Transportation Research Part E 46 (2010) 719–734

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Multi-level inventory management decisions with transportation cost consideration

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ARTICLE INFO

Article history:
Received 17 June 2009
Received in revised form 5 August 2009
Accepted 18 October 2009

Keywords:
Inventory management
Decentralized ordering
Centralized ordering
Transportation

ABSTRACT

In this article we address specific inventory management decisions with transportation cost consideration in a multi-level environment consisting of a supplier–warehouse–retailers. We develop two models – namely, decentralized ordering model and centralized ordering model to investigate the effect of collective ordering by retailers on the total inventory cost of the system. A numerical study shows that the proposed model is robust and generates reasonable cost savings. The models have potential in several multi-level applications such as fresh or frozen food delivery to stores of different supermarkets or the supply of medicine to a number of hospitals from a wholesaler.

1. Introduction

Inventory models developed for the deployment of stock in a source-deliver supply chain take complexities of multi-level distribution systems into account but usually fall short in considering transportation cost. Increasing oil costs, highway congestion, increasing cost of short-hauls, and consolidation of distribution centers are examples of problems that may increase transportation costs. Source-deliver chains desire not only agility but also lower costs in the network. According to Swenseth and Godfrey (2002), upwards of 50% of total logistics costs can be attributed to transportation.

Classical inventory management strategies are not applicable and many companies are searching for new supply chain inventory strategies to contain the rising costs of transportation, find offsetting savings, maintain low inventories, and also ensure on-time deliveries. Even though there is considerable research on inventory control and transportation management, much less is available on the combined problem. The traditional Economic Order Quantity (EOQ) model captures only the trade-off between inventory carrying cost and setup or ordering cost. In this respect the transportation cost usually is neglected or included in another cost such as setup cost.

In this paper, a single item inventory model is considered with several retailers, one warehouse and one supplier. We develop two new models – namely (1) decentralized ordering and (2) centralized ordering. The decentralized ordering model is a constructive extension of the classic optimal Economic Order Quantity (EOQ) model. In the presented model, we consider two components in the per order cost: a fixed ordering cost which excludes transportation costs, and a discrete transportation cost. We try to minimize the total inventory cost while considering the transportation cost as a part of it. This cost is imposed whether a truck is fully loaded or only partly loaded. Hence, we integrate inventory and transportation management into one mathematical model. We develop the transportation cost based on a practical application. Since the number of trucks required is always a positive integer, the transportation cost is a discrete function of the order quantity. We also

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doi:10.1016/j.tre.2009.12.012

search for the optimal strategy of the warehouse (i.e., how often to place orders) to determine the optimal review period. Simple algorithms are also presented to compute the optimal order quantity for the retailers and the optimal review for the warehouse.

Based on our numerical experiment, we show that the transportation cost contains a considerable percentage of the total inventory cost. There are new elements in our model which distinguish it from other extensions to the traditional EOQ models with regard to transportation cost; these features are discussed in the next section.

In the centralized ordering model, we propose a collective form of ordering by retailers and minimize the inventory cost of the retailers and the warehouse jointly. Here retailers observe their customers' demand, and then collaborate to explore the optimal joint ordering, and send it to the warehouse. A continuous review model and a simple algorithm are applied to determine the optimal order quantity and optimal re-order point of the system.

We show that total cost of the model can be decreased through collaboration among the retailers and the warehouse. Numerical examples are used to solve both models and compare the cost savings.

The paper is structured into five sections. Section 2 presents a literature review dealing with inventory models and transportation cost elements. Section 3 briefs the boundary of supply chain inventory problem, i.e. the inventory policy adopted for retailers and the warehouse. Section 4 formulates the decentralized ordering policy. Then in Section 5, the model is extended to study the effect of a centralized (collective) form of ordering by the downstream entities and combined delivery on total costs. The benefits of transportation considerations are then highlighted through numerical studies in Section 6. A sensitivity analysis is conducted in this section as well to evaluate the outcomes of numerical result for different values. Finally, Section 7 presents brief conclusions.

2. Literature overview

Several attempts have been made to extend the EOQ model to different conditions. For this purpose, a few authors incorporated transportation costs into the lot-size determination analysis. Baumol and Vinod (1970) considered an inventory-theoretic model of freight transport to determine order quantity and transportation. Their objective was to minimize the total transportation, ordering, and carrying costs. The model however considered a per unit constant transportation cost. Das (1974) worked on the same model with a few different assumptions. His model considered the determination of a fixed order quantity and safety stock sizes from the order size. Buffa and Reynolds (1977) extended these works by adding stock-out costs and shipment discounts based on minimum full truckloads. Burwell et al. (1997) developed a model for determining the reseller's lot-size and price assuming that there are freight and all-unit quantity discount breakpoints in the pricing schedule offered by the supplier. Blumenfeld et al. (1987) developed a decision support tool for the analysis of the logistics operations at General Motors that resulted in a 26% reduction in logistics costs. While allowing the analysis and models to be as simple as possible, the authors developed a tool that allowed the Delco Electronics Division to examine the impact on total corporate cost due to different shipping strategies for its products. The authors stated that the minimization of total network cost required the simultaneous determination of optimal routes and shipment sizes and they focused on analyzing the trade-off between inventory and transportation costs. Results obtained from the research are reported in a series of papers (Blumenfeld et al., 1985; Burns et al., 1985).

Gupta (1992) considered a situation in which a fixed cost is incurred for a transport mode such as a truck that has a fixed load capacity. He developed a model to determine the optimal lot-size, which minimizes the sum of the inventory holding, ordering and transportation costs. Zhao et al. (2004) addressed the problem of evaluating the optimal ordering quantity in a supplier–customer model by considering the transportation cost. They made a trade-off among production, inventory and transportation costs where transportation cost involved fixed and variable costs.

The approach that we propose in Section 4 (the decentralized ordering model) is similar to Gupta's (1992) but with some extensions and differences. First, we use a multi-level (one warehouse–multiple retailers) model with a determined inventory policy for each element. These policies facilitate safety stock at the retailers and warehouse. Second, we make a more precise inventory cost estimation for carrying cost by adding the lead-time and the demand during the lead-time and by including the distance between warehouse and retailers as a factor in the transportation cost. Third, the demands are assumed to be stochastic. Finally, we consider both fixed and variable cost of transportation in our model while a fixed transportation cost was only addressed in Gupta's research.

In the area of centralized (collective) ordering at downstream entities, to the best of our knowledge, little research has been carried out where many firms (retailers or manufacturers) collaborate and send their order for one item as a combined-order to one supplier. However, there are many research publications on the Joint Replenishment Problem (JRP) in which several items are replenished at a single stocking point. A complete definition of JRP is available in Goyal (1973, 1974) and Goyal and Satir (1989).

3. Structure of source-deliver inventory decisions

A two-level supply chain consisting of a warehouse (distribution center) and N retailers is considered in our model (Fig. 1).