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Evaluating supply chain flexibility with order quantity constraints and lost sales

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ABSTRACT

In a flexible supply chain buyers and suppliers are willing to accommodate the uncertainties and variations in each other's businesses. In many instances the buyer may prefer to use supply flexibility, as opposed to an inventory holding strategy, to counter demand uncertainty. We consider the case where the buyer releases a fixed period replenishment order to the supplier under a supply contract defined by three parameters: (i) supply price per unit (ii) minimum order quantity and (iii) order quantity reduction penalty. Following a demand drop the buyer therefore has two flexibility options in the order cycle: (i) to place an order less than the supplier specified minimum order quantity and pay the associated penalty, or (ii) place no order and lose the sales for the current period. There is no penalty for not placing an order. A key buyer decision then is Q_{lost}, the order or replenishment quantity level below which no order is placed and the sales are lost. A model for deriving the expected supply and lost sales cost as a function of Q_{lost} is presented, and it is shown that the optimal value of Q_{lost} is the inflexion point of the lost sales cost and the quantity penalty. The model is then used to select the supplier that minimizes the procurement plus lost sales costs from a given set of supply bids and a known expected customer demand behavior. Finally, the buyer also has the option to make capital investments in the supplier so as to reduce the minimum order quantity and hence reduce the projected supply costs. We evaluate the economics of this tactic.

1. Introduction

Modern supply chains demand a flexible supply relationship between buyer and seller. In many instances the demand for the end product is highly uncertain. In such cases the buyer may prefer to use supply flexibility, as opposed to an inventory holding strategy, to counter the demand drop. Frequently, though, the unit supply cost is penalized as a function of the decreasing order quantity. Das and Abdel-Malek (2003) define supply chain flexibility as the robustness of the buyer–supplier relationship under changing supply conditions. A highly flexible relationship is one in which there is little deterioration in the procurement cost under different supply conditions. In a flexible relationship the supply contract allows the buyer to transmit some of the adverse effects of customer uncertainty to the supplier. This results in a reduction in inventory risk for the buyer. A good supply contract must therefore be robust enough to provide sufficient flexibility and should permit economic component supply for both parties in all possible market scenarios.

Das and Abdel-Malek (2003) observe that supply relationships are prone to deteriorate as demand uncertainty increases, since one or both parties attempt to violate an inflexible contract. They identify two common cases of buyer requests when demand is uncertain: (i) a short lead time order shipment following a demand surge, and (ii) a smaller than normal order quantity following a demand drop. They presented a model for estimating the supply or procurement costs for a given supply contract with these requests. They assume the buyer demand is known to be normally distributed, and from this they are able to derive the likelihood of each request occurring and the associated cost penalty. They extended their model to select the best supplier for a specific product when there are several candidate suppliers. The selection objective was to minimize the expected annual procurement costs.

This paper considers case (ii), which is following a demand drop the resulting order quantities are much smaller. We assume the buyer places replenishment orders to the supplier once in each fixed period. The buyer can also choose not to place an order and there is no penalty for this. Under low demand conditions the buyer therefore has two flexibility options in the order cycle: (i) to place an order less than the supplier specified minimum quantity and pay a quantity penalty, or (ii) place no order and lose the sales

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for the current period and accept the lost sales penalty. The two penalty functions are inversely related; hence as demand drops below the minimum quantity, the buyer will first opt for option (i) then if the demand drops further the second option is more attractive. The second flexibility was not considered by Das and Abdel-Malek (2003), and in effect the penalty increased monotonically as the order quantity decreased. Here both flexibility options are considered, and the demand point where the switch occurs is derived. Note that there is a third option in which the buyer places an order equal to the supplier specified minimum quantity. In this option the buyer avoids both penalties, but exposes itself to an inventory risk. We assume that the buyer has already decided that this is not an efficient option.

Companies are increasingly convinced that when demand drops it is better to lose the sales rather than expose the supply chain to substantial inventory risk and discount pricing. We define as Q_{lost} the demand or order quantity level below which the buyer opts not to place a replenishment order and accepts the lost sales. In this paper we develop a model for deriving the expected supply costs plus lost sales cost as a function of Q_{lost}. We show that the optimal value of Q_{lost}, in the context of the annual procurement cost, is simply the inflexion point of the lost sales cost and the quantity penalty.

The model is then used to select the supplier that minimizes the procurement plus lost sales costs. This assumes there are a given set of supply bids and a known expected customer demand behavior. The supply bid is the supply contract proposed by each of the candidate suppliers. The contract specifies the minimum supply quantity above which there is no cost penalty, and the cost penalty function below the minimum quantity. Once a supplier is selected, then additional collaborations may occur between buyer and supplier in an effort to increase the supply flexibility. One common tactic is capital investment in the supplier facilities, these may be used to reduce setup costs or purchase more efficient equipment. The buyer offers to pay for these investments, and in exchange the supplier offers to reduce the minimum order quantity. We present a model for evaluating the economics of this buyer investment.

1.1. Lost sales as a supply chain tactic

The (s,S) or base stock reorder inventory policy has traditionally been the most widely applied inventory policy. Here s is the inventory level below which a replenishment order is placed and potentially some of the demand is unmet. Conceptually, two situations appear when demand is unmet, they are either backlogged (backordered) or the sales are lost. Most analysis of the (s,S) model assumes the unmet demand is backordered. Corsten and Gruen (2004) observe though, that in large parts of the retail industry unmet demand converts into lost sales. Bendre and Thorstenson (2008) find that the lost sales case has considerable significance as a supply chain tactic. Especially, in sectors like specialty retails and spare parts where it is frequently observed as the standard business practice in case of shortages.

The current trend towards lean supply chains demands a greater balance between inventory and service levels. In many cases the trend is to minimize the inventory risk by ordering smaller replenishment quantities that are equal to the demand forecast. This is particularly true in retail sectors such as electronics, where product price declines are common. When the demand drops to levels where the supply costs negate potential profits, then buyers are willing to accept the lost sales and consequently avoid the inventory risk. Agrawal et al. (2002) recommend that in developing sourcing strategies one must consider the performance capabilities of the supply base. Furthermore, they state that the supplier selection decision must consider cost differences, lead times, and flexibility of production. The model presented here can be used to select suppliers in such settings, and prescribe the order level below which sales are selectively lost.

2. Related research

There is an extensive literature associated with lost sales inventory models. For instance, Hill et al. (2007) consider a single-item, two echelon, continuous-review inventory model in which several retailers have their stock replenished from a central warehouse. Aprile et al. (2006) study some supply chain configurations based on different degrees of flexibility referring to both process and logistics aspects. Wijngaard (2004) investigates the influence of a restricted production capacity on the effect of advance demand information. On the other hand, Dai et al. (2008) study a two-echelon supply chain with one supplier and two retailers. The supplier carries all inventories and replenishes the retailers as needed. Chiang and Monahan (2005) propose a two-echelon dual channel inventory model based on queuing model. They develop operational measures of supply chain flexibility by defining a cost structure, which captures two different operational cost factors: inventory holding cost and lost sales cost. Some researchers assume that the shortages are backlogged for sometime before becoming lost sales. Bassok and Anupindi (1997) studies minimum order quantity with shortages that can be backlogged. They derive the optimal purchase policy for the buyer for a given total minimum quantity commitment and a discounted price. Lodree (2007) determine optimal stocking policies for a supply chain characterized by long procurement lead time with shortages that are partially backlogged. Once a shortage is realized, the supplier has the option to initiate an emergency replenishment at an expensive premium or incur lost sales penalty, and the buyer has the option to wait for the supplier's replenishment or to fulfill the shortage from the supplier's competitors. They also consider contract cancellation.

In contrast to the low demand case studied here, some researchers have studied the case where demand cannot be met from the supplier's capacity and an additional supply source is considered. Sinha and Sarmah (2007) consider a two-stage supply chain, in which the supplier's production capacity is less than the annual demand of the retailer. The supplier may recover the deficit by procuring the same from an external source at a certain price and then supplying it back to the retailer. Mohebbi (2003) presents an analytical model for computing the stationary distribution of the on-hand inventory system with compound Poisson demand, Erlang distributed lead time, and lost sales, where the supplier can assume one of the two "available" and "unavailable" states at any point in time according to a continuous-time Markov chain. Chang (2007) studies the problem of relationship management in supply chains from the point view of a supplier providing a certain proportion of compensation for buyers when stock-outs occur. Findings indicate that the demand rate for inventory system of the supply chain from external market will change when there is lost resulted by stock-outs. Therefore, it will be feasible that initiator (i.e. the supplier) make appropriate compensation for buyer in case of stock-outs so as to maintain cooperative relationship with buyer and improve the operation efficiency of complete supply chain system.

Diponegoro and Sarker (2006) discuss a production supply problem with fixed shipment batch and fixed delivery intervals of finished product. A pragmatic method was proposed to determine near optimal cycle time, batch size, and the number of orders for a finite planning horizon. They show that the problem with lost