行政院國家科學委員會專題研究計畫　成果報告

在隨機需求下損耗性商品之整合性供應鏈存貨模式

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計畫主持人：吳玫瑩

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在隨機需求下損耗性商品之整合性供應鏈存貨模式

Integrated Supply Chain Inventory Model for Deteriorating Item with Random Demand

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執行期限: 92 年 11 月 1 日 至 93 年 7 月 31 日

主持人: 吳玫瑩　中華大學資訊管理系

摘要

本研究發展一套損耗性商品在隨機需求下整合性政策之供應鏈存貨模式，供應鏈的成員包括: 零售商、製造商及供應商。透過數學模式的發展獲得最佳的生產與訂購批量以及最佳運送次數，以達到整體供應鏈的聯合總成本最小化。經由數學例題的結果顯示，由整合性的觀點所獲得的最佳解可以比單獨觀點所獲得的最佳解之聯合總成本低。最後，利用變異數分析探討一些關鍵因子如: 服務水準、標準差、前置時間及損耗率對於最佳解的影響。本研究的結果可以協助供應鏈中的採購管理者在類似的情況下作出正確的決策，以達到整體供應鏈的聯合總成本最小化。

關鍵詞: 供應鏈管理，隨機需求，損耗性商品，整合性政策

Abstract

This study develops a random demand inventory model for deteriorating items in an integrated supply chain with three parties: the buyer, the producer and the supplier. A mathematical model is derived for minimizing the joint total cost of three parties with the optimal lot size and the number of deliveries. A numerical example shows that the integrated policy results in an impressive cost-reduction compared with any independent decision. Finally, an analysis of variance is performed to illustrate how the key factors: service level, standard deviation of demand, lead time, and deterioration rate affect the optimal solution. This study could help a supply chain purchasing manager at that situation decide on how much to order as well as obtain the minimum joint total cost.

Keywords: Supply chain management, Random demand, Deteriorating items, Integrated policy

1. Introduction

According to studies of Tersine (1994), when demand was treated as continuous, the most frequently used distribution was the normal distribution. Liao and Shyu (1991) first presented a probabilistic inventory model in which the demand during lead time followed a normal distribution. Ben-Daya and Raouf (1994) extended Liao and Shyu's model and considered both order quantity and lead time as decision variables to minimize the sum of the total cost, where the shortages were neglected. Later, Ouyang et al. (1996) extended Ben-Daya and Raouf's model to consider the issue of shortages and allowed backorders or lost-sales. Moon and Choi (1998) improved Ouyang et al.'s (1996) model by simultaneously optimizing both order quantity and reorder point. Later, Ouyang et al. (2002) extended Moon and Choi's model to take quality-related cost into account in determining the optimal ordering policy.

In a highly competitive market, the minimum joint total cost could be achieved if all the partners are willing to co-operate. In some of the literature, models have been established for optimizing supply chain operations by minimizing the joint total cost. Kim and Ha (1997) developed an integrated inventory model to derive the minimal joint total cost between the buyer and the vendor where the deterioration issue was neglected. In real life situation, the inventory models are considered in which inventory is depleted not only by demand but also by decay. Thus studying the deteriorating inventory is becoming very important. In the literature, Ghare and Schrader (1963) were the first researchers to consider exponentially decaying inventory for a constant demand. Yang and Wee (2000) extended the Kim and Ha's (1997) inventory model to consider deterioration and the integration of vendor and buyer. Later, Rau et al. (2003) and Wu et al. (2003) extended the integrated model to consider multi-echelon inventory system for deteriorating items with different demand assumptions.

From the above literature review, we find that this study might be the first simultaneously to consider the case of random demand with a normal distribution and integrated multi-echelon inventory model for deteriorating items. The result in this study has shown that the integrated viewpoint is more economical compared with an independent viewpoint.

2. Assumption and notations

The mathematical model developed in this study is based on the following assumptions:

(1) The demand rate is random with a normal distribution.
(2) The production rate is deterministic and constant.
(3) The deterioration rate is deterministic and constant.
(4) The planning period is known.
(5) The lead time is allowed.
(6) Single buyer, producer and supplier with one type of item are considered.
(7) Multiple lot-size deliveries per order are considered.
(8) The delivery quantity is constant for each delivery.

In order to establish the inventory model, the following notations are used:

T	Planning period
N	Number of deliveries per planning period T
t	Period of the replenishment cycle
LT	Lead time of the replenishment
t_P	Period of the finished goods per production
q_B	Lot-size of finished goods per delivery from the producer to the buyer
Ss	Safety stock at the buyer in period t
q_P	Lot-size of finished goods for production during period t_P
q_{PW}	Lot-size of raw materials per delivery from the supplier to the producer's warehouse
Q_{PW}	Lot-size of raw materials per delivery from the second tier supplier to the supplier
$I_B(t')$	Finished goods inventory level at time t' for the buyer
$I_P(t')$	Finished goods inventory level at time t' for the producer
$I_{PW}(t')$	Raw materials inventory level at time t' for the producer's warehouse
$I_S(t')$	Raw materials inventory level at time t' for the supplier
TC_B	Total cost for the buyer
TC_{PP}	Total cost for the producer's production
TC_{PW}	Total cost for the producer's warehouse
TC_P	Total cost for the producer, that

	is, $TC_P = TC_{PP} + TC_{PW}$
TC_S	Total cost for the supplier
TC	Joint total cost with TC_B, TC_P and TC_S
A	Ordering cost of finished goods per order for the buyer
F_B	Receiving cost of finished goods per receiving for the buyer
H_B	Holding cost of finished goods per unit for the buyer
P_B	Deteriorated cost of finished goods per unit for the buyer
α_B	Overstock cost of finished goods per unit for the buyer
β_B	Stockout cost of finished goods per unit for the buyer
θ_B	Deterioration rate for the buyer's finished goods
P	Production rate for the producer
S_P	Setup cost per setup for the producer
F_P	Delivery cost of finished goods per deliver for the producer
H_P	Holding cost of finished goods per unit for the producer
P_P	Deteriorated cost of finished goods per unit for the producer
β_P	Finished goods stockout cost per unit for the producer
θ_P	Deterioration rate for the producer's finished goods
F_{PW}	Receiving cost of raw materials per receive for the producer
H_{PW}	Holding cost of raw materials per unit for the producer's warehouse
P_{PW}	Deteriorated cost of raw materials per unit for the producer
θ_{PW}	Deterioration rate for the producer's raw materials
S	Order cost of raw materials per order for the supplier
F_S	Delivery cost of raw materials per delivery for the supplier
H_S	Holding cost of raw materials per unit for the supplier
P_S	Deteriorated cost of raw materials per unit for the supplier
θ_S	Deterioration rate for the supplier's raw materials

3. The inventory model development

The supply chain system under this study is illustrated in Fig.1, and the inventory level for deteriorating item for each party in the supply chain is depicted in Fig.2. In order to fulfill each demand, the supplier delivers raw materials to the producer's warehouse at a fixed period; the producer withdraws raw materials from his own warehouse and processes them into finished goods, then delivers finished goods to the buyer at a replenishment cycle.

3.1. The finished goods inventory model for the buyer

In this study, the demand is treated as a normal distribution with mean D and standard deviation σ. When a deteriorating item with an exponential distribution for its deterioration is considered, the lot size of q_B is obtained as follows:

$$q_B = \frac{D}{\theta_B}\left(e^{\theta_B(t+LT)} - 1\right) + \frac{Z\sigma\sqrt{(t+LT)}}{e^{-\theta_B(t+LT)}} \quad (1)$$

Under a random demand environment, when the lot size of q_B is ordered, a firm might faces overstock or stockout. Then, the expected overstock and stockout cost can be derived as follows:

$$\begin{aligned} Expected\ \ overstock &= q_B F_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) - \left(xF_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) - \sigma\sqrt{(t+LT)}f_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right)\right) \\ &= (q_B - x)F_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) + \sigma\sqrt{(t+LT)}f_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) \end{aligned} \quad (2)$$

$$\begin{aligned} Expected\ \ stockout &= (x - q_B) + q_B F_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) - \begin{pmatrix} xF_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) \\ -\sigma\sqrt{(t+LT)}f_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) \end{pmatrix} \\ &= (x - q_B)\left(1 - F_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right)\right) + \sigma\sqrt{(t+LT)}f_s\left(\frac{q_B - x}{\sigma\sqrt{(t+LT)}}\right) \end{aligned} \quad (3)$$

Thus, the buyer's total cost of finished goods per period T can be expressed as the sum of the order cost, receiving cost, holding cost, deteriorating cost, overstock cost and stockout cost, that is:

$$TC_B = \left\{\frac{A}{T}\right\} + \left\{\frac{F_B * n}{T}\right\} + \left\{\frac{\left(\frac{\min(q_B, q_P) - D(t+LT) - ss}{\theta_B}\right) * H_B * n}{T}\right\} + \left\{\frac{(\min(q_B, q_P) - D(t+LT) - ss) * P_B * n}{T}\right\}$$
$$+ \left\{\frac{\left\{(\min(q_B, q_P) - x) * F_S\left(\frac{\min(q_B, q_P) - x}{\sigma\sqrt{(t+LT)}}\right) + \sigma\sqrt{(t+LT)} * f_S\left(\frac{\min(q_B, q_P) - x}{\sigma\sqrt{(t+LT)}}\right)\right\} * \alpha_B * n}{T}\right\}$$
$$+ \left\{\frac{\left\{(x - \min(q_B, q_P)) * \left(1 - F_S\left(\frac{\min(q_B, q_P) - x}{\sigma\sqrt{(t+LT)}}\right)\right) + \sigma\sqrt{(t+LT)} * f_S\left(\frac{\min(q_B, q_P) - x}{\sigma\sqrt{(t+LT)}}\right)\right\} * \beta_B * n}{T}\right\} \quad (4)$$

Where $\left(\frac{\min(q_B, q_P) - D(t+LT) - ss}{\theta_B}\right)$ is the total holding quantity of finished goods during period ($t+LT$), and $(\min(q_B, q_P) - D(t+LT) - ss)$ is the total deteriorating quantity of finished goods during period ($t+LT$).

3.2. The inventory model for the producer

3.2.1. The producer's finished goods inventory model

When $t_P > t$, the producer is unable to satisfy the buyer's demand during period t, and results in a shortage. Hence, q_P can be written as the following relationship:

$$q_P = \begin{cases} q_B & ,if \;\; t_P \le t, \;\; then \;\; no \;\; stockout \;\; for \;\; the \;\; producer \\ \frac{P}{\theta_P}(1 - e^{-\theta_P t}) & ,if \;\; t_P > t, \;\; then \;\; stockout \;\; for \;\; the \;\; producer \end{cases} \quad (5)$$

The total cost of finished goods for the producer per period T can be expressed as the sum of the setup cost, delivery cost, holding cost, deteriorating cost, and stockout cost, is:

$$TC_{PP} = \left\{\frac{S_P * n}{T}\right\} + \left\{\frac{F_P * n}{T}\right\} + \left\{\frac{\left(\frac{P * \min(t, t_P) - \min(q_B, q_P)}{\theta_P}\right) * H_P * n}{T}\right\}$$
$$+ \left\{\frac{(P * \min(t, t_P) - \min(q_B, q_P)) * P_P * n}{T}\right\} + \left\{\frac{\max(q_B - q_P, 0) * \beta_P * n}{T}\right\} \quad (6)$$

Where $\left(\frac{P * \min(t, t_P) - \min(q_B, q_P)}{\theta_P}\right)$ is the total holding quantity of finished goods during period t, and $(P * \min(t, t_P) - \min(q_B, q_P))$ is the total deteriorating quantity of finished goods during period t.

3.2.2. The producer's warehouse inventory model

The total cost for the producer's warehouse of raw materials per period T can be expressed as the sum of the receiving cost, holding cost, and deteriorating cost, i.e.

$$TC_{PW} = \left\{\frac{F_{PW} * n}{T}\right\} + \left\{\frac{\left(\frac{q_{PW} - P * \min(t, t_P)}{\theta_{PW}}\right) * H_{PW} * n}{T}\right\} + \left\{\frac{(q_{PW} - P * \min(t, t_P)) * P_{PW} * n}{T}\right\} \quad (7)$$

Where $\left(\frac{q_{PW} - P * \min(t, t_P)}{\theta_{PW}}\right)$ is the total holding quantity of raw materials during period t, and $(q_{PW} - P * \min(t, t_P))$ is the total deteriorating quantity of raw materials during period t.

Then, the producer's total cost, TC_P is:

$$TC_P = TC_{PP} + TC_{PW} \quad (8)$$

3.3. The inventory model for the supplier

Assume supplier's opening inventory to be Q_{PW}, and the ending inventory after period t to be q_{PW}. Then, total cost of raw materials for the supplier per period T can be expressed as the sum of the order cost, delivery cost, holding cost, and deteriorating cost, i.e.

$$TC_S = \left\{\frac{S}{T}\right\} + \left\{\frac{F_S * n}{T}\right\} + \left\{\frac{\frac{Q_{PW}(1-\theta_S)^t - Q_{PW}}{\ln(1-\theta_S)} * H_S * n}{T}\right\} + \left\{\frac{(Q_{PW} - q_{PW}) * P_S * n}{T}\right\} \quad (9)$$

Where $(Q_{PW} - q_{PW})$ is the total deteriorating quantity of raw materials during period t.

3.4. The integrated inventory model

The integrated joint total cost TC for the buyer, the producer and the supplier is the sum of TC_B, TC_P and TC_S, and can be written as:

$$TC = TC_B + TC_P + TC_S \quad (10)$$

4. Numerical example

Let us consider the following numerical example: T=1 week. The buyer's parameter data: D N(12,000, 500^2), SL = 90%, LT = 0.01, A = \$300, F_B = \$25, H_B = \$15, P_B = \$110, θ_B = 0.08, α_B = \$15, β_B = \$110. The producer's parameter data: P = 24,000 units, S_P = \$500, F_P = \$150, F_{PW} = \$20, H_P = \$12, H_{PW} = \$10, P_P = \$90, P_{PW} = \$85, θ_P = 0.095, θ_{PW} = 0.09, β_P = \$90. The supplier's parameter data: S = \$250, F_S = \$125, H_S = \$8, P_S = \$75, θ_S = 0.1.

Substituting the above parameter's data into the model, then the optimal solution can be derived as shown in Tables 1 and 2.

In Tables 1 and 2, for each viewpoint, the optimal lot size and delivery number is obtained where the total cost is minimized. The joint total cost from the integrated viewpoint is \$109,225, which results in an impressive joint total cost reduction compared with any independent viewpoint from the buyer, the producer or the supplier. This result suggests that the partners in the supply chain could develop a mutual agreement in order to benefit from the lowest joint total cost. Besides, in Table 2, because the demand is random, it is necessary to consider the safety stock to prevent stockout. The phenomenon results in the buyer's holding cost, deterioration cost, and overstock cost to be increased noticeably, hence the buyer's total cost TC_B is much more than the producer and the supplier's total cost.

5. Analysis of variance

In order to study how various key factors affect the buyer's total cost, the producer's total cost, the supplier's total cost, and the joint total cost, a analysis of variance for key factors of service level, standard deviation, lead time, and deterioration rate is performed. The experiment is performed as shown in Table 3. Then we conduct an analysis of variance with statistical software SPSS, and the main result is summarized in Table 4.

The main purpose of this section is to study the relationship between the total costs (TC_B, TC_P, TC_S, TC) and factors (SL, σ, LT, θ). Table 4 indicates some conclusions from this analysis. In the analysis, we use the significance level, α= 5%. Thus, we see that the main factors of SL, σ, LT and θ significantly affect the total costs of TC_B, TC_P, TC_S and TC. Besides, in the factor interaction, we see that $\sigma*LT$, $\sigma*\theta$ and $LT*\theta$ has a significance, which indicates significant interaction between these factors. However, $SL*LT$ and $SL*\theta$ has a little significance, which indicates no significant interaction between these factors.

6. Conclusions

In a competitive environment, the cooperation is especially important in the supply chain. The result in this study has shown that the integrated viewpoint is more economical compared with an independent viewpoint.

This study has also performed an analysis of variance to show that how various key factors for the random demand affect various total costs for the partners in a supply chain. The key factors include service level, standard deviation, lead time, and deterioration rate. When the demand is random, in order to have a higher service level, the safety stock must be increased in order to prevent stockout; but sometime it turns into overstock. In this study, adopting the most economic service level is suggested, instead of the perfect service level, and this adoption can obtain the lowest joint total cost, buyer's total cost, producer's total cost, and supplier's total cost.

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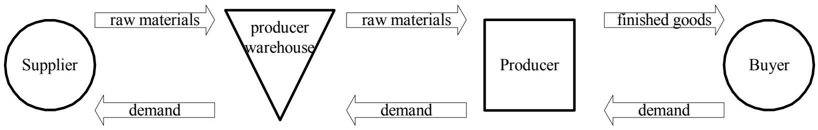

Fig. 1. The supply chain system

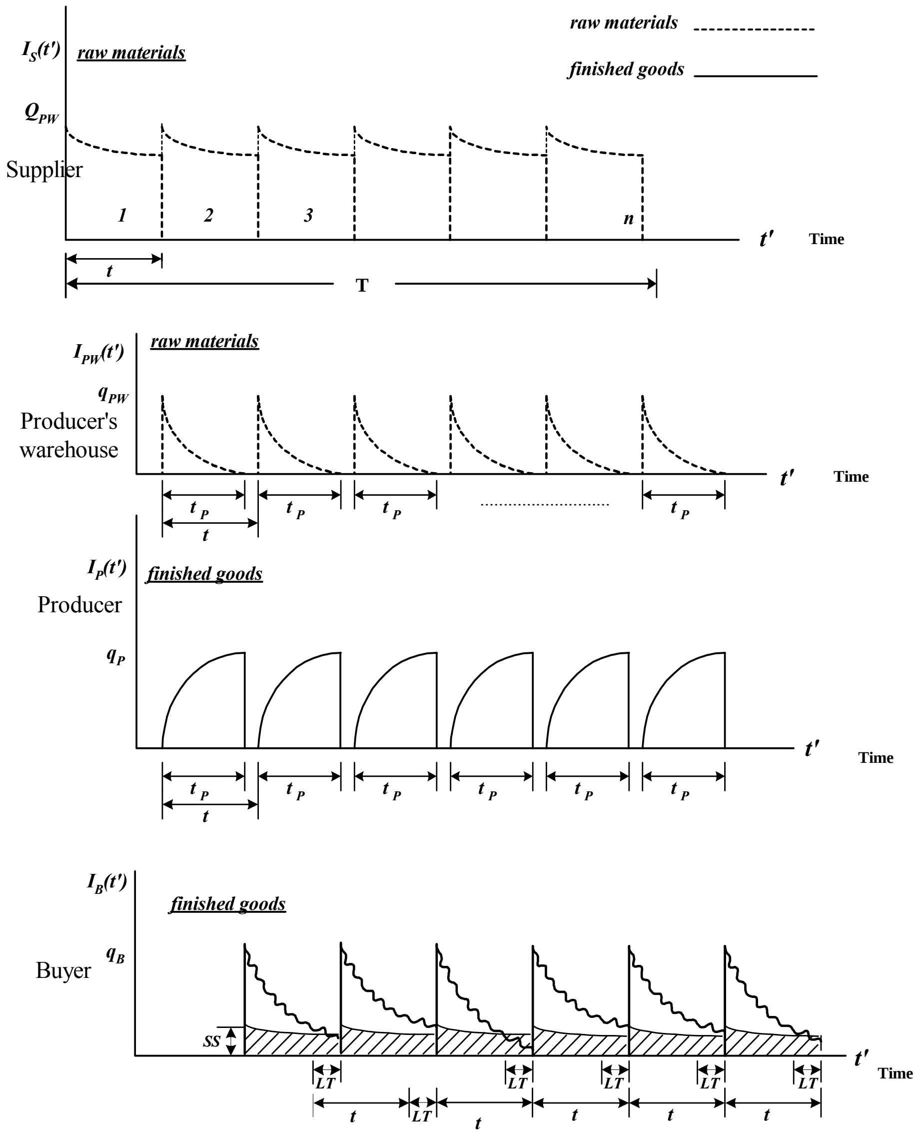

Fig .2. Inventory level of the supply chain

Table 1 Quantity for various viewpoints

Viewpoint	n	t_P	ss	q_B	q_P	q_{PW}	Q_{PW}
Buyer	7	0.0878	253	2,099	2,099	2,116	2,148
Producer	14	0.0486	184	1,164	1,164	1,169	1,178
Supplier	42	0.0219	118	524	524	525	527
Integrated	13	0.0517	190	1,237	1,237	1,243	1,253

Table 2 Total cost for various viewpoints

Viewpoint	n	TC_B	TC_P	TC_S	TC
Buyer	7	58,381	29,429	35,028	122,838
Producer	14	64,189	24,547	20,666	109,403
Supplier	42	105,309	37,345	13,864	156,519
Integrated	13	62,900	24,609	21,716	109,225

Table 3 The related data for experiment result

SL	σ	LT	θ	TC_B	TC_P	TC_S	TC
50%	0	0.01	-4%	8,947	20,621	11,651	41,219
			4%	11,521	25,304	15,071	51,896
		0.05	-4%	24,193	30,371	18,996	73,560
			4%	34,777	40,392	26,817	101,985
	2,000	0.01	-4%	235,405	28,431	40,979	304,816
			4%	266,572	34,448	51,625	352,645
		0.05	-4%	237,202	44,341	60,435	341,978
			4%	280,559	54,326	74,380	409,265
70%	0	0.01	-4%	8,947	20,621	11,651	41,219
			4%	11,521	25,304	15,071	51,896
		0.05	-4%	24,193	30,371	18,996	73,560
			4%	34,777	40,392	26,817	101,985
	2,000	0.01	-4%	168,232	33,566	39,787	241,585
			4%	197,371	39,672	46,386	283,429
		0.05	-4%	178,130	49,670	55,158	282,958
			4%	220,537	61,416	63,888	345,840
90%	0	0.01	-4%	8,947	20,621	11,651	41,219
			4%	11,521	25,304	15,071	51,896
		0.05	-4%	24,193	30,371	18,996	73,560
			4%	34,777	40,392	26,817	101,985
	2,000	0.01	-4%	149,204	44,520	42,090	235,814
			4%	173,411	56,586	52,457	282,455
		0.05	-4%	162,776	64,239	56,190	283,205
			4%	199,932	86,625	70,630	357,187

Table 4

The main result for analysis of variance

Factor	Dependent variable	Sum of square	Degree of freedom	Mean square	F test	Significance
SL	TC_B	7638746669.08	2	3819373334.54	574.87	.000
	TC_P	552971599.00	2	276485799.50	54.00	.000
	TC_S	32926025.33	2	16463012.67	9.19	.007
	TC	5313122763.08	2	2656561381.54	279.60	.000
σ	TC_B	207393202262.04	1	207393202262.04	31215.53	.000
	TC_P	2558039424.00	1	2558039424.00	499.56	.000
	TC_S	7935206666.67	1	7935206666.67	4427.29	.000
	TC	354098897867.04	1	354098897867.04	37268.98	.000
LT	TC_B	1741607325.38	1	1741607325.38	262.14	.000
	TC_P	1631982352.67	1	1631982352.67	318.71	.000
	TC_S	1129293204.17	1	1129293204.17	630.07	.000
	TC	13394382768.38	1	13394382768.38	1409.76	.000
θ	TC_B	2540127777.04	1	2540127777.04	382.32	.000
	TC_P	526575280.17	1	526575280.17	102.84	.000
	TC_S	403850104.17	1	403850104.17	225.32	.000
	TC	8731428685.04	1	8731428685.04	918.99	.000
$SL*\sigma$	TC_B	7638746669.08	2	3819373334.54	574.87	.000
	TC_P	552971599.00	2	276485799.50	54.00	.000
	TC_S	32926025.33	2	16463012.67	9.19	.007
	TC	5313122763.08	2	2656561381.54	279.60	.000
$SL*LT$	TC_B	39122196.75	2	19561098.38	2.94	.104
	TC_P	14218858.33	2	7109429.17	1.39	.298
	TC_S	7763420.33	2	3881710.17	2.17	.171
	TC	51648800.25	2	25824400.13	2.72	.119
$SL*\theta$	TC_B	11907245.58	2	5953622.79	.90	.442
	TC_P	25807708.33	2	12903854.17	2.52	.135
	TC_S	7319324.33	2	3659662.17	2.04	.186
	TC	16291406.58	2	8145703.29	.86	.456
$\sigma*LT$	TC_B	29404134.38	1	29404134.38	4.43	.065
	TC_P	99552266.67	1	99552266.67	19.44	.002
	TC_S	104516960.67	1	104516960.67	58.31	.000
	TC	218400633.38	1	218400633.38	22.99	.001
$\sigma*\theta$	TC_B	1175426070.04	1	1175426070.04	176.92	.000
	TC_P	24389568.17	1	24389568.17	4.76	.057
	TC_S	40052000.67	1	40052000.67	22.35	.001
	TC	2074997470.04	1	2074997470.04	218.39	.000
$LT*\theta$	TC_B	162432457.04	1	162432457.04	24.45	.001
	TC_P	53826140.17	1	53826140.17	10.51	.010
	TC_S	21481768.17	1	21481768.17	11.99	.007
	TC	610858690.04	1	610858690.04	64.29	.000
Error	TC_B	59795191.54	9	6643910.17		
	TC_P	46085365.50	9	5120596.17		
	TC_S	16131050.00	9	1792338.89		
	TC	85510517.04	9	9501168.56		
Total	TC_B	533903078249.00	24			
	TC_P	43524836546.00	24			
	TC_S	41385799554.00	24			
	TC	1243873266641.00	24			

計畫成果自評:

本計畫主要發展一套損耗性商品在隨機需求下整合性供應鏈之存貨模式，透過數學模式的推導獲得最佳的生產與訂購批量以及最佳運送次數，達到整體供應鏈的聯合總成本最小化。經由數學例題的結果證明: 由整合性的觀點所獲得的最佳解可以比單獨觀點所獲得的最佳解之聯合總成本低。最後，利用變異數分析探討一些關鍵因子對於最佳解的影響。根據原計畫的預期目標分述如下:

(1) 發展供應商、製造商及零售商的損耗性商品之隨機需求存貨模式
(2) 應用電腦程式的撰寫求出供應鏈中的供應商、製造商及零售商的聯合總成本
(3) 藉由數學例題證明由整合性的觀點可獲得使聯合總成本最低的最佳解
(4) 利用變異數分析探討一些關鍵因子對於最佳解的影響

本研究已遵照原計畫執行完成以上目標，並將內容說明於正文中，透過正文的內容可知，本研究已達到原計畫書中所提出的預期目標與成果，此成果亦可提供學界及業界的人士參考。

(1) 以學術而言: 在供應鏈中損耗性商品的存貨政策常常被忽略，因此透過本計畫，可提升學界人士對此相關議題之興趣與重視。

(2) 對業界而言: 在現實的環境中，有許多隨機需求的損耗性商品存在於生鮮超市中，本計畫成果可以協助供應鏈中的管理者在採購、生產及物流決策上之參考，以達到整體供應鏈的聯合總成本最小化。

最後，提供數個議題作為未來研究之方向:

(1) 採取彈性數量政策，以使採購及生產更符合實際需求，減少存貨過剩或不足的現象。

(2) 利用供應商管理庫存方式(vendor managed inventory, VMI)，透過買賣雙方彼此的合作協調，降低供應鏈的整體成本。

(3) 增加損耗性商品之殘值，以提高供應鏈整體利潤之提升。