A multi-agent framework for coordinating pooled inventories in distribution systems

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Competitive distribution of goods to customers or other businesses requires a cost effective provision of certain service targets. There exists a variety of distribution strategies. This paper deals with a strategy that aims to achieve cooperation benefits by transshipments. In distribution inventory systems, goods are supplied to a central warehouse and then allocated and shipped to local warehouses or retailers, or, in a decentralized system, directly shipped to stocking points without passing through a central depot. The overall problem of inventory management then is to find target inventory levels for all stocking points (or equivalently, find ordering policies) that achieve a certain service level target at minimal costs or minimize the sum of inventory holding and stockout penalty costs.

Practical applications range from retail distribution systems to service systems for spare parts. In many of these applications, there is only an initial procurement opportunity for regular supply. Any excessive demands have to be covered by alternative (emergency) supply modes or are lost. For spare parts, there is a final manufacturing batch at the end of the product's life cycle and this final batch has to cover all future service demands. In case of fashion goods, a single order is placed in advance of the selling season. As a consequence, these kinds of decision problems are solved using the stochastic, single period newsvendor problem.

Such an operating policy can be improved by allowing the retailers or stocking points to cooperate. In cases where some location is out of stock or has a low inventory level whereas other locations have sufficient or excessive inventory, it might be beneficial to transship units between stockpoints. Using this strategy of virtual inventory pooling, the total cost of the distribution system can be reduced without rendering the required service level, or alternatively, a higher service level can be achieved with the same amount of inventory. The analysis of transshipment policies involves several decisions that, in general, have to be assessed simultaneously. Short term operational decisions are 1) when to transship (in advance of or in reaction to stockouts) or whether to transship at all, 2) from which other retailer(s) to ship (supply mode decision). The existence of a beneficial transshipment opportunity leads to another more strategic decision about the setting of safety inventory levels which can be lowered due to the multiple (lower cost) supply modes.

A special case of transshipment problem arises if the costs and lead times for transshipping units are negligible. Then, the problem of centrally coordinating several stockpoints reduces

to virtually controlling a single central inventory. Any demand from any stockpoint can be served from any location with positive inventory without any extra cost or delay. As a consequence, a lower bound on total systems inventories under transshipments is given by the level of inventory that is necessary to serve the different classes or regions of customers from a central inventory.

These decisions can organizationally be tackled be setting general rules or can be decided depending on the current state of the entire or part of the distribution system. Such rules prescribe to ship all or nothing, or to ship any amount of units above the reorder point or above the level of safety stock. The decision from where to source of often addressed by grouping certain locations into so called pooling groups or by setting up priority sourcing lists. State dependent rules decide about transshipments based on the current inventory level and on the timing of outstanding orders.

The majority of research on transshipments considers centralized systems where all cost parameters and all current inventory levels are common knowledge and decisions are carried out centrally. Under decentralized decision making, the problem of incentive compatible setting of transfer prices arises. Multi-agent systems represent a framework for coordination between autonomous or semi-autonomous agents. This framework is applied and discussed in computer science applications, e.g. the development of internet agents. Several types of coordination exist. Because of the overall complexity, multi-agent systems, especially the ability to decompose a complex centralized decision problem into many simpler decentralized and distributed decision problems, offer a means to model and solve complex coordination problems in reasonable time. In case of transshipment inventory problems, the available literature shows that an exact analysis is only possible in certain restrictive situations, e.g. single period models where all stockpoints have identical costs, single period models with non-identical costs but only two locations.

The paper is organized as follows. In Section 2 we present the general multi-agent framework. In Section 3, we first review the basics of the newsvendor model which is later used as the main tool to determine the bids for coordination in a dynamic fashion. Further, different transfer pricing methods investigated in the management accounting literature are discussed for its suitability in safety inventory pooling coordination. Having done this, Section 4 presents the determination of the actual transshipment quantities and the solution of the sourcing problem. Section 5 presents numerical examples in order to illustrate the framework. The final section summarizes the advantages and disadvantages of the proposed methodology and discusses several open issues for future research.