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A supplier–retailer supply chain with intermediate storage for batch ordering

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ABSTRACT

We consider a single-commodity production-inventory supply chain in a supplier–retailer setting with batch production for the supplier, batch ordering for the retailer, and intermediate storage between the supplier and the retailer. These features have been studied in the literature of supply chain management, and are common in practice, especially in retailing and convenience store industries. This study is innovative in changing the ownership of commodity at the intermediate storage to enable more flexible delivery, as well as in allowing for non-linear cost structures. The supplier determines the number of shipments to produce and the retailer determines the number of batches to order. In the paper we suggest algorithms to identify the optimal decisions for the integrated, retailer-led, and supplier-led supply chains, respectively. The algorithms gain efficiency from pertinent analytical *bounds*. Numerical experiments are reported to benchmark our results against those in the literature and to provide sensitivity analysis for the batch lot size and cost parameters. Insights are gained for the integration and the operations of the supply chain.

1. Introduction

Unless induced to act differently, members of a supply chain in general take self optimization over social optimization, i.e., each tends to operate in conditions that are best to oneself, ignoring the effect of such conditions on other members and the whole supply chain. Ever since the pioneering works on optimal policies of the socially optimal integrated system (Goyal, 1976; Banerjee, 1986), there have been many researches on the issue, comparing various aspects of integrated systems with self-centered ones. Interested readers can refer to review papers of Goyal and Gupta (1989), Ben-Daya et al. (2008), Glock (2012a) and Thomas and Griffin (1996) for related works. This paper investigates the integration of a supply chain with several *delivery issues*, including delivery frequency, the intermediate storage allowing flexible delivery, and non-linearity due to economies of scale in operations. Moreover, the paper explicitly models the change of commodity ownership, and the existence of a minimum, standard batch size in operations, which are two of the issues usually neglected in the literature.

The very first hurdle to turn a self-centered supply chain into an integrated one rests on the intrinsic differences in the scales of operations cycles of members. Nowadays, a retailer often adopts lean retailing, which leads to frequent deliveries in small quantities (page 77 of Abernathy et al., 1999). A supplier may adopt lean manufacturing as well. However, the economies of scale in production, such as quantity discounts for acquiring raw material, setup costs for switching production among products, etc., often render the production lot sizes of the supplier larger than the ordering quantities of the retailers. There must be a venue to store items produced by suppliers and not immediately required by retailers. The venue may actually be a supplier warehouse, a retailer warehouse, or an *intermediate storage* controlled and managed by the negotiation between suppliers and retailers. With concepts such as just-in-time delivery and vendor-managed-inventory, suppliers nowadays have taken up more responsibility for the pipe-line inventory. This responsibility of suppliers is sometimes interpreted as pushing inventory upstream to suppliers by retailers (c.f. the discussion in Grout, 1999, and David and Eben-Chaime, 2003). In reality, whether inventory is pushed upstream or not depends on when and where the ownership of items changes hands in the supply chain.

In this paper, we explicitly model the effect of the change of inventory ownership on supply chain integration. We consider an intermediate storage such that suppliers are responsible for the items on the way to the intermediate storage. The ownership of items is changed from suppliers to (relevant) retailers right at arriving at the intermediate storage, and from that point onwards the retailers are responsible for the items.

We must emphasize that the intermediate storage can be physical or conceptual. The benefits of physical intermediate storage

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are well-documented as the *flexible distribution strategy* (page 36 of Bowersox et al., 2007), the *intermediate inventory storage point distribution strategy* (Section 7.3 of Simchi-Levi et al., 2008), etc., in the literature. For practical examples, see Hofbauer (2010) for the benefits of distribution centers between suppliers and retailers for the convenience store industry, page 600 in Bell and Salmon (1996) for the flagship strategy in each major metropolis when a company enters new geographic markets, and Section 5.2 of Pfohl and Shen (2008) for 3PL warehouses in Shanghai area for various European apparel retailers. However, the intermediate storage can be purely conceptual in this paper. We care about the intermediate storage as the venue to change the ownership of items and to have logistics operations on items. Where it actually locates is unimportant. Physically an intermediate storage can be a venue such as a distribution center between a supplier and its retailers, or a warehouse at the supplier or the retailer. Our theoretical derivation is flexible. By setting parameters to appropriate values, our model gives results to identify contributions of the intermediate storage for the supply chain under different operations conditions.

While our model is flexible, the nature of the intermediate storage such as the storage capacity or the number of retailers served is beyond the scope of this paper. See Xu (2008) for supply chains that explicitly model the storage capacity; see Goyal and Gupta (1989), Ben-Daya et al. (2008), Thomas and Griffin (1996), Glock (2012b), and Hoque (2011) for single- or multi-supplier supply chains with single or multiple retailers.

Our model further considers the practical issue of the *standard batch size* exists in many operations: the quantities ordered by the retailers, produced and shipped by suppliers, and stored throughout the supply chain are all integer multiples of a standard batch size. In physical terms, the standard batch size may be the quantity of a case, a (full) truckload, or a container. As shown in David and Eben-Chaime (2008), for the classical integrated supplier–retailer system, the accuracy of the continuous model as an approximation of the discrete one depends on the dynamics of the system. Given this result, the optimal decisions in our model are found by the exact procedures on discrete variables without rounding from any continuous variables.

As in the investigation of supply chain integration in Goyal (1976), Banerjee (1986) and Hill (1997), our supply chain is of single-supplier, single-retailer. The retailer regularly places orders to the supplier requesting a certain multiple of the standard batch size in each order. The supplier has the freedom, if necessary, to consolidate retailer orders in a production run and to ship produced items to the intermediate storage in several *shipments*. The decision variables in this study include the ordering quantity of the retailer, the production batch size of the supplier, and the shipment batch size of the supplier.

In addition to the fixed setup cost in each production run for the supplier, some cost terms are allowed to be non-linear functions of the decision variables. The fixed ordering cost of a replenishment order incurred at the retailer can be a non-linear decreasing convex function of the number of standard batches ordered, and the fixed delivery cost of a shipment sent by the supplier to the intermediate storage can be a non-linear decreasing convex function of the number of standard batches shipped. These functional forms, non-linear and decreasing convex, capture the economies of scale in operations: the fixed shipment cost (or the fixed ordering cost) of each standard batch decreases with the total number of batches shipped (or ordered) for batches placed in the same order (c.f. the non-transmissible learning in Keachie and Fontana, 1966). A concrete example of this learning effect is that the charge of a third-party logistics company in shipping or delivering a standard batch decreases with the increase in the number of batches contracted. This type of reduction of production setup cost in supply chain integration has been considered and is referred to as the *learning effect* (in Kim et al., 2008, page 6210). We follow the convention to use the term this way.

There are cost terms linear in decision variables. The retailer breaks down each shipment received at the intermediate storage into standard batches, with each *delivery* being a standard batch to the retailing site. Such *flexible delivery* is obtained at a cost, with inventory holding cost proportional to the sum of average inventory at the intermediate storage as well as at the retailing site. Similarly, the supplier pays an inventory holding cost proportional to the average inventory under her responsibility.

We determine the optimal decisions for three *operations modes* of the above supply chain. The supplier and retailer can collaborate in the *integrated mode*, c.f. Banerjee (1986), or operate in the *retailer-led mode*, i.e., the retailer makes decisions best for herself and the supplier co-operates accordingly, or operate in the *supplier-led mode*, i.e., the supplier makes decisions best for herself and the retailer co-operates accordingly. Our comparison of the optimal decisions and costs of these three operations modes provide insights to supply chain integration.

The supply chain outlined above has delivery features on delivery frequency, intermediate storage, and learning effect. In our analytical derivation, we derive functional relationships of the model under the three operations modes with full delivery features. In the numerical analysis, we investigate the effects of the delivery features on supply chain integration. By taking up specific sets of parameter values, we obtain a series of results from our general model with increasing complexity in delivery features, ranging from a standard supply chain without any flexibility delivery feature (i.e., a supply chain operating on single batches of the standard batch size, strictly linear delivery and shipment costs with batch, and without any intermediate storage) to a supply chain with full features. The results of our numerical study are comparable with relevant researches since the values of parameters are transplanted from the literature.

The rest of the paper is organized as follows. Section 2 contains the integrated problem, with retailer-led and supplier-led supply

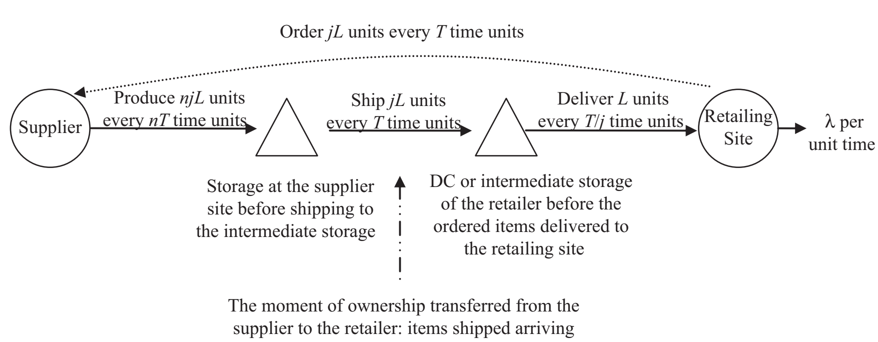

Fig. 1. The Relationship between the supplier and the retailer.