Optimum Settings of Process Mean, Economic Order Quantity, and Commission Fee

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Abstract

In the present paper we modify Chen and Liu's model by considering both consignment policy and quality loss of products. Taguchi's quadratic quality loss function is adopted for evaluating the product quality. The optimal parameters of manufacturer's process mean and commission fee and retailer's economic order quantity are simultaneously determined by maximizing the expected total profit of society. A comparative study between the modified model and the original Chen and Liu's model is provided for illustration. Numerical results show that the selling price per unit and the mean of the demand of customer have major effects on the expected profit of the supply chain system.

Key Words: Economic Order Quantity, Commission Fee, Taguchi's Quadratic Quality Loss Function, Process Mean, Consignment Policy

1. Introduction

In a supply chain system, the trade-off problem between manufacturer and retailer to obtain the maximum expected total profit of society always receive considerable attention. The manufacturer considers the sale, manufacturing, inventory, shipment, and management of products for obtaining the maximum expected profit. Meanwhile, the retailer considers the order quantity, the holding cost, and the goodwill loss for obtaining the maximum expected profit. Seifert et al. [1] explained the resulting procurement change and then proposed the benefits of using spot markets from a supply chain perspective. Consequently, they developed a mathematical model that determines the optimal order quantity via forward contracts and spot markets. Haksoz and Seshadri [2] had a discussion on the supply chain system with spot markets and presented a literature review of recent related works.

Chen and Liu [3] presented the optimum profit model between the producers and the purchasers for the supply chain system with pure procurement policy from the regular supplier and with mixed procurement policy from the regular supplier and the spot market. Chen and Liu [4] further proposed an optimal consignment policy considering a fixed fee and a per-unit commission. Their model determines a higher manufacturer's profit than the traditional production system and coordinates the retailer to obtain a large supply chain profit. Li and Liu [5] considered the problem for the retailer determining his optimal order quantity and for the manufacturer determining his optimal reserve capacity. Their model is able to enhance profit for both sides of the supply chain. Chen and Huang [6] addressed the problem that the retailers purchase their products from options and online spot markets for hedging the risk of demand uncertainty.

Economic selection of the mean of process characteristic is an important problem for modern statistical process control because it usually has a significant effect

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on the expected profit/cost per item. Recently, many researchers have addressed this work in which both 100% and sampling inspection of products are considered for different models. Taguchi [7] presented the quadratic quality loss function for redefining the product quality. Hence, based on this quality loss function, the optimum product quality should lead to the quality characteristic with minimum bias and variance. Recently, this quality loss function has been successfully applied in the problem of optimum process mean setting.

Chen and Liu's model [4], which is assumed that the product quality is perfect, with consignment policy did not consider the used cost of customers. Hence, in the present paper, we propose a modified Chen and Liu's model with quality loss function and 100% inspection for product, where the quality characteristic of product is assumed to be normally distributed. Taguchi's [7] quadratic quality loss function is applied in evaluating the product quality. The optimal retailer's order quantity and the manufacturer's process mean and commission fee are jointly determined by maximizing the expected total profit of society including the manufacturer and the retailer [8]. The motivation behind this work stems from the fact that neglect of the quality loss of product may overestimate the expected total profit of society.

2. Modified Chen and Liu's Consignment Policy

To simplify mathematical manipulations, some assumptions are made in the modified Chen and Liu's model as follows:

1. The demand of customer (X) and the quality characteristic of product (Y) are independent.
2. The variable production cost per unit is proportional to the value of quality characteristic of product.
3. Imperfect products occur in the production system and the 100% inspection of product is executed before shipping to the customer.
4. The non-conformance of product is scrapped and sold at a lower price.
5. The used cost of product is measured using Taguchi's quadratic quality loss function.
6. The manufacturer guarantees that the retailer will be at least as well-off as in the traditional production system.

By applying the loss function, the retailer's profit may be expressed by

$$\pi_r^{CP} = \begin{cases} \alpha X - h_r(Q-X) + A_1 - X \cdot Loss(Y), X < Q, L \le Y \le U \\ \alpha Q - S_r(X-Q) + A_1 - Q \cdot Loss(Y), X \ge Q, L \le Y \le U \end{cases} \tag{1}$$

Then the retailer's expected profit can be obtained as follows:

$$\begin{aligned} E(\pi_r^{CP}) = \{ & \frac{1}{2\sigma_x}(\alpha + h_r)\cdot\left[Q^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right] \\ & -\left[Qh_r\frac{1}{\sigma_x}\left(Q - \mu_x + \frac{1}{2}\sigma_x\right)\right] - s_r\cdot\frac{1}{2\sigma_x}\cdot\left[(\mu_x + \frac{1}{2}\sigma_x)^2 - Q^2\right] \\ & +(\alpha + s_r)\frac{1}{\sigma_x}\cdot\left[\mu_x + \frac{1}{2}\sigma_x - Q\right]Q + A_1\}\cdot B \\ & -\frac{A}{2\sigma_x}\left[Q^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right] - Q\cdot\left(\mu_x + \frac{1}{2}\sigma_x - Q\right)\cdot\frac{A}{\sigma_x} \end{aligned} \tag{2}$$

where

$$\begin{aligned} A = k\{ & [(\mu_y - y_0)^2 + \sigma_y^2]\cdot\left[\Phi\left(\frac{U-\mu_y}{\sigma_y}\right) - \Phi\left(\frac{L-\mu_y}{\sigma_y}\right)\right] \\ & +\sigma_y[(\mu_y - 2y_0 + L)\phi\left(\frac{L-\mu_y}{\sigma_y}\right) - (\mu_y - 2y_0 + U)\phi\left(\frac{U-\mu_y}{\sigma_y}\right)]\} \end{aligned} \tag{3}$$

$$B = \Phi\left(\frac{U-\mu_y}{\sigma_y}\right) - \Phi\left(\frac{L-\mu_y}{\sigma_y}\right) \tag{4}$$

Letting the partial derivative of Eq. (2) with respect to Q be zero, i.e., $\frac{\partial E(\pi_r^{CP})}{\partial Q} = 0$, results in the optimal order quantity for the retailer as follows:

$$Q_r^* = (\mu_x - \frac{\sigma_x}{2}) + \frac{[(\alpha + s_r)B - A]\sigma_x}{[(\alpha + s_r + h_r)B - A]} \tag{5}$$

The profit of the supply chain system can be given by

$$\pi_t^{CP} = \begin{cases} RX - (b+cy+i)Q - h_t(Q-X) - X \cdot Loss(Y), \\ X < Q,\ L \le Y \le U \\ RQ - (b+cy+i)Q - s_t(X-Q) - Q \cdot Loss(Y), \\ X \ge Q,\ L \le Y \le U \\ (S_p - b - cy - i)Q, \mu_x - \dfrac{\sigma_x}{2} < X < \mu_x + \dfrac{\sigma_x}{2}, \\ Y < L \text{ or } Y > U \end{cases} \tag{6}$$

Therefore, the supply chain system's expected profit can be obtained as follows:

$$E(\pi_t^{CP}) = \{\frac{1}{2\sigma_x}(R+h_t)\cdot\left[Q^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right] - \left[Qh_t\frac{1}{\sigma_x}\left(Q - \mu_x + \frac{1}{2}\sigma_x\right)\right] - s_t\cdot\frac{1}{2\sigma_x}\cdot\left[(\mu_x + \frac{1}{2}\sigma_x)^2 - Q^2\right] + (R+s_t)\frac{1}{\sigma_x}\cdot\left[\mu_x + \frac{1}{2}\sigma_x - Q\right]Q\}\cdot B - \frac{A}{2\sigma_x}\left[Q^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right] - Q\cdot\left(\mu_x + \frac{1}{2}\sigma_x - Q\right)\cdot\frac{A}{\sigma_x} + S_p(1-B)Q - (b + c\mu_y + i)Q \tag{7}$$

Letting the partial derivative of Eq. (7) with respect to Q be zero, i.e., $\frac{\partial E(\pi_t^{CP})}{\partial Q} = 0$, leads to the optimal order quantity for the supplier chain system as follows:

$$Q_t^* = (\mu_x - \frac{\sigma_x}{2}) + \frac{[(R+s_r)B - A + Z_{11}]\sigma_x}{[(R+s_t+h_t)B - A]} \tag{8}$$

where

$$Z_{11} = S_p(1-B) - b - c\mu_y - i \tag{9}$$

Setting $Q_r^* = Q_t^*$ gives the optimal per-unit commission as follows:

$$\alpha^* = -s_r + \frac{[(R+s_t)B - A + Z_{11}]h_r B + A(h_t B - Z_{11})}{(h_t B - Z_{11})B} \tag{10}$$

The profit of the manufacturer can be expressed by:

$$\pi_m^{CP} = \begin{cases} (R-\alpha)X - (b+cy+i)Q - h_m(Q-X) - A_1, X < Q,\ L \le Y \le U \\ (R-\alpha)Q - (b+cy+i)Q - s_m(X-Q) - A_1, X \ge Q,\ L \le Y \le U \\ (S_p - b - cy - i)Q, \mu_x - \dfrac{\sigma_x}{2} < X < \mu_x + \dfrac{\sigma_x}{2},\ Y < L \text{ or } Y > U \end{cases} \tag{11}$$

Thus, the manufacturer's expected profit can be obtained as follows

$$E(\pi_m^{CP}) = \{\frac{1}{2\sigma_x}(R-\alpha+h_m)\cdot\left[Q^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right] - \left[Qh_m\frac{1}{\sigma_x}\left(Q - \mu_x + \frac{1}{2}\sigma_x\right)\right] - s_m\cdot\frac{1}{2\sigma_x}\cdot\left[(\mu_x + \frac{1}{2}\sigma_x)^2 - Q^2\right] + (R-\alpha+s_m)\frac{1}{\sigma_x}\cdot\left[\mu_x + \frac{1}{2}\sigma_x - Q\right]Q - A_1\}\cdot B + S_p(1-B)Q - (b + c\mu_y + i)Q \tag{12}$$

There are four decision variables in the modified Chen and Liu's model with consignment policy, including order quantity (Q), per-unit commission (α), fixed commission (A_1), and process mean of product (μ_y). The mathematical model for obtaining the optimal values of these decision variables is as follows:

$$\text{Max } E(\pi_m^{CP}) \tag{13}$$

subject to

$$E(\pi_r^{CP}) \ge E(\pi_r^{PS}) \tag{14}$$

where

$$E(\pi_r^{PS}) = \{\frac{1}{2\sigma_x}(R+H)\cdot\left[Q_1^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right] - \left[Q_1(W_1+H)\cdot\frac{1}{\sigma_x}\left(Q_1 - \mu_x + \frac{1}{2}\sigma_x\right)\right] \cdot\left[\Phi\left(\frac{U-\mu_y}{\sigma_y}\right) - \Phi\left(\frac{L-\mu_y}{\sigma_y}\right)\right] - \frac{1}{2\sigma_x}\left[Q_1^2 - \left(\mu_x - \frac{1}{2}\sigma_x\right)^2\right]\}\cdot A + (R - W_1 + S)\cdot Q_1\cdot\left(\mu_x + \frac{1}{2}\sigma_x - Q_1\right)\cdot\frac{1}{\sigma_x}$$

$$\cdot\left[\Phi\left(\frac{U-\mu_y}{\sigma_y}\right)-\Phi\left(\frac{L-\mu_y}{\sigma_y}\right)\right]-S\cdot\frac{1}{2\sigma_x}\cdot\left[(\mu_x+\frac{1}{2}\sigma_x)^2-Q_1^2\right]$$
$$\cdot\left[\Phi\left(\frac{U-\mu_y}{\sigma_y}\right)-\Phi\left(\frac{L-\mu_y}{\sigma_y}\right)\right]-\frac{1}{\sigma_x}\cdot\left[\mu_x+\frac{1}{2}\sigma_x-Q_1\right]Q_1\cdot A \tag{15}$$

$$A=k\{[(\mu_y-y_0)^2+\sigma_y^2]\cdot\left[\Phi\left(\frac{U-\mu_y}{\sigma_y}\right)-\Phi\left(\frac{L-\mu_y}{\sigma_y}\right)\right]$$
$$+\sigma_y[(\mu_y-2y_0+L)\phi\left(\frac{L-\mu_y}{\sigma_y}\right)-(\mu_y-2y_0+U)\phi\left(\frac{U-\mu_y}{\sigma_y}\right)]\} \tag{16}$$

$$Q_1=\frac{[A-(R+H+S)B]\mu_x+\frac{1}{2}[A-(R+S-H-2W_1)B]\sigma_x}{A-(R+H+S)B} \tag{17}$$

$$W_1=\frac{\frac{1}{2}\sigma_x[(S+R-H+2t)B-A]+\mu_x[(R+H+S)\cdot B-A]}{2B\sigma_x} \tag{18}$$

$$B=\Phi\left(\frac{U-\mu_y}{\sigma_y}\right)-\Phi\left(\frac{L-\mu_y}{\sigma_y}\right) \tag{19}$$

$$t=\frac{b+c\mu_y+i-S_p\left[1-\Phi\left(\frac{U-\mu_y}{\sigma_y}\right)+\Phi\left(\frac{L-\mu_y}{\sigma_y}\right)\right]}{\Phi\left(\frac{U-\mu_y}{\sigma_y}\right)-\Phi\left(\frac{L-\mu_y}{\sigma_y}\right)} \tag{20}$$

$$E_1(\pi_r^{CP})=\{\frac{1}{2\sigma_x}(\alpha+h_r)\cdot\left[Q_t^2-\left(\mu_x-\frac{1}{2}\sigma_x\right)^2\right]$$
$$-\left[Q_t h_r\frac{1}{\sigma_x}\left(Q_t-\mu_x+\frac{1}{2}\sigma_x\right)\right]-s_r\cdot\frac{1}{2\sigma_x}\cdot\left[(\mu_x+\frac{1}{2}\sigma_x)^2-Q_t^2\right]$$
$$+(\alpha+s_r)\frac{1}{\sigma_x}\cdot\left[\mu_x+\frac{1}{2}\sigma_x-Q_t\right]Q_t\}\cdot B$$
$$-\frac{A}{2\sigma_x}\left[Q_t^2-\left(\mu_x-\frac{1}{2}\sigma_x\right)^2\right]-Q_t\cdot\left(\mu_x+\frac{1}{2}\sigma_x-Q_t\right)\cdot\frac{A}{\sigma_x} \tag{21}$$

$$Q_t=(\mu_x-\frac{\sigma_x}{2})+\frac{[(R+s_r)B-A+Z_{11}]\sigma_x}{[(R+s_t+h_t)B-A]} \tag{22}$$

$$Z_{11}=S_p(1-B)-b-c\mu_y-i \tag{23}$$

$$\alpha=-s_r+\frac{[(R+s_t)B-A+Z_{11}]h_rB+A(h_tB-Z_{11})}{(h_tB-Z_{11})B} \tag{24}$$

$$E(\pi_r^{CP})=E_1(\pi_r^{CP})+A_1B \tag{25}$$

$$A_1=[E(\pi_r^{PS})-E_1(\pi_r^{CP})]/B \tag{26}$$

The following solution procedure may be applied for obtaining the optimal solution of Eqs. (13) and (14):

Step 1. Substituting Eqs. (22), (24), and (25) into Eq. (13) results in the only one unknown decision variable, μ_y, in the model.

Step 2. Let L < μ_y < U. One may use the direct search method for obtaining the optimal μ_y^* with the maximum manufacturer's expected profit for the manufacturer.

Step 3. Substitute this optimal μ_y^* from Step 2 into Eqs. (22), (24), and (25). Then we can obtain the optimal values of order quantity (Q*), per-unit commission (α*), and fixed commission (A_1^*).

Step 4. Substituting the combination of decision variables (Q^*, α^*, A_1^*, μ_y^*) into Eqs. (2), (15), and (7) leads to the optimal expected profit of retailer for consignment policy, the optimal expected profit of retailer for traditional production system, and the optimal expected profit of supply chain system for consignment policy, respectively.

3. Numerical Example and Sensitivity Analysis

The market demand is assumed to have a uniform distribution with mean 100 and variability 200. The numerical example employs financial parameters of $R = 30$, $S = 0.1$, $H = 0.36$, $S_p = 0.1$, $s_r = 0.1$, $s_m = 0.1$, $s_t = 0.2$, $h_t = 0.36$, $h_m = 0.18$, $h_r = 0.18$, $b = 0.1$, $i = 0.02$, $c = 1$ and quality parameters $y_0 = 5$, $\sigma_y = 0.5$, $k = 4$, $L = 3$, $U = 7$. By applying the aforementioned solution procedure for solving Eqs. (13) and (14), we can obtain the optimal process mean $\mu_y^* = 4.79$, which results in the optimal order quantity $Q^* = 164$, the per unit commission $\alpha^* = 1.902$ and the fixed commission fee A_1^* = 424.23 with the manufacturer's expected profit $E(\pi_m^{CP}) = 1476.42$, the retailer's expected profit for traditional system $E(\pi_r^{PS}) = 482.25$ the retailer's expected profit for consignment policy $E(\pi_r^{CP})$ = 482.25 and the expected profit of the supply chain system $E(\pi_t^{CP}) = 1958.68$. The optimal solution of the original Chen and Liu's model is: the order quantity $Q^* = 191$, the per unit commission $\alpha^* = 3.437$ and the fixed commission fee $A_1^* = 352.75$ with the manufacturer's expected profit $E(\pi_m^{CP}) = 2067.87$ the retailer's expected profit for traditional system $E(\pi_r^{PS}) = 679.30$ the retailer's expected profit for consignment policy $E(\pi_r^{CP}) = 679.30$ and the expected profit of the supply chain system $E(\pi_t^{CP})$ = 2747.17.

Tables 1−2 list ±20% magnitude change for parameter values and show their effects on the order quantity, process mean, per unit commission, fixed commission fee, manufacturer's expected profit, retailer's expected profit, and expected profit of the supply chain system for both models. A parameter is considered as a major effect on the expected profit if the change magnitudes of manufacturer's, retailer's and supply chain system's expected profits are greater than 10%. From Tables 1−2, we may have the following two observations:

1. As the selling price per unit, R, increases, the order quantity increases, the process mean is almost constant, the per unit commission increases, and the fixed commission fee increases. The selling price per unit has a major effect on the manufacturer's expected profit, retailer's expected profit, and expected profit of the supply-chain system for both models.
2. As the mean of the demand of customer, μ_x, increases, the order quantity increases, the process mean increases, the per unit commission decreases, and the fixed commission fee increases. The mean of the demand of customer is a major effect to the manufacturer's expected profit, retailer's expected profit, and expected profit of the supply-chain system for both models.

4. Discussion and Conclusion

Comparing Tables 1−2 also gives the following results:

1. The modified Chen and Liu's model always leads to a smaller order quantity, per unit commission, manufacturer's expected profit, retailer's expected profit, and supply-chain system's expected profit than those of the original Chen and Liu's [4].
2. The modified Chen and Liu's model generally results in a larger fixed commission fee than that of the original Chen and Liu's [4].

These results reflect that neglect of the quality loss of product causes to overestimate the expected total profit of society when the quality loss of product and the used cost of customers exist. The retailer and manufacturer should adopt the conservative policy for procurement, production, and consignment.

The sensitivity analysis shows that the selling price per unit and the mean of the demand of customer have a major effect on the manufacturer's expected profit, retailer's expected profit, and expected profit of the supply-chain system. Hence, exact estimation on these parameters is always required to avoid any incorrect outcome.

In the present paper, we present a modified Chen and Liu's model with consignment policy and quality loss of product, which may be considered as a generation of the original Chen and Liu's model [4] by considering the imperfect product quality. The order quantity, process mean, per unit commission, and fixed commission are simultaneously determined in the modified model. The extension to modified Chen and Liu's model with multi-attribute quality characteristics may be left for further study.

Notations

α	the per-unit commission paid by the manufacturer to the retailer
Q	the order quantity by the retailer
h_r	the per-unit carrying cost for the retailer
s_r	the goodwill loss per unit of stock-out for the retailer
X	the stochastic demand of customer having an uniform distribution,

Table 1. The effect of parameters of optimal solution for modified Chen and Liu's [4] model

R	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
24	155	4.80	1.680	300.10	1044.65	338.39	1383.04
30	164	4.79	1.902	424.23	1476.42	482.25	1958.68
36	170	4.79	2.107	550.24	1914.35	628.19	2542.54
μ_x	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
80	144	4.77	1.940	298.63	1138.30	342.30	1480.60
100	164	4.79	1.902	424.23	1476.42	482.25	1958.68
120	184	4.81	1.867	506.06	1858.64	578.35	2436.99
σ_x	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
160	151	4.81	1.868	415.68	1568.88	476.41	2045.29
200	164	4.79	1.902	424.23	1476.42	482.25	1958.68
240	177	4.77	1.940	387.08	1429.91	442.40	1872.31
K	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
3.2	165	4.74	1.757	428.68	1494.09	488.14	1982.23
4.0	164	4.79	1.902	424.23	1476.42	482.25	1958.68
4.8	164	4.82	2.070	419.80	1459.80	476.71	1936.51
σ_y	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.4	165	4.79	1.558	431.70	1502.72	491.01	1993.73
0.5	164	4.79	1.902	424.23	1476.42	482.25	1958.68
0.6	164	4.80	2.287	415.48	1443.45	471.28	1914.73
b	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	164	4.79	1.906	424.67	1478.89	483.07	1961.96
0.10	164	4.79	1.902	424.23	1476.42	482.25	1958.68
0.12	164	4.79	1.899	423.77	1473.96	481.43	1955.39
c	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.8	171	4.83	2.060	443.21	1597.12	522.45	2119.57
1.0	164	4.79	1.902	424.23	1476.42	482.25	1958.68
1.2	158	4.75	1.824	400.38	1361.16	443.87	1805.03
i	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.016	164	4.79	1.903	424.31	1476.92	482.42	1959.34
.020	164	4.79	1.902	424.23	1476.42	482.25	1958.68
.024	164	4.79	1.902	424.14	1475.93	482.09	1958.02
S_p	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	164	4.79	1.902	424.22	1476.42	482.25	1958.67
0.10	164	4.79	1.902	424.23	1476.42	482.25	1958.68
0.12	164	4.79	1.902	424.23	1476.43	482.25	1958.68
s_r	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	164	4.79	1.922	422.23	1476.49	482.25	1958.74
0.10	164	4.79	1.902	424.23	1476.42	482.25	1958.68
0.12	164	4.79	1.882	426.23	1476.36	482.25	1958.61
s_m	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	164	4.79	1.902	424.23	1476.49	482.25	1958.74
0.10	164	4.79	1.902	424.23	1476.42	482.25	1958.68
0.12	164	4.79	1.902	424.23	1476.36	482.25	1958.61

Table 1. Continued

s_t	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.16	164	4.79	1.900	424.46	1476.43	482.25	1958.68
.20	164	4.79	1.902	424.23	1476.42	482.25	1958.68
.24	164	4.79	1.905	423.99	1476.42	482.25	1958.67
h_r	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.144	164	4.79	1.737	437.85	1478.85	482.25	1961.10
.180	164	4.79	1.902	424.23	1476.42	482.25	1958.68
.216	164	4.79	2.068	410.60	1473.99	482.25	1956.25
h_m	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.144	164	4.79	1.902	424.23	1478.85	482.25	1961.10
.180	164	4.79	1.902	424.23	1476.42	482.25	1958.68
.216	164	4.79	1.902	424.23	1473.99	482.25	1956.24
h_t	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.288	164	4.79	1.914	423.11	1476.40	482.25	1958.65
.360	164	4.79	1.902	424.23	1476.42	482.25	1958.68
.432	164	4.79	1.891	425.31	1476.42	482.25	1958.67
S	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	164	4.79	1.902	425.74	1474.91	483.77	1958.68
0.10	164	4.79	1.902	424.23	1476.42	482.25	1958.68
0.12	164	4.79	1.902	422.71	1477.94	480.74	1958.68
H	Q	μ_y	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.288	164	4.79	1.902	425.44	1475.21	483.46	1958.67
.360	164	4.79	1.902	424.23	1476.42	482.25	1958.68
.432	164	4.79	1.902	423.02	1477.63	481.04	1958.67

Table 2. The effect of parameters of optimal solution for Chen and Liu's [4] model

R	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
24	188	2.707	275.95	1619.18	529.74	2148.92
30	191	3.437	352.75	2067.87	679.30	2747.17
36	192	4.166	429.62	2516.99	829.00	3345.99
μ_x	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
80	171	3.437	255.74	1656.02	513.55	2169.57
100	191	3.437	352.75	2067.87	679.30	2747.17
120	211	3.437	404.07	2525.42	799.35	3324.77
σ_x	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
160	173	3.437	327.81	2117.55	657.78	2775.33
200	191	3.437	352.75	2067.87	679.30	2747.17
240	209	3.437	330.10	2065.78	653.22	2719.00
B	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	191	3.488	348.62	2070.73	680.25	2750.98
0.10	191	3.437	352.75	2067.87	679.30	2747.17
0.12	191	3.387	356.74	2065.02	678.35	2743.37

Table 2. Continued

C	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.8	192	4.018	304.34	2096.52	688.84	2785.36
1.0	191	3.437	352.75	2067.87	679.30	2747.17
1.2	189	2.994	387.40	2039.42	669.82	2709.24
I	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.016	191	3.447	351.94	2068.44	679.49	2747.93
.020	191	3.437	352.75	2067.87	679.30	2747.17
.024	191	3.427	353.56	2067.30	679.11	2746.41
s_r	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	191	3.457	350.75	2067.88	679.30	2747.18
0.10	191	3.437	352.75	2067.87	679.30	2747.17
0.12	191	3.417	354.75	2067.87	679.30	2747.17
s_m	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	191	3.437	352.75	2067.88	679.30	2747.18
0.10	191	3.437	352.75	2067.87	679.30	2747.17
0.12	191	3.437	352.75	2067.87	679.30	2747.17
s_t	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.16	191	3.432	353.24	2067.87	679.30	2747.17
.20	191	3.437	352.75	2067.87	679.30	2747.17
.24	191	3.442	352.27	2067.87	679.30	2747.17
h_r	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.144	191	2.729	420.06	2071.13	679.30	2750.43
.180	191	3.437	352.75	2067.87	679.30	2747.17
.216	191	4.144	285.44	2064.61	679.30	2743.91
h_m	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.144	191	3.437	352.75	2071.13	679.30	2750.43
.180	191	3.437	352.75	2067.87	679.30	2747.17
.216	191	3.437	352.75	2064.61	679.30	2743.91
h_t	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.288	191	3.618	334.71	2067.85	679.30	2747.15
.360	191	3.437	352.75	2067.87	679.30	2747.17
.432	190	3.273	369.12	2067.85	679.30	2747.15
S	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
0.08	191	3.437	354.25	2066.37	680.80	2747.17
0.10	191	3.437	352.75	2067.87	679.30	2747.17
0.12	191	3.437	351.25	2069.37	677.80	2747.17
H	Q	α	A_1	$E(\pi_m^{CP})$	$E(\pi_r^{CP})$	$E(\pi_t^{CP})$
.288	191	3.437	354.38	2066.24	680.93	2747.17
.360	191	3.437	352.75	2067.87	679.30	2747.17
.432	191	3.437	351.12	2069.50	677.67	2747.17

$$X \sim U\left[\mu_x - \frac{1}{2}\sigma_x, \mu_x + \frac{1}{2}\sigma_x\right]$$

μ_x the mean demand of customer
σ_x the variability of customer demand
A_1 the fixed commission fee paid by the manufacturer to the retailer
R the per-unit retailer price
c the per-unit manufacturing cost/the variable production cost per unit
h_t the per-unit carrying cost in the supply chain system
s_t the goodwill loss per unit of stock-out in the supply chain system
h_m the per-unit carrying cost for the manufacturer
s_m the goodwill loss per unit of stock-out for the manufacturer
H the carrying cost per unit for the retailer in the traditional production system
S the goodwill loss per unit of stock-out for the retailer in the traditional production system
Y the quality characteristic of product, which is assumed that $Y \sim N(\mu_y, \sigma_y^2)$
μ_y the mean of quality characteristic of product
σ_y the standard deviation of quality characteristic of product
L the lower specification limit of product quality characteristic
U the upper specification limit of product quality characteristic
$Loss(Y)$ the quality loss per unit, $Loss(Y) = k(Y - y_0)^2$
k the quality loss coefficient
y_0 the target value of product quality characteristic
$\Phi(\cdot)$ the cumulative distribution function of standard normal random variable
$\phi(\cdot)$ the probability density function of standard normal random variable
W the selling price per unit for the conformance product in the traditional production system
S_p the discounted price per unit for the non-conformance product scrapped in the traditional production system
b the constant production cost per unit
i the inspection cost per unit
π_m^{CP} the manufacturer's profit for consignment policy
$E(\pi_m^{CP})$ the manufacturer's expected profit for consignment policy
π_r^{CP} the retailer's profit for consignment policy
$E(\pi_r^{CP})$ the retailer's expected profit for consignment policy
π_t^{CP} the supply chain system's profit for consignment policy
$E(\pi_t^{CP})$ the supply chain system's expected profit for consignment policy
π_m^{PS} the manufacturer's profit in the traditional production system
$E(\pi_m^{PS})$ the manufacturer's expected profit in the traditional production system
π_r^{PS} the retailer's profit in the traditional production system
$E(\pi_r^{PS})$ the retailer's expected profit in the traditional production system

References

[1] Seifert, R. W., Thonemann, U. W. and Hausman, W. H., "Optimal Procurement Strategies for Online Spot Markets," *European Journal of Operational Research*, Vol. 152, pp. 781−799 (2004).
[2] Haksoz, C. and Seshadri, S., "Supply Chain Operations in the Presence of a Spot Market: A Review with Discussion," *Journal of the Operational Research Society*, Vol. 58, pp. 1412−1429 (2007).
[3] Chen, S. L. and Liu, C. L., "Procurement Strategies in the Presence of the Spot Market - An Analytical Framework," *Production Planning & Control*, Vol. 18, pp. 297−309 (2007).
[4] Chen, S. L. and Liu, C. L., "The Optimal Consignment Policy for the Manufacturer under Supply Chain Coordination," *International Journal of Production Research*, Vol. 46, pp. 5121−5143 (2008).
[5] Li, J. and Liu, L., "Supply Chain Coordination with Manufacturer's Limited Reserve Capacity: An Extended Newsboy Problem," *International Journal of*

Production Economics, Vol. 112, pp. 860−868 (2008).
[6] Chen, S. L. and Huang, S. C., "Managing Supply Chain Risk with Options and Online Spot Markets," *Journal of Statistics & Management Systems*, Vol. 13, pp. 389−407 (2010).
[7] Taguchi, G., *Introduction to Quality Engineering*, Asian Productivity Organization, Tokyo (1986).
[8] Chen, C. H., "The Trade-Off Model between Retailer's and Manufacturer's Profits," *International Journal of Reliability and Quality Performance*, Vol. 2, pp. 21−31 (2010).

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