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Inventory management with advance supply information

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ABSTRACT

We consider a single stage inventory system with stochastic capacity. The manager receives forecasts from the upstream source about future capacity availability within an information horizon, referred to as "advance supply information". We study two main questions: (i) How can advance supply information be utilized when making replenishment decisions? (ii) What is the value of such information sharing, compared to a fixed base-stock policy? We show that state-dependent base-stock policies are optimal. We develop easily computable and implementable heuristic policies. We numerically test the accuracy of the approximations and analyze the value of collaboration under various business scenarios.

1. Introduction

The biggest challenge of supply chain management is the uncertainty on both sides of the demand-supply equation. Supply chain implementations in industry emphasize both demand and supply collaboration, i.e. the sharing of downstream and upstream information, respectively. At a global manufacturer with several sites all over the world, the classical planning processes that are performed within the four walls of a company such as Demand Planning, Master Planning and Factory Planning, can now be extended beyond these four walls with the help of collaboration tools and software. These tools and software connect the manufacturer with the downstream and upstream supply chain partners. Over the past decade, the efforts of Wal-Mart, Target, Procter & Gamble, Sears, Ace Hardware, JC Penney, Cisco Systems, IBM, SUN Microsystems and Dell Computer have shown that such a proactive and anticipatory business model that involves coordination and collaboration between supply chain partners is better able to increase sales revenues and margins that shareholders expect (Ireland and Crum, 2005).

Upstream members of the supply chain typically have better information about the state of their facilities and their potential ability to deliver any orders in the immediate future. Such information, when provided to the downstream supply chain partner, has the potential to improve decision making. We refer to this kind of information exchange as supply collaboration. For example, we observed in a consulting project the implementation of a supply collaboration tool by SUN Microsystems as part of their Breakthrough Supply Chain Initiative in 2000. Similarly, IBM PC Division also implemented a process through which they are able to send their requirements to their suppliers who then send their projected availabilities back to IBM (this process is named "Try-For-Fit" internally). These projected availabilities were provided for a certain horizon and were updated every week. These real life examples demonstrate that companies utilize supply side information as well as demand side information.

In academic literature, there have been several papers that investigate the sharing of advance demand information. However, there is relatively limited work on upstream information sharing. This discrepancy between academic literature and industry focus gave us the main motivation for this paper.

We analyze a periodic review, single stage, single item inventory system. The inventory system replenishes its inventory from an external upstream source and there is a limitation on the amount of the replenishment in any given period, which makes the inventory system a capacitated one. The capacity varies stochastically. The manager of the inventory system receives forecasts from the upstream source about the capacity availability of future periods within a given rolling information horizon. We refer to these forecasts as "advance supply information". The evolution of the capacity availability forecasts is modeled via the Martingale Method of Forecast Evolution (MMFE). The forecasts may be the result of different processes within the organization of the upstream source. For example, the upstream source may be serving multiple downstream partners and some of its capacity in a future period may have been committed to other downstream partners. Consider a situation where the upstream source is working with two customers, A and B, and suppose that customer A is a higher priority customer. This means that if capacity is insufficient to meet both demands at any given point, customer B receives only the remaining capacity (if any) after customer A's demand is satisfied as much as possible. In addition, suppose that the upstream source receives advanced demand information from customer A for a certain number of future periods.

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Suppose that the capacity of the upstream source is 100 units, and the advanced demand forecast from customer A for two periods from now is 40 units. In such a case, the upstream source provisionally commits to using 40 units of capacity for customer A two periods from now, and its expected availability for customer B is 60 units for the same period. The upstream source can provide this information to customer B as *advance supply information* and this information can be very useful to customer B for its own planning purposes. Knowing that two periods from now, the expected availability is 60 units, the manager of the inventory system may choose to inflate his current orders somewhat if he believes that a capacity of 60 may not be sufficient two periods from now. This is the main idea investigated in this paper. We consider the problem faced by customer B, working with an upstream source, who provides the inventory system with advance supply information. The capacity forecasts (supply information) may also vary due to other private information of the upstream source, such as upcoming scheduled downtime for maintenance or inspection or future staffing variations, etc.

In our model, the upstream source does not make any decisions, but simply provides the inventory manager with capacity availability forecasts, who then optimizes her replenishment policy. We assume that the upstream source has already agreed on sending the capacity forecast information truthfully to the inventory manager. Assuming such truthful information sharing, we address two main points throughout the paper:

1. How can the manager utilize and integrate the advance supply information into the replenishment decisions? Our first goal is to develop a simple-to-implement policy that takes advance supply information into account.
2. We would like to identify the types of operating environments under which advance supply information is most valuable, compared to a fixed base-stock policy.

In order to focus on the advance supply information aspect, we use a simple single stage inventory model with full backlogging and independent and identically distributed (i.i.d) demand, but most of our results can be relaxed as usual (e.g. to longer leadtimes, Markov modulated demands). We first analyze the structural properties of the optimal solution. We show that state-dependent base-stock policies are optimal for the inventory problem with advance supply information.

In order to determine the state-dependent base-stock levels, one would have to solve a high dimensional dynamic program, which will be impractical for all but the simplest cases. Even if the solution is available, it may not be easy to implement. Therefore, we next focus on developing easily computable and implementable heuristic policies. The heuristics rely on the idea of assuming a functional form (represented as $K(F)$) for the relationship between the forecast vector F and the state-dependent base-stock level. Given a functional form, the heuristic has a single parameter to be optimized. First, we develop a simulation-based method to optimize the parameter of the heuristic for any predetermined functional form $K(F)$. The method involves simulating the system just once using an arbitrary parameter. Second, we study a particular functional form $K(F)$, the cumulative forecasts within the information horizon, inspired by a deterministic version of the problem. Using an asymptotic approximation, we develop a closed-form formula for the optimal parameter of this cumulative-forecast-dependent base-stock policy under normal demands. Through computational experiments, we test the accuracy of the approximations and analyze the value of collaboration under various business scenarios.

There are three main research streams pertinent to our work. The first group of papers are on single item/single-location capacitated inventory problems. Federgruen and Zipkin (1986a,b) prove the optimality of modified base-stock policies for a single-location inventory problem with a deterministic capacity constraint for infinite horizon problems using both the discounted and the average cost criteria. Ciarallo et al. (1994) prove the optimality of modified base-stock policies under a stochastic capacity constraint. Glasserman (1997) develops bounds and approximations for setting base-stock levels in production-inventory systems with both deterministic and stochastic capacity constraints. Tayur (1993) develops methods to compute optimal base-stock levels for capacitated inventory systems that relies on the analysis of shortfalls. Kapuscinski and Tayur (1998) study a capacitated production-inventory system with periodic (cyclic) demand. Iida (2002) studies a non-stationary periodic review production-inventory system with uncertain production capacity and demand.

The second group of relevant papers are on supply chain information sharing. Gavirneni et al. (1999), Lee et al. (2000), Cachon and Fisher (2000) and Gaur et al. (2005) are some of the papers that analyze the value of downstream information sharing. However, upstream information has received limited attention in the literature. Song and Zipkin (1996) study an inventory model where the supply system evolves according to a Markovian system which determines how replenishment leadtimes change over time. They identify the optimal policy which includes parameters that change dynamically reflecting the current supply conditions. Contrary to conventional wisdom, they show that a longer leadtime does not necessarily lead to a higher base-stock levels. Chen and Yu (2004) study the value of leadtime information in a single-location inventory model with a Markovian leadtime process. Through a numerical study, they show that the value of leadtime information can be significant. Jain and Moinzadeh (2005) consider a two stage supply chain where the manufacturer allows the retailer access to its inventory status. They provide an exact method for computing performance and develop a procedure for evaluating the optimal policy.

The third group of papers are on production-inventory systems with dynamic forecast updates. Graves et al. (1986, 1998) and Heath and Jackson (1994) are papers that explicitly address how to model an existing forecasting process in a production setting. They independently develop the Martingale Model of Forecast Evolution (MMFE). Gullu (1996a,b) build on this model to investigate the value of information in a production-inventory system and a depot-retailer system, respectively. Toktay and Wein (2001) consider a capacitated production stage that produces a single item in a make-to-stock manner and model advance demand information via MMFE. Iida and Zipkin (2006) consider an inventory system with dynamic demand forecast updates based on the MMFE and develop a computational approach to obtain approximate solutions. Aviv (2001) shows that integrating demand forecast information into the replenishment decisions reduces, on average, the supply chain costs by 11%. Chen and Lee (2009) consider a two stage supply chain where the retailer's external demand is assumed to unfold according to an MMFE process and the retailer shares its projected future orders with the supplier. Gallego and Ozer (2001) show that state-dependent (s,S) and base-stock policies are optimal for systems under advance demand information with and without a fixed ordering cost, respectively. Other related studies include Gallego and Ozer (2003) and Ozer and Wei (2004). All these studies investigate downstream demand information. We study the sharing of upstream supply information.

To summarize, the contributions of this paper are:

1. We introduce the notion of "advance supply information", which complements the studies on inventory management with advance demand information.