Abstract

Until very recently, the key focus of stochastic inventory planning models was demand uncertainty, supply was largely assumed to be unlimited and uninterruptible. However with intense competition, firms are now sourcing supplies from across the world and there has been a significant increase in the incidents of supply failure. In general, off-shore suppliers are cheaper but unreliable; while on-shore suppliers are reliable and expensive. In addition, due to long distance transportation, the off-shore orders must be placed much in advance when the demand estimate is likely to be less accurate. Often the demand information improves progressively till it is revealed completely at the time of demand fulfilment. Hence in order to optimise the total cost, buyers need to strike a balance between:

- **Supply Cost**
- **Supply Reliability**
- **Supply Lead Time**

Firms need to develop a portfolio of suppliers to achieve this balance and the proportion of off-shore and on-shore suppliers is an important characteristics of this portfolio. When there is a difference in the supply lead time of the suppliers, apart from splitting the orders optimally, another important decision is placement of these orders: simultaneous or sequential. In case of **sequential ordering**, an advance order can be placed with the off-shore supplier and based on the delivery status of this order and the update on the demand information; a subsequent order can be placed with the on-shore supplier. Between the two ordering points, demand information as well as supply information about the previous order gets updated. Supply information updating could simply mean that before a new order is placed all previous orders have arrived. However since it is now possible to track a particular order through different stages of production and delivery using sophisticated communication devices, the expected yield from an order can be updated continuously. One example of this information updating is when a firm opts for pre-shipment inspection for an off-shore supplier; the goods are shipped after inspection, hence, in this case, the yield is known at the time of the shipment itself. This update on the supply status is as crucial as the update on the demand information in deciding the

optimal order size. Hence it is argued here that there is a need to develop models for updating ***supply information*** on the lines of ***demand information updating*** models.

Single period, two stage analytical models are derived to minimise the total operating cost consisting of: ordering cost, salvage cost, unmet demand cost and stock holding cost. The two stages here represent the two sequential ordering opportunities with different cost and supply uncertainty parameters. The question is: What are the optimal order sizes for each of the ordering opportunities that minimise the total operating cost?

Supply uncertainty is restricted to quantity uncertainty alone, lead time uncertainty has not been considered for this analysis. Two standard representations of quantity uncertainty are used: *binomial* and *stochastically proportional yield*. For the binomially distributed supply case, the optimal ordering policy is derived for a **multi-stage** problem (instead of just 2 stages). Convexity is proven and a closed form analytical solution is obtained for the generic demand distribution. For the stochastically proportional yield case, the number of stages is restricted to 2 while three different levels of demand information updating are considered:

- No-update: Demand information across two stages does not change. For this case the convexity result and the closed form solution has been derived for uniformly distributed demand and supply.
- Complete-update: Stage 2 order is placed only after the complete demand is known. Convexity is proven for uniformly distributed supply and the closed form solution is obtained for uniformly distributed demand
- Partial update: There is partial demand information improvement across the two stages, but it is not complete. At Stage 1, the range of the demand distribution is known while the mean is unknown which is revealed at Stage 2. The convexity result is proven for uniformly distributed supply and demand and optimal order conditions are derived.

Key contributions of the thesis:

- Developing the concept of ***supply information updating*** on the lines of ***demand information updating*** and highlighting this gap in the inventory planning literature.

- Demonstrating analytically the role of sequential ordering in managing demand and supply uncertainty. Often supply uncertainty is addressed by having multiple suppliers, in this work it is shown that apart from placing multiple orders what is more useful is placing them sequentially with information updates.
- Deriving optimal order quantities when demand and supply are stochastic and there is sequential ordering opportunity with demand and supply information getting updated.
- Extending the solution of the unreliable newsboy model derived by Gerchak et al (1988) and showing that the solution is non-linear in certain range of cost parameters.
- Proving that the *ordering point* at each stage is independent of the supply uncertainty parameters of that stage.
- **Key managerial insights:** There were three important insights:
  a. It was proven analytically that the cost reduction due to an additional ordering opportunity (Stage 2) with information updating is significant even if this opportunity is associated with higher ordering cost and higher uncertainty. The value associated with this additional opportunity was directly proportional to the level of information updating.
  b. The second important finding was that the optimal expected cost is highest for a supplier where there is a possibility of complete supply failure compared to any other kind of supply unreliability. For example, a supplier with high mean and low variance would be costliest if he is not able to ensure a minimum yield percentage. This finding is quite relevant for the supplier selection process where the selection is often based only on the mean and the variance of the supply distribution.
  c. The third important finding was that the optimal safety stock at any stage is independent of the supply uncertainty associated with that stage; it only depends on the uncertainty associated with the following stages or future ordering opportunities.