Operations Research Letters 42 (2014) 234–237

Contents lists available at ScienceDirect

Operations Research Letters

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

The impact of partial information sharing in a two-echelon supply chain

Matan Shnaiderman [a,*], Fouad El Ouardighi [b]

[a] Department of Management, Bar-Ilan University, Ramat-Gan, 52900, Israel

[b] Operations Management Department, ESSEC Business School, B.P. 105, 95021, Cergy Pontoise, France

ARTICLE INFO

Article history:
Received 23 September 2013
Received in revised form
6 March 2014
Accepted 21 March 2014
Available online 28 March 2014

Keywords:
Supply chain management
Information sharing
Stochastic demand
Autoregressive process

ABSTRACT

We consider a simple two-echelon supply chain composed of a manufacturer and a retailer in which the demand process of the retailer is an AR(1) where the random component is a function of both sides' information. We focus on partial information sharing under which each side informs the other of an interval in which the exact value of its own component of demand lies. These various levels of information sharing can reduce the supply chain costs.

1. Introduction

Efficient matching of supply with demand significantly reduces the costs of inventories and shortages in a supply chain (SC). One factor affecting the efficiency of this match is the level of demand information sharing between SC members. In practice, full information sharing among SC members remains an exception, while partial and no information sharing are prevalent. It is therefore essential to compare the SC costs and inventory levels associated with several information sharing levels between the SC members.

The objective of this paper is to determine how intermediate levels of information sharing between SC members influence their total costs, i.e., how partial information sharing can reduce these costs. This fills a gap in the existing research, which concentrates almost exclusively on full information and/or no information sharing without looking at what may happen in between. We consider a simple SC with one manufacturer and one retailer. At each period of time, the manufacturer is assumed to collect information about demand at the retailer's site. Based on [3], the information collected is based on historical demand data and other information signals (see below), that correlate with future demand. As [3,14], we suppose that the retailer's demand process is autoregressive of order 1, i.e., AR(1). [14] examines the case where the only information shared is about historical demand, which means that only the retailer has information to share. They find that the manufacturer's on-hand inventory and average cost may decline significantly when the retailer's information is shared (assuming that the manufacturer does not use the retailer's historical orders to calculate past demand). The authors find that decreasing of lead time can reduce the retailer' cost. Thus, the retailer may require reducing the lead time against information sharing. [3] extends this model such that the information on historical demand and other information signals can be shared between the SC members. Other papers, in which the demand satisfies an autoregressive process, are [2,12,15].

Our paper differs from these previous studies in two ways. Firstly, as stated earlier, it is unusual in considering several levels of partial information sharing about future demand, between no information sharing and full information sharing. By partial information sharing, we refer to a situation where each SC member informs the other not of the exact value of his own component of demand, but of an interval in which this value lies. Other forms of partial information sharing may consist in sharing components of the demand process (see [8,6,11]). Doing so, the SC members do not lie; they just do not tell "the whole truth" (alternatively, [5] suggests a model where the forecast provider has an incentive to provide an overly optimistic demand assessment). This situation is plausible whenever mutual trust does not prevail yet between the SC members. Yet, these intermediate levels of information may, as we show, reduce the costs of both sides. Secondly, under nonnegative correlation between adjacent demands (as we assume), the manufacturer can use the retailer's previous orders to estimate

* Corresponding author. Tel.: +972 505528951.
E-mail addresses: shnidem@biu.ac.il, Matan.Shniderman@biu.ac.il (M. Shnaiderman).

http://dx.doi.org/10.1016/j.orl.2014.03.006
0167-6377/

efficiently the past demand [16,1,17]. In contrast, if the retailer's demands are ARMA(p, q) with negative correlation levels, information sharing regarding the retailer's shocks may be effective for the manufacturer even in the simple case of AR(1) process, as stated in [7,9]. Since information sharing may be very beneficial [9], it is important to determine the time series model of the propagation of demand under partial information sharing. Though we assume that the retailer shares her information with the manufacturer, we actually analyze how information sharing by the manufacturer influences the costs of both sides. Finally, as for [14]'s "lead time reduction charge", we consider an information charge, defined as a financial amount, imposed by the manufacturer in return for sharing his information.

The paper is organized as follows. In Section 2, we state the problem, and the retailer's and manufacturer's optimal base stocks are respectively calculated under various information sharing levels. In Section 3, we define a manufacturer's information charge, and a numerical example is conducted. Section 4 concludes.

2. Statement of the problem

Let us assume a two-echelon SC in which a manufacturer ("he") replenishes the inventories of a retailer ("she") with a single product type. Orders are placed each period. Let n be the index of review periods. At the beginning of each period, the retailer orders inventory from the manufacturer, based on expected demand for future periods, and the manufacturer ships the inventory immediately. The lead time from the manufacturer to the retailer is equal to L periods. If the manufacturer does not have enough inventory to meet the retailer's current order, he then uses an outside source at an additional cost (see [14,8]). Next, the manufacturer produces inventory, based on the expected retailer order for the next period. The random demand at the retailer for period n is denoted by d_n, and it is a simple autoregressive AR(1) process

$$d_1 - \mu = \varepsilon_1, \qquad d_n - \mu = \alpha(d_{n-1} - \mu) + \varepsilon_n, \quad n > 1, \tag{1}$$

where $\varepsilon_1 = \varepsilon_1^0$ and $\varepsilon_n = \varepsilon_{n-1}^r + \varepsilon_{n-1}^m + \varepsilon_n^0$, $n > 1$. Here, μ is the non-conditional expected value of the periodic demand, $0 \le \alpha < 1$, while ε_{n-1}^r and ε_{n-1}^m are information observed by the retailer and the manufacturer respectively during period $n-1$. This information, based on signals as promotion plans, changes in weather conditions, security alertness, etc., statistically explains the demand for period n. According to [3], the demand process remains AR(1) under these assumptions. We assume that $\varepsilon_n^t \sim \mathrm{N}(0, \sigma_t^2)$ and $\mathrm{Cor}(\varepsilon_n^t, \varepsilon_n^0) = 0$ for $t \in \{r, m\}$. Generally, the white noise ε_n is based on a trivariate normal distribution, and its three components may be correlated. For example, if ε_{n-1}^r and ε_{n-1}^m are based on weather forecast, then the retailer's information is supposed to be correlated with the manufacturer's information. For instance, [3] assumes that ε_{n-1}^r and ε_{n-1}^m are correlated for every n, but disregards partial information sharing. However, for mathematical tractability, derived from the partial information sharing, we assume that those components are not correlated. This may be the case when the manufacturer, who comes in contract with several customers for different products, has information regarding the future demand which is not known to a local retailer. Furthermore, the most significant effect of information sharing is obtained while the components are not correlated. The standard deviations σ_t are assumed to be significantly smaller than μ, so that the probability of negative demand is negligible (e.g., [14]). Also, both the retailer and the manufacturer adopt the order-up-to policy, (e.g., [12,13]). We assume that the constant parameters are well known to both sides, and first analyze the retailer's model.

2.1. The retailer's model

Let J_n^r denote the net inventory at the retailer's facility at the end of period n. At that time period, the retailer's holding cost and penalty cost are respectively $C_{h,n}^r(J_n^r) = h_r \cdot \max(J_n^r, 0)$ and $C_{p,n}^r(J_n^r) = p_r \cdot \max(-J_n^r, 0)$, where h_r and p_r denote the costs per unit, and the total cost is

$$C_n^r = C_{h,n}^r + C_{p,n}^r. \tag{2}$$

At the beginning of period n, the retailer orders A_n units of inventory, which will arrive at her facility at the beginning of $n + L$. At the end of $n + L$, the net inventory of the retailer will be $J_{n+L}^r = Y_n^r - \sum_{k=0}^{L} d_{n+k}$, where Y_n^r denotes the base-stock level to which the retailer orders up. We use $f_X(.)$ and $F_X(.)$ to denote respectively the pdf and cdf of a random variable X. The value of Y_n^r that minimizes the retailer's periodic expected cost is

$$Y_n^{r^*} = F^{-1}_{\sum_{k=0}^{L} d_{n+k}}(p_r/(h_r + p_r)). \tag{3}$$

From (1) we obtain (if $L \ge 1$)

$$\begin{aligned}\sum_{k=0}^{L} d_{n+k} = {} & \frac{\alpha(1-\alpha^{L+1})}{1-\alpha}(d_{n-1} - \mu) + (L+1)\mu \\ & + \left(\frac{1-\alpha^{L+1}}{1-\alpha}\right)(\varepsilon_{n-1}^r + \varepsilon_n^0 + \varepsilon_{n-1}^m) \\ & + \sum_{k=1}^{L}\left(\frac{1-\alpha^{L+1-k}}{1-\alpha}\right)\varepsilon_{n+k}.\end{aligned} \tag{4}$$

The distribution of the components of ε_n in (4) depends on the level of information sharing between the SC members. We assume that the retailer shares all of her information about ε_{n-1}^r. As $\alpha \ge 0$ (due to [16]), the manufacturer's cost is influenced only negligibly by the information received from the retailer. Sharing of the manufacturer's information on ε_{n-1}^m may be significant for both sides. Therefore we consider three different information sharing levels: No sharing at all, sharing all of the information, and partial sharing. The expectation and standard deviation of (4) are respectively

$$\begin{aligned} m_n = {} & \alpha(1-\alpha^{L+1})(d_{n-1} - \mu)/(1-\alpha) + (L+1)\mu \\ & + (1-\alpha^{L+1})(\varepsilon_{n-1}^r + x_1)/(1-\alpha), \quad \text{and}\end{aligned} \tag{5}$$

$$S_n = \sqrt{(\sigma_r^2 + \sigma_m^2 + \sigma_0^2)\sum_{k=1}^{L}\left(\frac{1-\alpha^{L+1-k}}{1-\alpha}\right)^2 + \left(\frac{1-\alpha^{L+1}}{1-\alpha}\right)^2(\sigma_0^2 + y_1)}, \tag{6}$$

where the components x_1 and y_1 depend on the level of information sharing. Let $\Phi(\cdot)$ denote the cdf of the standard normal distribution. While $\sum_{k=0}^{L} d_{n+k}$ is normally distributed, the optimal base-stock (3) is equal to

$$Y_n^{r^*} = m_n + \Phi^{-1}(p_r/(h_r + p_r))S_n. \tag{7}$$

Under no information sharing, the value of ε_{n-1}^m is not known to the retailer, and therefore $x_1 = 0$ and $y_1 = \sigma_m^2$ in (5) and (6) respectively. Under full information, at the beginning of n the retailer knows the exact value of ε_{n-1}^m. In this case, we get $x_1 = \varepsilon_{n-1}^m$ and $y_1 = 0$. Clearly, the variance (6) is reduced.

Regarding partial information from the manufacturer, the latter informs the retailer of an interval $[-4\sigma_m, 4\sigma_m]$ within which ε_{n-1}^m lies. Due to the normal distribution, the interval is defined as 4 standard deviations so that the probability of having values out of this interval is negligible. Let $K \ge 1$ be an integer. A level of information equal to K means that the interval $[-4\sigma_m, 4\sigma_m]$ is partitioned into K equal subintervals, and there exists a unique $0 \le i_n^m \le K-1$ such that $\varepsilon_{n-1}^m \in [-4\sigma_m + (i_n^m/K)8\sigma_m, -4\sigma_m + ((i_n^m+1)/K)8\sigma_m]$: the manufacturer updates the retailer about that i_n^m. The only component in the RHS of (4) which is neither constant nor normally distributed from the retailer's standpoint is $\varepsilon_{n-1}^m(1-\alpha^{L+1})/(1-\alpha)$. Assume that the level of information from the manufacturer to the retailer is K, and denote $a_n^m = -4\sigma_m + 8i_n^m\sigma_m/K$ and