Fuzzy Closed-Loop Supply Chain considered Container Return Time

Sheng-Long Kao, Chien-Min Su, Ming-Feng Yang, Lu-An Chen

ABSTRACT - This study considers a scenario where single supplier supplying a finished product to single buyer. In order to ensure safe transportation for the customer, finished product is packed in returnable transport items (RTIs). Empty RTIs are retreated to the supplier and used for the next delivery. We consider the return time of RTIs is stochastic in this paper as a result of some unexpected factors. We promote the problem of incorporating the flow of both the finished product and RTIs and formulating a non-linear programming model of the closed-loop supply chain expected total costs. Secondly, we analyze the results of this paper in which the behavior of the model is revealed. Additionally, we add fuzzy to this paper in order to acquire a more appropriate result under the uncertain environment.

Index Terms—returnable transport item, supply chain, uncertain environment, closed-loop, fuzzy

I. INTRODUCTION

Governmental regulations have prompted many industrial companies to attach great importance to sustainability issues and public consciousness of the social and environmental responsibility in recent years. The conception of closed-loop supply chains, which expressly take account of product returns and reusable packaging material is definitely in accord with sustainable development issues and thus conduce to initiatives that concentrate on the decrease of waste generation and resource consumption.

In many industrial companies, so-called returnable transport items (RTIs), such as containers, pallets or crates, are widely used to make to greener production and logistics processes. A relative study of Goellner and Sparrow (2014) on the environmental influence of disposable containers and recycled thermally controlled shipping containers impressively showed that reusable containers lead to 75% lower CO2 emissions through their lifetime, as compared to disposable containers. As a result, appropriately coordinating the usage of RTIs and finished products in a closed-loop supply chain helps to lower the cost of disposing used packaging material and reduce unnecessary waste generation.

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Moreover, we assume that the return time of RTIs is stochastic due to some uncertain factors which could be the result of labor shortages, damages of RTIs or cleaning operations that have to be performed at the buyer before RTIs can be returned to the supplier. Above uncertain factors may cause delays in returning empty RTIs and lead to stock out at the supplier's side. Therefore, we programs a coordinated supply chain inventory system model by supposing that the products manufactured by the vendor are shipped in RTIs during delivery process and assuming a stock out of RTIs may occurs at the vendor and thus cause products to deteriorate. In addition, we adjust the inclusion of fuzzy supplier’s production rate to our proposed model. The purpose of this research studies how the negative effects determined by delays in returning RTIs impact the performance of whole closed-loop supply chain considered fuzzy production.

We must take the derivation of the expected total cost function with regard to n to verify the function is accordingly convex and obtain the optimal RTI lot size (n). In this case, application of the signed distance is useful for fuzzy numbers and finding the estimation of the common minimum total cost.

II. LITERATURE REVIEW

In a survey of the related literature, reusable packaging material has increasingly been the popular topic of research. Kim, Glock, and Kwon (2014) studied the scenario of a single supplier shipping a product possible of deteriorating to a single buyer. The authors assumed that the return time of empty RTIs is stochastic and exponentially distributed in this research. The results of this research clearly illustrates that increasing the return lot size of RTIs and the freight quantity of products helps to decrease the probability of backorders and related cost. Another popular topic with regard to the usage of RFID is designed to simplify tracks and disposal of RTIs (e.g. Hellstrom 2009, Ilic et al. 2009 and Kim and Glock 2014) and the prediction of RTIs return status including damage situation or quantities. (e.g. Goh and Varaprasad 1986, Kelle and Silver 1989, Klug 2011). Glock and Kim (2014) researched a single supplier shipping a product to various buyers. The authors assumed supplier used RTIs to deliver the product to the buyers, which caused two sorts of inventory that are necessary to be considered at the supplier and the buyers, that is RTIs inventory and finished products inventory. The results of this research implied that the demand rate of the buyers and their individual RTIs return times are significant for the operation of the whole supply

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chain.

Another key point of this research reviewed here studies inventory replenishment strategy under stochastic lead times. By reason of stochastic RTIs return lead times, shipments may arrive early, on time or late at the supply chain. However, whether shipments arrive early or late, it will lead to a profit reduction in the inventory system. A quite correlative model was developed by Sajadieh and Jokar (2009), whose model primarily presumed that lead times are considered to be exponentially distributed. Hoque (2013) extended this model and considered that lead times have normal distribution and programmed a more accurate formulation of the inventory holding charges of the supply chain. Another extension of these models was proposed by Sajadieh and Thorstenson (2014), who consider a second supplier and made this scenario in comparison with the case of single source. Their results implied that duplicate source is profitable particularly on condition that lead time varies extremely, shipping delays lead to very huge shortage costs, suppliers' set up costs are low, and buyer's carrying charges are quite higher than supplier's.

In today's complicated environment, fundamental inventory model unable to solve more realistic problem of inventory and supply chain and thus more and more scholars adopt fuzzy theory to inventory model, for example, H.M. Lee and J.S. Yao (1998) fuzzified both of the demand and the production to resolve the problem of economic production quantity. The results indicated that the total cost is a little higher than in the traditional model; however, it acquired a superior use of the EPQ in the crisp generating little interruption in the production and demand model. M.F. Yang, H.J. Tu and C.M. Wang (2007) modified and added fuzzy to setup cost and ordering cost in this inventory model and then adopted two methods to defuzzify and estimate the yearly total cost. C.H. Pan and M.F. Yang (2008) proposed and added fuzzy theory to demand rate and production rate, and then adopted the signed distance, a sorting method for fuzzy numbers, to calculate the general total cost in a uncertain environment. T.F. Liang, T.S. Huang, and M.F. Yang (2012) proposed a multiple fuzzy goals programming (MFGP) model to solve project management (PM) decision problems under uncertain environment. This model aimed at minimizing total costs, total execution time and total crashing costs regarding direct costs, indirect costs, contractual forfeit, period of activities and budget restriction.

III. MATERIALS AND METHODS

To develop our proposed model, the following terminology will be used throughout this study.

3.1 Notations

- S: supplier's set-up cost (\$/setup)
- A: buyer's ordering cost (\$/order)
- P: production rate for finished products at the supplier's site (kg/year)
- D: demand rate for finished products at the buyer's site (kg/year)
- h_b: inventory carrying cost for finished products at the buyer's site (\$/unit/time)
- h_s: inventory carrying cost for finished products at the supplier's site (\$/unit/time)
- g_b: inventory carrying cost for RTIs at the buyer's site (\$/unit/time)
- g_s: inventory carrying cost for RTIs at the supplier's site (\$/unit/time)
- π: shortage cost factor for finished products at the buyer's site (\$/unit/time)
- Q: lot size of finished products (kg)
- n: RTI lot size to delivery Q units of the finished products (an integer variable)
- α: transport capacity of a single RTI (kg)
- L_0: expected RTI return time with $L_0 > 0$
- t: real RTI return time with $t > 0$
- σ: standard deviation of RTI return time
- $\tilde{P}$: Triangular fuzzy number, $\tilde{P} = (P - \Delta_3, P, P + \Delta_4),\ 0 < \Delta_3 < P,\ 0 < \Delta_4$
- $f(.)$: probability density function of lead time
- $F(.)$: cumulative distribution function of RTI return time

The model is developed under the following assumptions:

3.2 Assumptions

- This paper studies a closed-loop supply chain with a single supplier and a single buyer.
- Mean return time L_0 is assumed to be stochastic.
- The time and cost for loading, transporting and unloading RTIs are considered to be ignorable.
- Shortages are allowed and assumed to lead to shortage cost.
- Deterioration of the finished products will not occur during the production time and stockouts in RTIs at the supplier's side.

3.3 Model development

This paper considers a scenario where a company or industry transport products to its customer by using RTIs which will be returned once they have been emptied.Thus, the return time of RTIs with mean L_0 is assumed to be stochastic and that three different cases may be determined by the realised RTIs return time :

Case 1: $0 < t \le L_0$

RTIs are returned to the supplier before the lot of finished products has been accomplished, which makes supplier essential to store the return RTIs and leads to inventory holding charge for RTIs at the supplier. The returned shipments of RTIs reach to the supplier between times 0 and L_0. The estimation of total cost per cycle of case1 is expressed as follow:

$$TC_{case1}(Q) = \int_0^{L_0} \left(S + (L_0 - t)ng_s + \frac{h_s Q^2}{2\tilde{P}} \right) f(t)dt + \int_0^{L_0} \left(A + \frac{h_b Q^2}{2D} + R_1 g_b \right) f(t)\,dt$$

where

$$R_1 = \left(1 \times \frac{\alpha}{D} + 2 \times \frac{\alpha}{D} + \cdots + (n-1) \times \frac{\alpha}{D} \right) = \frac{\alpha n(n-1)}{2D}$$

Case 2: $L_0 < t \le L_0 + Q/D$

Late return shipments of RTIs lead to inventory holding charge for finished products at the supplier but supplier doesn't need to store RTIs inventory as returned RTIs are directly packed and transported to the retailer. After the delivery of finished products reaches to the buyer, we'll find the lot size Q exceeds the backorders quantity. The returned shipments of RTIs reach to the supplier between times L_0 and L_0+Q/D. The estimation of total cost per cycle of case2 is expressed as follow:

$$TC_{case2}(Q) = \int_{L_0}^{L_0+Q/D}\left(S+\left(\frac{Q^2}{2\tilde{P}}+(t-L_0)Q\right)h_s\right)f(t)dt$$

$$+\int_{0}^{L_0+Q/D}\left(A+\frac{(t-L_0)^2 D\pi}{2}+\frac{h_b(Q-(t-L_0)D)^2}{2D}+R_2 g_b\right)f(t)\,dt$$

where

$$R_2 = w\left(\frac{(w+1)\alpha-(t-L_0)D}{D}\right)+\left(\frac{n(n-1)}{2D}-\frac{w(w+1)}{2D}\right)\alpha \text{ with } w=\frac{(t-L_0)D}{\alpha}$$

Case 3: $L_0+Q/D < t < \infty$

Return shipments are late and shortage occurs, but the backorder quantity equals the lot Q. The returned shipments of RTIs reach to the supplier between times $L_0+Q/D < t < \infty$. The estimation of total cost per cycle of case3 is expressed as follow:

$$TC_{case3}(Q) = \int_{L_0+Q/D}^{\infty}(S+A)f(t)\,dt + \int_{L_0+Q/D}^{\infty}\left(\frac{Q^2}{2}\left(\frac{h_s}{\tilde{P}}-\frac{\pi}{D}\right)-L_0 Q(h_s+\pi)\right)f(t)\,dt + \int_{L_0+Q/D}^{\infty}(h_s+\pi)Qt\,f(t)dt$$

After concluding case1 to case3, the expected total cost of of per unit of time can be stated as follow:

$$ETC(Q) = \frac{(S+A)D}{Q}+\int_{0}^{L_0}\left(k_1(Q)-(t-L_0)\frac{g_s D}{\alpha}\right)f(t)dt + \int_{L_0}^{L_0+Q/D}\left(D(h_s-h_b)(t-L_0)+k_1(Q)+\frac{L_0(L_0-1)D^2 g_b}{2Q\alpha}\right)f(t)\,dt$$
$$+\frac{D}{2Q}\left(D\left(\pi+h_b-\frac{g_b}{\pi}\right)\int_{L_0}^{L_0+Q/D}(t-L_0)^2 f(t)\,dt + g_b\int_{L_0}^{L_0+Q/D}(t-L_0)f(t)\,dt\right) + D\int_{L_0+Q/D}^{\infty}\left((h_s+\pi)(t-L_0)+\frac{Q}{2}\left(\frac{h_s}{\tilde{P}}-\frac{\pi}{D}\right)\right)f(t)dt$$

where

$$k_1(Q) = \frac{QD}{2}\left(\frac{h_s}{\tilde{P}}+\frac{h_b}{D}\right)+\frac{(Q-\alpha)}{2\alpha}g_b$$

By substituting $n\alpha$ for Q, the expected total cost of of per unit of time can be expressed by:

$$ETC(n) = \frac{(S+A)D}{n\alpha}+\int_{0}^{L_0}\left(k_2(n)-(t-L_0)\frac{g_s D}{\alpha}\right)f(t)dt + \int_{L_0}^{L_0+n\alpha/D}\left(D(h_s-h_b)(t-L_0)+k_2(n)+\frac{L_0(L_0-1)D^2 g_b}{2n\alpha^2}\right)f(t)\,dt$$
$$+\frac{D}{2n\alpha}\left(D\left(\pi+h_b-\frac{g_b}{\pi}\right)\int_{L_0}^{L_0+n\alpha/D}(t-L_0)^2 f(t)\,dt + g_b\int_{L_0}^{L_0+n\alpha/D}(t-L_0)\,f(t)dt\right) + D\int_{L_0+n\alpha/D}^{\infty}\left((h_s+\pi)(t-L_0)+\frac{n\alpha}{2}\left(\frac{h_s}{\tilde{P}}-\frac{\pi}{D}\right)\right)f(t)dt$$

where

$$k_2(n) = \frac{n\alpha D}{2}\left(\frac{h_s}{\tilde{P}}+\frac{h_b}{D}\right)+\frac{(n-1)}{2}g_b$$

Definition 1. From kaufmann and Gupta (1991), Zimmermann (1996), Yao and Wu (2000), for a fuzzy set $\tilde{B} \in$ R and $0 \le \alpha \le 1$, the α-cut of the fuzzy set $\tilde{B}$ is $B(\alpha) = \{x \in \mathrm{R} \mid \mu_B(x) \ge \alpha\} = [B_L(\alpha), B_U(\alpha)]$, We can obtain the following equation.

the α-cut $(0 \le \alpha \le 1)$ of $\tilde{P}$'s left side and right side is given by:

$P_L(\alpha) = (P-\Delta_3)+\alpha\Delta_3 > 0,$
$P_U(\alpha) = (P+\Delta_4)-\alpha\Delta_4 > 0$
and
$0 < P_L(\alpha) < P_U(\alpha)$

$$\left(\frac{1}{P}\right)_L(\alpha) = \frac{1}{P_U(\alpha)} = \frac{1}{(P+\Delta_4)-\alpha\Delta_4}$$
$$\left(\frac{1}{P}\right)_U(\alpha) = \frac{1}{P_L(\alpha)} = \frac{1}{(P-\Delta_3)+\alpha\Delta_3}$$

The signed distance of $1/\tilde{P}$ to $\tilde{0}_1$ is defined as:

$$\frac{1}{\tilde{P}} = d\left(\frac{1}{\tilde{P}},\tilde{0}_1\right) = \frac{1}{2}\int_0^1\left[\left(\frac{1}{P}\right)_L(\alpha)+\left(\frac{1}{P}\right)_U(\alpha)\right]d\alpha = \frac{1}{2}\left[\frac{1}{\Delta_3}\ln\frac{P}{P-\Delta_3}-\frac{1}{\Delta_4}\ln\frac{P}{P+\Delta_4}\right]$$

Streamlined distance method is used to the defuzzification of $ETC(n)$. The expected total cost of per unit of time can be rearranged as follow:

$$ETC(n) = \frac{(S+A)D}{n\alpha}+\int_{0}^{L_0}\left(k_2(n)-(t-L_0)\frac{g_s D}{\alpha}\right)f(t)dt + \int_{L_0}^{L_0+n\alpha/D}\left(D(h_s-h_b)(t-L_0)+k_2(n)+\frac{L_0(L_0-1)D^2 g_b}{2n\alpha^2}\right)f(t)\,dt$$
$$+\frac{D}{2n\alpha}\left(D\left(\pi+h_b-\frac{g_b}{\pi}\right)\int_{L_0}^{L_0+\frac{n\alpha}{D}}(t-L_0)^2 f(t)\,dt + g_b\int_{L_0}^{L_0+n\alpha/D}(t-L_0)\,f(t)dt\right)$$
$$+D\int_{L_0+n\alpha/D}^{\infty}\left((h_s+\pi)(t-L_0)+\frac{n\alpha}{2}\left(\frac{h_s}{2}\left(\frac{1}{\Delta_3}\ln\frac{P}{P-\Delta_3}-\frac{1}{\Delta_4}\ln\frac{P}{P+\Delta_4}\right)-\frac{\pi}{D}\right)\right)f(t)dt$$

3.4 Solving Procedure

By the second-order partial deviation of $ETC(n)$, we takes the derivative of $ETC(n)$with respect to n, which is a convex function and proves that a minimum solution can be found.

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$$\frac{\partial ETC(n)}{\partial n^2}=\frac{2(S+A)\tilde{D}}{n^3\alpha}+\left((n+1)\lambda-1\right)\frac{g_b\alpha}{ne\tilde{D}}e^{-\lambda(\frac{n\alpha}{\tilde{D}})}>0$$

$$n^* = \sqrt{\frac{2(S+A)D+\left(D^2\left(\pi+h_b-\frac{g_b}{\alpha}\right)\right)\int_{L_0}^{L_0+n\alpha/D}(t-L_0)^2 f(t)dt+\left(g_bD^2\left(\frac{{L_0}^2-L_0}{\alpha}\right)\right)\int_{L_0}^{L_0+n\alpha/D}f(t)dt+g_bD\int_{L_0}^{L_0+n\alpha/D}(t-L_0)f(t)dt}{\alpha\left(\left(\alpha D\left(\frac{h_s}{P}+\frac{h_b}{D}\right)+g_b\right)\int_0^{L_0+n\alpha/D}f(t)dt+\alpha D\left(\frac{h_s}{\tilde{P}}-\frac{\pi}{D}\right)\int_{L_0+n\alpha/D}^{\infty}f(t)dt+f(L_0+n\alpha/D)\left(\frac{({L_0}^2-L_0)Dg_b}{n\alpha}\right)\right)}}$$

where

$$\frac{1}{\tilde{P}}=\frac{1}{2}\left[\frac{1}{\Delta_3}\ln\frac{P}{P-\Delta_3}-\frac{1}{\Delta_4}\ln\frac{P}{P+\Delta_4}\right]$$

By considering the case of an exponentially distributed lead time, i.e., $f(t)=\lambda e^{-\lambda t}$ with $\lambda=1/L_0$, we can determine an optimal solution for n.

$$n^* = \sqrt{\frac{2(S+A)D+g_bD^2\left(\frac{{L_0}^2-L_0}{\alpha e}\right)+\frac{g_bD}{e}\left(\left(\frac{L_0}{2}\right)\left(\frac{n\alpha}{DL_0}\right)^2-\left(\frac{D({L_0}^2-L_0)}{\alpha}\right)\right)e^{-(n\alpha/DL_0)}}{\alpha\left(\left(\alpha D\left(\frac{h_s}{\tilde{P}}+\frac{h_b}{D}\right)+g_b\right)+\left(\frac{(L_0-1)Dg_b}{n\alpha e}-\frac{\alpha(\pi+h_b)}{e}-\frac{g_b}{e}\right)e^{-(n\alpha/DL_0)}\right)}}$$

where

$$\frac{1}{\tilde{P}}=\frac{1}{2}\left[\frac{1}{\Delta_3}\ln\frac{P}{P-\Delta_3}-\frac{1}{\Delta_4}\ln\frac{P}{P+\Delta_4}\right]$$

Furthermore, an optimal solution for n can be found by increasing n stepwise from 1 until ETC increases for the first time. An optimal solution for n* has to satisfy the following condition:

$$ETC(n^*-1)\geq ETC(n^*)\leq ETC(n^*+1)$$

IV. NUMERICAL EXAMPLE

We refer to the parameters of Kim, Glock, and Kwon (2014) and analyzed the numerical results of our inventory model. The following data were acquired:

The mean return lead time of RTIs averages 0.0023 years (L_0= 0.0023 years). The RTI capacity, α, is 500 kg. Inventory carrying charges for RTIs and finished products at the vendor's and retailer's side are h_s = \$0.0045/kg, h_b = \$0.005/kg, $g_s = g_b$ = \$13.6 per RTI. The other model notations are stated as follows: D = 3,400,000 kg per year, P = 4,533,000 kg per year, S = \$2970 per setup, A = \$1562 per order and π = \$2.5 per unit short. Additionally, we need to decide multiple sets of (Δ_3, Δ_4) directly to calculate the expected total cost in an uncertain environment. All of the results would be presented in Table III.

Table I
VARIOUS PARAMETER FACTORS

L_0	α	D	P	π
0.0023	500	3400000	4533000	2000

TableⅡ
VARIOUS PARAMETER FACTORS

h_s	h_b	g_s	g_b	S	A
0.0045	0.005	13.6	13.6	2970	1562

(1) When $\Delta_3 < \Delta_4$, the total cost in traditional model is larger than in fuzzy model. That is to say if the variation between Δ_3 and Δ_4 is smaller in proposed fuzzy model, the correlated variation of ordering quantity and total cost between the fuzzy model and the traditional model will also be smaller.

TABLE III
NUMERICAL EXAMPLE RESULTS

Δ_3	Δ_4	$\frac{1}{\tilde{P}}$	n	$ETC(n)$
250000	500000	0.000000218	1855	32949.2
500000	1000000	0.000000217	1856	32941.8
750000	1500000	0.000000216	1856	32933.8
1000000	2000000	0.000000216	1856	32933.8
1250000	2500000	0.000000217	1855	32941.7
1500000	3000000	0.000000219	1855	32954.8
3000000	3000000	0.000000265	1836	33279.2
2500000	1250000	0.000000258	1839	33230.6
2000000	1000000	0.000000245	1844	33138.5
1500000	750000	0.000000236	1848	33075.8
1000000	500000	0.000000229	1851	33026
500000	250000	0.000000224	1853	32991.5

(2) When $\Delta_3 > \Delta_4$, the total cost in traditional model is lower than in fuzzy model.

(3) According to the TABLE III, we can note that the minimum of expected total cost equals 32933.8\$ while Δ_3= 750000, Δ_4= 1500000 and Δ_3= 1000000, Δ_4= 2000000.

V. CONCLUSION

In this proposed model we found on condition that longer return lead time would increase the probability of delays resulting in huge backorders at the retailer in returning RTIs. Apparently excessive backorders cause the production cost and shortage cost to get higher, and even make the competitiveness and operation of the supply chain decline over a long time. Relatively we could adopt an appropriate approach to decrease huge backorders by increasing the return lot size of RTIs or inspiring buyers to return RTIs on time.

Future research could extend previous structure to assume that RTIs can be rented from service provider, including the decision of optimal payment proposal and the consideration

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of renting time. These extensions are worth studying for related academic field.

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