainly restricted to systems with two echelons similar to the one depicted in Fig. 1, and some contributions limit the system further by not considering the central warehouse and/or allowing only a limited number of stocking points in the second echelon.

Nevertheless, optimal control of lateral transshipments has been researched in many different settings. As already mentioned, some authors consider a single echelon whereas others consider two. Models also differ in the number of stocking locations, types of ordering, and so on. One key feature is whether a transshipment policy is using *complete pooling* or *partial pooling*. The former is a general term attached to policies where the transshipping location is willing to share all of its stock, the latter is used when part of the stock is held back to cover future demand. In the next section, we will provide a list of characteristics, and corresponding tables that can be used to quickly compare the various contributions to the literature. This is followed by a detailed review of the contributions over a number of sections. The organization of those sections will be clarified at the end of the next section, after discussing the key characteristics. In the final section, we end with conclusions and identify opportunities for future research.

2. Classification

As discussed in the previous section, an important distinction is the one between proactive transshipments that occur at fixed points in time and reactive transshipments that can happen at any time. The contributions to the literature are further classified by a number of characteristics related to the inventory system, the ordering policy and to the modeling of transshipments in particular. These characteristics are listed in Table 1, with the type of transshipment as proactive or reactive included for completeness.

In Tables 2–4, we use these characteristics to compare the different models that have been analyzed with proactive transshipments, reactive transshipments under periodic order review and reactive transshipments under continuous order review, respectively. The contributions are listed in alphabetical order based on the first author's name (and in increasing order based on the year of publication for multiple contributions by the same first author).

Table 1
Key characteristics for classifying the literature, related to the inventory system, ordering and transshipments.

Number of items	1, 2 or any number M
Number of echelons	1, 2 or P
Number of locations (Depots)	2, 3 or any number N
Identical locations?	Yes, (identical) costs or no
Unsatisfied demands	Backorder or lost sales
Timing of regular orders	Continuous review or periodic review
Order policy	(R,Q), (s,S), $(S-1,S)$, General or Other
Type of transshipments	Proactive or reactive
Pooling	Complete or partial
Decision making	Centralized or decentralized
Transshipment cost structure	Per item, per transshipment, both or none

The organization of the remainder of this paper is based on the characteristics listed in Table 1, and is also in line with Tables 2–4. We first review proactive lateral transshipments, then consider reactive transshipments under periodic review ordering, and end with reactive transshipments under continuous review ordering. There are additional subdivisions based on the characteristics that are most relevant for these three types of models. These divisions and subdivisions are shown in Table 5.

3. Proactive lateral transshipments

In periodic review replenishment models, the start or end (or some other point) of an order period provide 'natural' opportunities for redistributing the stock over all locations. This explains why, to the best of our knowledge, all research on proactive lateral transshipments is done in a periodic review setting.

Some authors have analyzed redistribution in isolation as a first step towards understanding its effect. We will discuss their contributions first, before continuing with studies on more complex situations, where redistribution is considered alongside replenishment decisions.

3.1. Standalone redistribution

Articles which study redistribution on its own either ignore ordering completely or assume a specific ordering policy with arbitrarily chosen parameters values. The research in this area has established ideas on when it is best to redistribute and whether acting proactively is beneficial.