

A Cooperative Inventory Model for Vendor-Buyer System with Raw Material Decisions, Deterministic Lead Time and Stochastic Demand

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Abstract
This study investigates integrated inventory problem for a two-stage supply chain consisting of a single vendor and single buyer. We develop a model for coordinating the replenishment decisions for raw material procurement, production, and shipment under stochastic environment. For attaining the model objective, we develop an algorithm to determine the optimal shipment-sized, safety factor, number of shipment and number of raw material replenishment based on minimum expected total cost. Furthermore, numerical examples are given to illustrate the effect of primary parameters on the lot size, safety factor, number of batches and expected total cost. The results from numerical examples shows that making production-inventory decisions jointly can reduces expected total cost comparing with making decisions individually.
Keywords: Supply chain, replenishment decision, raw material procurement, production, shipment, stochastic.

1. Introduction

In today's competitive market conditions, the coordination and collaboration of all parties in supply chain system is prerequisite (Tarantilis, 2008). Managing inventories jointly across the entire supply chain system was one of the best strategies to improve the supply chain performance, especially in reducing total cost. In modern inventory management, all parties in supply chain will agree to determine the optimal production and shipment policies jointly. Many researches proved that moving from managing inventory independently to jointly will always results in a significant cost saving.

Goyal (1976) was the first researchers introduced integrated vendor-buyer (IVB) model where the vendor produced a product in an infinite production rate and used lot-for-lot policy to deliver a product to the buyer. Then, the model was extended by many researchers, for example Banerjee (1986), Goyal (1988), Hill (1997) and Pujawan and Kingsman (2002). The comprehensive literature review on integrated vendor-buyer problem was presented by Ben-Daya et al. (2008).

In recent years, IVB model under stochastic environments has received significant research attention. Ben-Daya and Hariga (2004) investigated vendor-buyer model under stochastic demand and variable lead time. They relaxed the assumption of deterministic lead time and assumed that the lead time consists of time to produce a batch, transportation time and non-productive time. Hsiao (2008) extended Ben-Daya and Hariga's (2004) model and proposed a modified model under assumption of using two different reorder points and service level. Another extensions of IVB model under stochastic demand was done by Ouyang et al (2004). He presented a model with stochastic lead time demand and contollable lead time. Lin (2009) developed single-vendor-single-buyer integrated production inventory system with backorder price discount and variable lead time. He investigated the effect of investing in reducing ordering cost on the model. Jauhari et al (2011) developed vendor-buyer model considering variable lead time. They gave the flexibility to both vendor and buyer to determine the production cycle and delivery cycle.

The issues of raw material procurement in IVB model has not received a great deal of attention (Banerjee et al., 2007). All aforementioned stochastic vendor-buyer problems considered only production and inventory decisions in supply chain. However, considering raw material procurement into IVB model may results a significant benefit. In this paper we incorporate raw material procurement decisions into IVB model considering stochastic demand. We propose an iterative procedure to determine the shipment-sized, safety factor, number of shipment and number of raw material ordering based on minimum total cost. Furthermore, we present numerical examples to show the model's behaviour and the benefit of moving from making decision independently into making decision jointly.

2. Model Development

2.1 Notations

The following notations will be used to develop the model:

D demand in units per unit time
σ standard deviation of demand per unit time
P production rate in units per unit time

r rasio between finished goods and raw materials
K production setup cost
A order cost incurred by the buyer for each order size of nq
A_s raw materials order cost incurred by the vendor for each order size
F transportation cost for the buyer incurred with each shipment of size q
k safety factor
SS safety stock for the buyer
ES expected number of backorder
h_b finished product holding cost per unit per unit time for buyer
h_v finished product holding cost per unit per unit time for vendor
h_s raw material holding cost per unit per unit time for vendor
π backorder cost per unit
n shipment lot size factor, which is a positive integer
z raw materials lot size factor
q the size of equal shipments from the vendor to the buyer
ROP reorder point
TC_B total expected cost per unit time for the buyer
TC_V total expected cost per unit time for the vendor
TC integrated system expected total cost per unit time

2.2 Problem Description

We consider a two-stage production inventory problem which consists of single vendor-single buyer. We assume that the buyer uses a continuous review policy and the demand in buyer side follows a normal distribution with a mean of D per year and standard deviation of σ per year. The buyer orders the finished product to the vendor in a constant lot of size nq when the inventory position reaches reorder point (ROP) after receiving nth shipment. Each time an order is placed, a fixed ordering cost A incurs. The shipment size of q will be delivered from vendor to buyer and incurs transportation cost F. We assume that the demand in buyer during stockout period is fully backordered. The vendor produces the finished product in a lot of size nq with a finite production rate P and incurs a fixed setup cost K. In our model, we assume $P>D$. The vendor orders raw material from supplier in a constant lot size nq/rz and incurs raw materials order cost A_s. We assume that multiple input raw material deliveries could be arranged that each succeeding delivery arrives at the time when the inventory from previous delivery has just been depleted down to zero. This assumption is also used by Banerjee and Kim (1995) and Lee (2005).

2.3 Buyer's Cost Formulation

The total expected cost for the buyer consists of ordering cost, transportation cost, holding cost and backordered cost. Considering buyer's ordering cost is A and the number of order per unit time is D/nq, the expected ordering cost per unit time is given by DA/nq. The transportation cost F is incurred when vendor deliver a lot size q to the buyer then, the expected transportation cost per unit time is given by DF/q. We obtain the total expected cost per unit time for the buyer is as follows

$$TC_B = \frac{DA}{nq} + \frac{DF}{q} + h_b\left(\frac{q}{2} + k\sigma\sqrt{L}\right) + \left(\frac{D}{q}\right)\pi\sigma\sqrt{L}\psi(k) \tag{1}$$

where,

$$\psi(k) = \{f_s(k) - k[1 - F_s(k)]\} \tag{2}$$

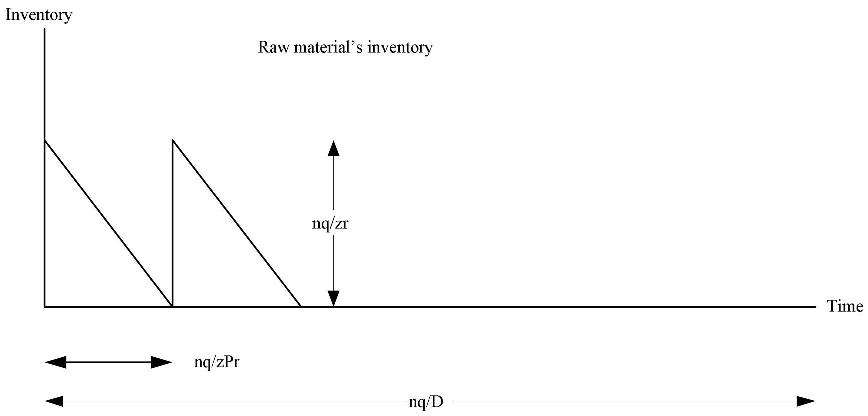
$f_s(k)$ is probability density function of standard normal distribution and $F_s(k)$ is cumulative distribution function of standard normal distribution. The derivation of Equation (2) is provided in Chopra and Meindl (2001). We use Hadley-Within's (1963) expression ($q/2$ + safety stock) to approximate the buyer's inventory level in Equation (1).

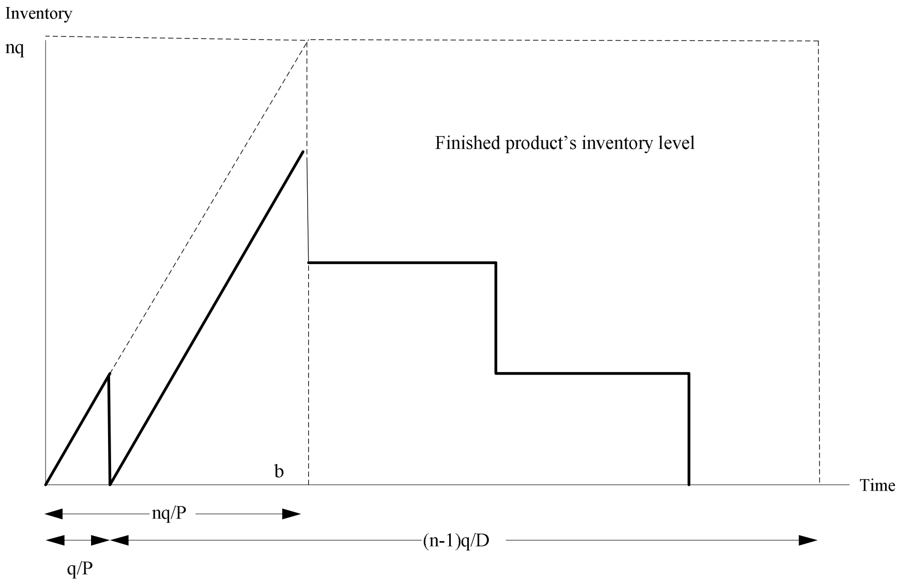
2.4Vendor's Cost Formulation

Vendor production lot size is nq for each production run and the production setup cost is K, the expected setup cost per unit time is given by DK/nq. The finished product's inventory level for the vendor is shown in Figure 1. In our model, we use lot streaming policy. Then, during the production period, once the first q units are produced, the vendor delivers them to the buyer, and then continuous making the delivery on average q/D units of time until the inventory level falls to zero.

Finished product's inventory level= $$\frac{\left(nq\left[\frac{q}{P}+(n-1)\frac{q}{D}\right]-\frac{n^2q^2}{2P}-\frac{q^2}{D}\left[1+2+....+(n-1)\right]\right)}{\frac{nq}{D}}$$

$$=\frac{q}{2}\left(n\left[1-\frac{D}{P}\right]-1+\frac{2D}{P}\right) \quad (3)$$





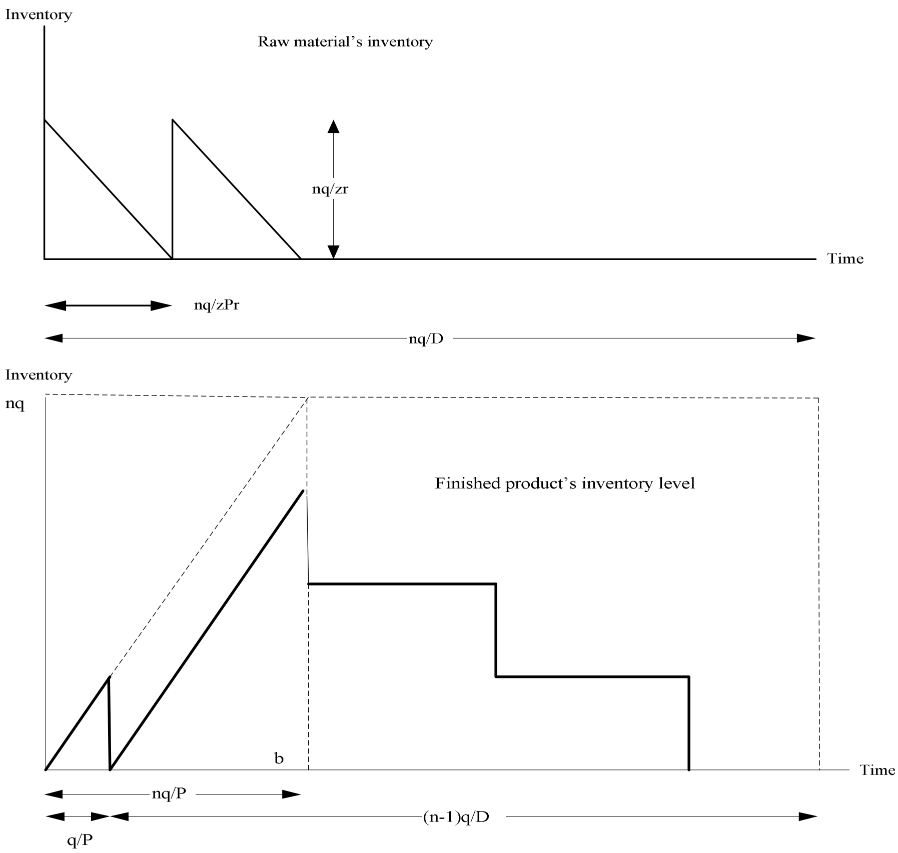


Figure 1. The inventory pattern of vendor

Consequently, the expression of total expected cost per unit time for the finished product in vendor can be presented as

TC_{V1} = finished product holding cost + setup cost

$$TC_{V1} = \frac{q}{2} h_v \left(n \left[1 - \frac{D}{P} \right] - 1 + \frac{2D}{P} \right) + \frac{DK}{nq} \qquad (4)$$

Considering Figure 1, we know that the vendor needs to replenish raw materials in lot size of *nq/rz* over *z* times for every production run. The raw material ordering cost per unit time is given by

$$\frac{A_s rDz}{nq} \qquad (5)$$

The average of raw material's inventory level is the time-weighted raw material inventory divided by cycle length. The raw material inventory level is given by

$$\frac{\frac{1}{2} x \frac{nq}{rz} x \frac{nq}{P}}{\frac{nq}{D}} = \frac{nqD}{2Pzr} \qquad (6)$$

Then, raw material's holding cost can be formulated by

$$h_s \frac{nqD}{2Pzr} \qquad (7)$$

The expected total cost for raw material is formulated by summing equation (5) and equation (7)

$$TC_{V2} = A_s \frac{rDz}{nq} + h_s \frac{nqD}{2Pzr} \qquad (8)$$

Consequently, the expected total for the vendor cost per unit time is given by

$TC_V = TC_{V1} + TC_{V2}$

$$TC_V = \frac{q}{2} h_v \left(n \left[1 - \frac{D}{P} \right] - 1 + \frac{2D}{P} \right) + \frac{DK}{nq} + A_S \frac{rDz}{nq} + h_s \frac{nqD}{2Pzr} \tag{9}$$

2.5 Total Cost Formulation

The expected total cost per unit time can be determined by adding equation (1) into (9). The expression of total cost for vendor-buyer system is given by

TC*(n,z,q,k)* =total cost for buyer+total cost for vendor

$$TC\ (n,z,q,k) = \frac{D}{nq}(A+Fn) + h_b\left(\frac{q}{2} + k\sigma\sqrt{L}\right)$$
$$+\left(\frac{D}{q}\right)\pi\sigma\sqrt{L}\psi(k) + \frac{q}{2} h_v \left(n \left[1 - \frac{D}{P} \right] - 1 + \frac{2D}{P} \right) + \frac{DK}{nq} + A_s \frac{rDz}{nq} + h_s \frac{nqD}{2Pzr} \tag{10}$$

3. Solution Methodology

Taking the first partial derivatives of TC*(n,z,q,k)* with respect to *k* and *q* and equating them to zero, we obtain :

$$F_S(k) = 1 - \frac{h_b q}{\pi D} \tag{11}$$

$$q^* = \sqrt{\frac{2D\left((\frac{A}{n} + F) + \frac{K}{n} + \frac{A_s rz}{n} + \pi\sigma\psi(k)\sqrt{L} \right)}{h_b + h_v\left(n\left[1 - \frac{D}{P}\right] - 1 + \frac{2D}{P} \right) + \frac{h_s nD}{Pzr}}} \tag{12}$$

Further, the second partial derivatives of TC*(n,z,q,k)* with respect to *n*, *q*, *k* and *z*, we obtain

$$\frac{\partial^2 TC(n,z,q,k)}{\partial^2 n} = \frac{2DA}{n^3 q} + \frac{2DK}{n^3 q} + \frac{2A_s rDz}{n^3 q} > 0 \tag{13}$$

$$\frac{\partial^2 TC(m,z,q,k)}{\partial q^2} = \frac{2D}{nq^3}(A+Fn) + \frac{D\pi\sigma\sqrt{L}\psi(k)}{q^3} + \frac{2DK}{nq^3} + \frac{2A_s rDz}{nq^3} > 0 \tag{14}$$

$$\frac{\partial^2 TC(n,z,q,k)}{\partial^2 k} = \frac{\pi D\sigma\sqrt{L} f_s(k)}{q} > 0 \tag{15}$$

$$\frac{\partial^2 TC(n,z,q,k)}{\partial^2 z} = \frac{h_s nqD}{Pz^3 r} > 0 \tag{16}$$

For fixed *n* and *z,* the minimum value of *TC(n,z,q,k)* will occur at the point (*q*,k**) which satisfies $\frac{\partial TC(n,z,q,k)}{\partial q} = 0$ and $\frac{\partial TC(n,z,q,k)}{\partial k} = 0$, simultaneously.

Here, we develop efficient and easy iterative procedure to determine the optimal values of all decision variables in our model. We use the basic idea of Ouyang et al. (2004) to determine the convergence value of *q* and *k*. The algorithm to solve the above problem is as follows :

1. set z=1 and $TC(z-1) = \infty$
2. set n=1 and $TC\,(q^*_{n-1}, k^*_{n-1}, n-1) = \infty$
3. start with shipment size of
$$q = \sqrt{\frac{2D\left((\frac{A}{n} + F) + \frac{A_s rz}{n} + \frac{K}{n} \right)}{h_b + \frac{h_s nD}{Pzr} + h_v\left(n\left[1 - \frac{D}{P}\right] - 1 + \frac{2D}{P} \right)}}$$
4. substitute q into Equation (11) to find k
5. compute q using Equation (12)
6. repeat steps 4 - 5 until no change in the values of q and k.
7. set $q^* = q$ and $k^* = k$, compute $TC\,(q^*_n, k^*_n, n)$ using Equation (10)

8. if $TC\ (q_n^*, k_n^*, n) \leq TC\ (q_{n-1}^*, k_{n-1}^*, n-1)$ repeat steps 3-7 with $n=n+1$, otherwise go to step 9.
9. compute $TC(z) = TC\ (q_{n-1}^*, k_{n-1}^*, n-1)$, if $TC(z) \leq TC(z-1)$ repeat steps 2-8 with $z=z+1$, otherwise go to step 10.
10. Compute $TC\ (q^*, z^*, k^*, m^*) = TC(z-1)$, then q^*, z^*, k^*, m^* are the optimal solution.

4. Numerical Example

In this section, we consider a basic problem : D= 1,000 unit/year, σ = 5 unit/year, P=3,200 unit/year, r= 0.8, L= 1 month, A= \$50/order, A_s= \$35/order, F= \$25/shipment, h_b= \$5/unit/year, h_v= \$4/unit/year, h_s= \$2/unit/year, π = \$15/unit, K= \$400/setup. In order to investigate the model's behaviour, we explore the effect of key model parameter's changes on buyer cost, vendor cost and total cost. The results of our numerical examples are summarized in Tabel 1. From this table it is shown that the increase in buyer's ordering cost leads to the increase in both vendor and buyer cost. In a higher buyer's ordering cost, the buyer will uses larger ordering lot size, hence, the frequency can be reduced. Consequently, the vendor will produces a larger production batch as there are larger buyer's ordering lot size. Investigating on the results associated with raw material procurement decisions, it is found that the model will orders less frequently as the raw material ordering cost getting bigger. The vendor will uses larger raw material lot size to reduce the impact of this condition.

As in table 1, the changes in both buyer's holding cost and raw material holding cost influences overall cost in the supply chain system. It is understable, because even the all parties will reduce his inventory level, the cost related to the frequency of order and number of production setup will always increases. Furthermore, facing a higher backorder cost, the buyer tend to has more safety stock. However, the increase in inventory level can not meet the increase in item backordered. It shows that the total cost increases slightly when there is an increase in the raw material's conversion factor. Since the lead time gets larger, the cost incurred to the buyer increases. The buyer uses larger reorder point and safety stock to maintain the inventory level during delivery period.

The investigation on how demand uncertainty affects performance of the all parties in the supply chain system may useful for practical management. Table 2 shows the effects of changes in standard deviation of demand on buyer cost and vendor cost in both two model, integrated model and independent model. As we assume in our model, when the parties use integrated model, they agree to share the cost information and determine their ordering, delivery and production lot jointly. In independent model, we first determine the optimal value of n, q, and k in IVB model without considering raw material decisions (TC_B + TC_{V1}). Secondly, we use the optimal value of n, q and k in first stage to determine the optimal value of z in raw material procurement function (TC_{V2}). The table shows that in both models, higher standar deviation of demand leads to higher cost incurred to the buyer and vendor. Furthermore, when the demand uncertainty increases, the buyer uses higher reorder point larger shipment size. It also shows that the cost related to raw material in vendor cost is relatively constant. However, the vendor cost increases significantly due to the increase on finished product cost. Even the vendor in our model faces deterministic environment, its cost will affected indirectly by the stochastic environment in buyer side. Affected by the increase in uncertainty factor, the buyer will uses larger reorder point and shipment size and in the other hand, the vendor will adopt a larger production batch. Finally, having a larger inventory, the cost related to the finished product in vendor side increases significantly.

It is also interesting to compare the performances of integrated model and independent model. The results from model comparations are presented in Table 2 and Table 3. From Table 2, we find that the moving from independent model into integrated model always results in a significant cost saving. For example, when standard deviation of demand is 5 units per year, the saving on total cost in moving from two-stage model into integrated model is 0.64%. The saving on buyer cost is 1.575% and the vendor suffer 0.172%. It can be seen that the vendor is always at disadvantage position. However, due to the increase of demand uncertainty, the saving on total cost and buyer cost decreases while the saving on vendor cost will increases. From Table 3, we also find that the length of lead time influences buyer cost, vendor cost and total cost. Longer lead time reduces the saving on total cost and buyer cost and adds the saving on vendor cost.

Table 1. The results of sensitivity analysis for varying parameter values (A, h_b, h_v,h_s,π, P, r and L)

Parameter	Value	*n*	*z*	*ROP*	*q*	Vendor Cost		Buyer Cost	Total Cost
						Raw Material	Finished Product		
A	50	3	1	85.653	161.95	247.42	546.59	676.81	1,470.82
	100	3	1	85.623	169.11	253.36	570.73	782.24	1,606.33
As	25	3	2	85.615	170.97	178.16	577.03	685.62	1,440.81
	150	3	1	85.598	174.89	433.66	590.25	689.89	1,713.80
hb	6	3	1	85.546	156.53	243.06	528.30	752.82	1,524.18
	8	4	1	85.539	118.62	244.35	563.43	813.27	1,621.05
hv	4	3	1	85.653	161.95	247.42	546.59	676.81	1,470.82
	6	2	1	85.480	205.26	228.56	615.79	770.66	1,615.00
hs	1	3	1	85.622	169.15	154.29	570.87	683.72	1,408.88
	3	3	2	85.621	169.56	259.12	572.28	684.15	1,515.55
π	25	3	1	85.999	161.94	247.4	546.53	678.30	1,472.23
	75	3	1	86.649	161.91	247.38	546.45	681.17	1,475.00
P	2,000	4	2	85.755	140.01	275.00	560.03	632.95	1,467.98
	4,000	3	1	85.648	163.22	210.2	571.29	677.96	1,459.45
r	0.5	3	2	85.637	165.76	225.78	559.43	680.35	1,465.56
	0.9	3	1	85.644	163.99	234.85	553.46	678.67	1,466.98
L	0.0625	3	1	64.509	161.92	247.39	546.49	674.82	1,468.7
	0.1	3	1	102.54	161.97	247.43	546.66	678.23	1,472.32

Tabel 2. The performances of integrated model vs independent model for various values of standard deviation of demand (σ)

Model	Parameters		Standard deviation of demand (unit per year)						
			5	10	20	30	40	50	60
Independent model	*n*		3	3	3	3	3	3	3
	z		2	2	2	2	2	2	2
	ROP		85.61	87.88	92.41	96.94	101.46	105.97	110.47
	q		172.85	173.12	173.64	174.18	174.71	175.24	175.78
	Buyer cost		687.64	702.37	731.82	761.24	790.63	819.98	849.31
	Vendor cost	Finished product	583.38	584.27	586.05	587.84	589.64	591.44	593.25
		Raw material	209.27	209.26	209.24	209.23	209.21	209.20	209.19
	Total cost		1,480.29	1,495.90	1,527.12	1,558.31	1,589.48	1,620.62	1,651.75
Integrated model	*n*		3	3	3	3	3	3	3
	z		1	1	1	1	1	1	1
	ROP		85.65	87.97	92.60	97.22	101.84	106.45	111.05
	q		161.95	162.17	162.60	163.04	163.48	163.92	164.36
	Buyer cost		676.81	691.66	721.32	750.96	780.57	810.16	839.71
	Vendor cost	Finished product	546.59	547.32	548.79	550.26	551.74	553.23	554.72
		Raw material	247.42	247.59	247.95	248.31	248.67	249.03	249.40
	Total cost		1,470.82	1,486.57	1,518.06	1,549.53	1,580.98	1,612.42	1,643.83
Total cost saving (%)			0.640	0.624	0.593	0.563	0.535	0.506	0.479
Buyer saving (%)			1.575	1.525	1.435	1.351	1.272	1.198	1.130
Vendor saving (%)			-0.172	-0.174	-0.182	-0.188	-0.195	-0.202	-0.209

Tabel 3. The performances of integrated model vs independent model for various values of lead time (L)

Model	Parameters		Lead time (year)					
			1/16	1/14	1/12	1/10	1/8	1/6
Independent model	n		3	3	3	3	3	3
	z		2	2	2	2	2	2
	ROP		64.47	73.53	85.61	102.49	127.78	169.88
	q		172.82	172.83	172.85	172.88	172.91	172.96
	Buyer cost		685.66	686.54	687.64	689.04	690.95	693.74
	Vendor cost	Finished product	583.26	583.31	583.38	583.46	583.58	583.75
		Raw material	209.27	209.27	209.27	209.27	209.27	209.27
	Total cost		1,478.19	1,479.12	1,480.29	1,481.77	1,483.80	1,486.76
Integrated model	n		3	3	3	3	3	3
	z		1	1	1	1	1	1
	ROP		64.51	73.58	85.65	102.54	127.84	169.95
	q		161.92	161.94	161.95	161.97	162.00	162.04
	Buyer cost		674.82	675.71	676.81	678.23	680.15	682.96
	Vendor cost	Finished product	546.49	546.53	546.59	546.66	546.75	546.89
		Raw material	247.39	247.40	247.42	247.43	247.46	247.49
	Total cost		1,468.70	1,469.64	1,470.82	1,472.32	1,474.36	1,477. 34
Total cost saving (%)			0.642	0.641	0.640	0.638	0.636	0.633
Buyer saving (%)			1.581	1.577	1.575	1.569	1.563	1.554
Vendor saving (%)			-0.170	-0.170	-0.171	-0.171	-0.171	-0.172

5. Conclusions

The main purpose of this study is to investigate a two-stage inventory lot sizing problem incorporating raw material procurement decisions. We present integrated model with equal-sized shipment under stochastic environment. Previous works on this problem, mostly focused on integrated vendor-buyer inventory problem in deterministic case without considering raw material procurement decisions. We consider that the demand in buyer side is stochastic and the demand shortages are assumed to be fully backordered. By analysing the integrated expected total cost, we develop an algorithm to determine the optimal shipment size, safety factor, number of shipment and number of raw material ordering. The results from numerical examples indicate that the integrated model always results in lower cost than two-stage model. Moreover, the increase in demand uncertainty and the length of lead time lead to the increase in buyer cost and vendor cost.

In future researches on this problem, we would consider variable lead time on this model. In many practical situations, the lead time should consists of the time of producing the lot, the setup time and the time of delivery. Another possible extensions is to consider multi buyers and multi products on the model. Finally, the case of stochastic lead time and stochastic demand is rarely discussed in the paper hence, incorporating them into the integrated model may provide valuable management insights.

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