Effective Quick Response in a Supply Chain

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Abstract. When an industry brings a new product to the market, a preliminary survey is usually conducted to grasp the demand. In the case of a retail store dealing in fashion or apparel goods, however, a prompt action is a key to win in the competition among other retail stores. This study deals with a quick response model, which is effective in supply chain management, for a retail store selling fashion or apparel goods. In this study, we consider to begin the sales of new products with a suitable lot size, and then observe the sales of each individual product for a relatively short period (monitoring period). Based on the demand quantity during the monitoring period, we derive the total demand distribution of each product over the monitoring period and its subsequent sales period (regular sales period) to determine an adequate reorder quantity of each product to the manufacturer. If the demand for a product during the regular sales period should exceed the order quantity of the product, the retailer will undergo the opportunity loss. On the other hand, when the demand during the regular period is less than the order quantity, the retailer will suffer from the dead stock. This indicates that the underlying problem is basically a newsvendor problem. Numerical examples are also presented to illustrate the proposed method.

Keywords: apparel, POS data, bivariate normal distribution, newsvendor problem

1. INTRODUCTION

Quick response (QR) was developed as an inventory management strategy with the idea to respond quickly to market changes by cutting lead time (Iyer and Bergen, 1997). It was first implemented in the middle 1980s by American apparel supply chains (Choi and Sethi, 2010). In the basic QR, a retailer sends POS data to its supplier, who then uses this information to improve demand forecasting and adjust production schedules.

Fisher and Raman (1996) is an early review and discussion of apparel QR supply chains that focused on the case, wherein the replenishment lead time is longer than the selling season. They modeled the total and first period demands as a bivariate normal distribution and found a strong correlation between the two. Gurnani and Tang (1999) conducted a single-period, two-order study with information updating under a bivariate normal model. Their study, motivated by the innovative work of Fisher and Raman (1996), also considered the case, wherein the replenishment lead time is longer than the selling season. The information was updated using the demand information after the initial order, and the newsvendor problem was applied to determine the optimal sizes of the initial and second orders.

In this study, we begin the sales of new products with suitable lot sizes for a relatively short period (monitoring period in the following), during which the sales tracking of each product is conducted. Based on the demand quantity during this monitoring period, we consider to derive the total demand distribution of each product over the monitoring and its subsequent relatively long sales period (regular sales period in the following). The lead time for a retail store is not very long because the order quantity from a retail store to the manufacturer is not very large in many cases, accordingly the monitoring period can be relatively short. It is, however, noted the initial quantity of each product at the store should be suitably large, sufficiently larger than the demand quantity during the monitoring period.

If the total demand for a product during the whole sales period exceeds the retailer's total order quantity, the retailer will undergo sales opportunities. Conversely, if the total demand during the whole sales period is less than the total order quantity, the retailer will need to carry over the remaining stock, which might be dead stock. This indicates that the underlying problem is significantly related to the demand forecasting problem associated with the newsvendor problem.

In Section 2, we review the relevant literature, and Section 3 describes our strategy. In Section 4, we present numerical examples to demonstrate the effectiveness of the proposed strategy. Finally, Section 5 gives our conclusions.

2. LITERATURE REVIEW

Choi and Sethi (2010) gave an extensive overview of work on QR. They divided the literature into three major areas: supply information management, demand information management, and the value of information and supporting technologies.

In supply information management, the main focus has been placed on optimal ordering and replenishment policies. Iyer and Bergen (1997) examined a QR strategy for a single-supplier single-retailer supply chain as the simplest case using single-period and single-order settings. Lau and Lau (1997) examined the single-period, two-order setting using normal and beta distribution, and compared the newsvendor problem in the two settings.

The demand information management literature presents many studies of the advance booking model. To quantify the benefits of advance booking orders, Weatherford and Pfeifer (1994) compared the expected profits against a range of economic and demand distribution parameters using illustrative numerical examples. Tang et al. (2004) used a single-firm model to quantify the benefits of the advance booking discount program and showed that inventory costs in the supply chain could be reduced. The literature also features studies of the impact by strategic consumers. Cachon and Swinney (2009) and Swinney (2011) examined the impact of QR on strategic consumer purchasing behavior. The studies demonstrated that strategic consumers were more willing to purchase at the regular price under QR (Cachon and Swinney, 2009) and that adopting QR may either increase or decrease the firm's profits as strategic consumers acquire the awareness of the product value (Swinney, 2011).

As for value of information and supporting technologies, the literature has studied the vendor management inventory (VMI) implementation, which has established itself as an important and widely used measure in QR supply chain management. Achabal et al. (2000) described the market forecasting and inventory management of the VMI decision support system and investigated the implementation of this system by a major apparel manufacturer and over 30 of its retail partners.

3. MODEL

In this section, we describe our model In Section 3.1, we show the notations and assumptions. In Section 3.2, we derive the conditional distribution of the total demand Y_i of item i over the monitoring period and the regular sales period when the demand X_i during the monitoring period t is observed. Section 3.3, we show how order quantity is determined on the basis of the total demand distribution above by applying the concept of the newsvendor problem. In Section 3.4, we describe our strategy for deciding whether to reorder. In Section 3.5, we show method of parameters.

3.1 Notations and Assumptions

The notations and assumptions in this study are as follows:

X_i : A random variable representing the demand quantity for item i $(i = 1,2,\cdots,n)$ during the monitoring period t

Y_i : A random variable representing the demand quantity for item i $(i = 1,2,\cdots,n)$ over the monitoring period and the regular sales one

$\mathbf{X}_i = (X_i, Y_i)$: i.i.d. random vector with $\mathbf{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma})$

$\boldsymbol{\mu} = (X_i, Y_i)$: Mean vector of $\mathbf{X}_i = (X_i, Y_i)$

$\boldsymbol{\Sigma} = \begin{pmatrix} \sigma_X^2 & \rho\sigma_X\sigma_Y \\ \rho\sigma_X\sigma_Y & \sigma_Y^2 \end{pmatrix}$: The variance-covariance matrix of $\mathbf{X}_i = (X_i, Y_i)$

σ_X^2 : Variance of X_i

σ_Y^2 : Variance of Y_i

ρ : Correlation coefficient

$Q_{i,0}$: Initial ordering quantity before the starting sales period of item i

$Q_{i,t}$: Reordering quantity at monitoring period t of item i

$\pi(Q_{i,t})$: Expected profit when the ordering quantity is $Q_{i,t}$

p_i : Selling price of item i

w_i : Raw price of item i $(w_i < p_i)$

v_i : Salvage value of item i $(v_i < w_i < p_i)$

c_i : Opportunity loss of item i

$\boldsymbol{\Phi}(\cdot)$: Cumulative distribution function of the standard normal distribution

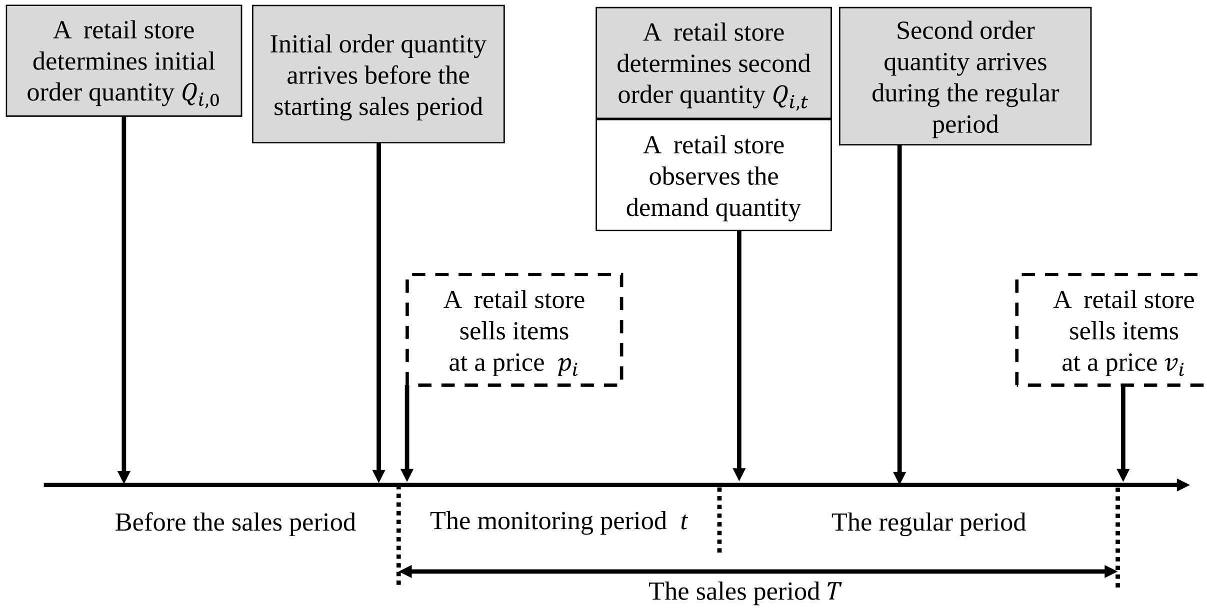

Figure 1: Event in the quick response strategy

In this study, we consider a multiple item supply chain when the lead time is shorter than the sales period. Generally, a retail store selling fashion items determines its initial order quantity $Q_{i,0}$ of item i using the past historical demand information of similar items in the similar category. However, if the demand of item i during monitoring period should unexpectedly grows very rapidly to exceed $Q_{i,0}$, we order an additional quantity $Q'_{i,0}$ before all the initial quantity $Q_{i,0}$ sells out and define $Q_{i,t}$ by letting $Q_{i,t} = Q_{i,0} + Q'_{i,0}$. It is assumed here that $Q'_{i,0}$ would be replenished before $Q_{i,0}$ sells out.

In the real circumstances, determination of the additional order quantity along with the timing of the additional order might be another problem to be solved. However, we do not deal with such a problem with the view to focusing on the determination of the reorder quantity for the regular sales period.

Figure 1 shows the procedure of our model briefly. The shading squares show event related to the order, the normal square shows event related to demand and the dot-line squares show event related to sales. All arrows show timing of event.

3.2 Total Demand Distribution

When the retailer observes the demand quantity $X_i = \sum_{j=1}^{t} d_{i,j} = D_i$ of item i during the monitoring period, the conditional distribution of the total demand quantity Y_i is given by $N(\mu', \sigma'^2)$, where we have

$$\mu' = \mu_Y + \rho\sigma_Y \frac{D_i - \mu_X}{\sigma_X} \tag{1}$$

$$\sigma' = \sigma_Y \sqrt{1-\rho^2} (\le \sigma_Y) \tag{2}$$

We have shown that the total demand distribution is given by $\mathbf{N}(\mu', \sigma'^2)$ .Next subsection overviews the newsvendor problem which provides an optimal reorder quantity for the regular sales period.

3.3 Newsvendor Problem

It is assumed here that when some items remains unsold at the end of the regular sales period, we can sell all of them at the clearance sale by setting its price as the salvage value v_i . Hence, item i generates the expected profit given by

$$\begin{aligned}\pi(Q_{i,t}) = &-Q_{i,t} w_i \\ &+E[p_i \times \min(Y_i, Q_{i,t}) \\ &+v_i (Q_{i,t} - Y_i)^+ - c_i (Y_i - Q_{i,t})^+]\end{aligned} \tag{3}$$

The retailer would seek to maximize $\pi(Q_{i,t})$ in Eq. (3) with respect to $Q_{i,t}$, which is the optimal reorder quantity.

It is, however, well known that the optimal quantity $Q_{i,t} = Q^*_{i,t}$ is given by the solution to the following equation:

$$F(Q^*_{i,t}) = \Phi\left[\frac{Q^*_{i,t} - \mu'}{\sigma'}\right] = \frac{p_i + c_i - w_i}{p_i + c_i - v_i} \qquad (4)$$

3.4 Reorder Quantity

The optimal reorder quantity can be discussed as follows:

(i) If we have $Q_{i,0} < Q_{i,t}$, the optimal reorder quantity is given by $Q_{i,t} - Q_{i,0}$, and the expected profit becomes $\pi(Q_{i,t})$.
(ii) Otherwise, we should not make a reorder, and the expected profit is given by $\pi(Q_{i,t})$

3.5 Parameters

In 3.2, we assumed that values of the parameters involved in the bivariate normal distribution, $\mathbf{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma})$, are known. This subsection considers how we can estimate them. By focusing upon item i, one of the simplest methods could be described as follows:

(1) Estimate $\boldsymbol{\mu}$ and $\boldsymbol{\Sigma}$ using the past demand data of similar items to item i of current concern during the monitoring and the regular sales period.

(2) Observe the demand quantity $X_i = \sum_{j=1}^{t} d_{i,j} = D_i$ of item i during the monitoring period.

(3) Obtain μ' and σ' by Eqs. (1) and (2), respectively, and then the total demand quantity Y_i follows $N(\mu', \sigma'^2)$.

4. NUMERICAL EXAMPLES

In this study, we could acquire actual weekly time series sales data of 296 kinds of apparel products during a single season at a retail store from some specific industry. Their selling price ranges from 9,800 yen to 18,000 yen. Based on these data, we discuss the effectiveness of our model through numerical examples. Especially, we investigate the influence of introducing a monitoring period prior to the regular sales period upon the total shortage cost incurred by stock-out to show the effectiveness of our model.

In the following, we consider three cases for the length of the monitoring period as shown in Table 1.

As mentioned before, the data set is for a single season, and therefore we regard the sales data during the same period as the monitoring period in Table 1 as the demand quantity during the actual monitoring period. The subsequent weekly sales data are regarded as the demand quantity during the regular sales period.

Table 1: Three cases associated with monitoring period

Monitoring period	t
For 1st week	1
For 1st and 2nd week	2
For 1st, 2nd and 3rd week	3

Table 2 shows parameter values of the model, where they are represented in terms of the ratio of selling prices. Since the data set is for a single season, we regard those of 100 randomly selected products as the past data to estimate the parameter values involved in the bivariate normal distribution. Table 3 indicates the estimates of such parameters. The sales data set of the remaining 196 products is treated as the sales in the current season. It is, however, assumed that the sales data corresponding to the monitoring period are presently available and we are to forecast the total demand quantity on the basis of the sales data during the monitoring period as well as the past data.

Table 2: Parameter values of the model.

p	Selling price	¥9,800～¥18,000
w	Raw price	$p \times 0.4$
v	Salvage value	$p \times 0.2$
c	Opportunity loss	$p - w$

Table 3: Parameter estimates of a bivariate normal distribution

t	1	2	3
μ_X	32.090	55.500	85.400
σ_X	46.001	77.069	116.194
μ_Y	268.360		
σ_Y	363.331		
ρ	0.972	0.978	0.984

For the purpose of examining the total shortage cost in the case of no monitoring period, the initial order quantity is $Q_{i,0}$ is determined by solving a newsvendor problem on the basis of the normal distribution $N(\mu_Y, \sigma_Y^2)$. The result is $Q_{i,0} = 603$. This initial order quantity, $Q_{i,0} = 603$, is applied to all the three case in Table 1 as well. This is because we emphasize the difference in the length of monitoring periods.

Table 4: Shortage and carried-over (selling price ranging from 9,800 to 18,000 yen)

Monitoring period	Number of short items	Number of carried-over items
$t=0$	23,508	70,243
$t=1$	8,433	71,438
$t=2$	5,526	71,268
$t=3$	3,663	71,129

Table 4 reveals the total number of short items along with the total number of carried-over items in the three cases along with the case of $t=0$. It is observed in Table 4 that introducing a monitoring period prior to the regular sales period can reduce the number of short items sharply and efficiently with slight increase in the number of unsold and carried-over items, which is most significant in QR. It is also shown that the longer monitoring period tends to reduce more shortage without increasing the number of carried-over items remarkably.

We could acquire two more data sets for the same season, the selling price of one of them ranges from 19,800 yen to 28,000 yen while the selling price of the other data set ranges from 4,980 yen to 9,500 yen. We analyzed these two data sets in the same way and obtained Tables 5 and 6. Both tables indicate the similar results to the above mentioned.

Table 5: Shortage and carried-over (selling price ranging from 19,800 to 28,000 yen)

Monitoring period	Number of short items	Number of carried-over items
$t=0$	11,977	918
$t=1$	3,872	1,214
$t=2$	2,473	1,160
$t=3$	943	1,360

Table 6: Shortage and carried-over (selling price ranging from 4,980 to 9,500 yen)

Monitoring period	Number of short items	Number of carried-over items
$t=0$	23,797	151,831
$t=1$	4,968	161,872
$t=2$	3,871	160,448
$t=3$	3,038	159,061

When we compare Tables 4, 5, and 6, it can be observed that the number of short items decreases with increasing selling price. This is because the conditional variance of demand quantity for lower-price products, which is given by Eq. (2), is much larger than that of higher-price products, and presumably the opportunity loss of higher-price products is relatively larger than that of lower-price products.

It is also shown in Tables 4, 5, and 6 that the number of carried-over items tends to decrease with increasing selling price. This can also be explained in terms of the conditional variance of demand quantity; the conditional variance of demand quantity for lower-price products is larger than that of higher-price products, indicating the number of carried-over items in Table 6 is much larger than those in Tables 4 and 5. In addition, the large number of carried-over items are partly due to the large size of the initial order quantity; it is set to identical to that with no monitoring period.

5. CONCLUSIONS

In this study, we proposed a strategy for inventory control when the replenishment lead time is relatively shorter than the sales period. In the case of a relatively small-scale retail store, the order quantity of each individual product is also smaller, accordingly the lead time is shorter than that of large-scale retail store.

Under the proposed strategy, we divide the sales period into two periods; one is the monitoring period, which is a short period, and the other is the regular sales period which is a long period. Before the monitoring period starts, we make an initial order for individual products and observe the demand quantity during the monitoring period. Just before the monitoring period ends, we make a reorder for each product so that we can sell them during the regular sales period without undergoing stock-out.

Presented were numerical examples through which we discussed the effectiveness as well as the efficiency of our strategy. As a result, introducing a monitoring period prior to the regular sales period would be able to remarkably reduce the number of short items, and thereby reduce the total shortage cost.

In this study, however, the initial order quantity is assumed to be adequately determined so that we would not undergo the stock-out during the monitoring period. The determination of the initial order quantity is another problem to be solved for the future work.

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