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 conducive 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.

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 chain.
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 correlating 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 shortage cost. M.F. Yang, H.J. Tu and C.M. Wang (2007) modified and added fuzzy theory to inventory model, for example, H. S. H. (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.

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

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 supplier’s site (kg/year)
- \( h_s \): inventory carrying cost for finished products at the buyer’s site (\$/unit/time)
- \( h_b \): inventory carrying cost for finished products at the supplier’s site (\$/unit/time)
- \( g_s \): inventory carrying cost for RTIs at the buyer’s site (\$/unit/time)
- \( g_b \): inventory carrying cost for RTIs at the supplier’s site (\$/unit/time)
- \( \pi \): 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 deliver Q units of the finished products (an integer variable)
- \( y \): transport capacity of a single RTI (kg)
- \( L_0 \): expected RTI return time with \( L_0 > 0 \)
- \( t \): real RTI return time with \( t > 0 \)
- \( \sigma \): standard deviation of RTI return time
- \( P \): Triangular fuzzy number, \( \tilde{P} = (P - \Delta_3, P, P + \Delta_4) \)
- \( f(\cdot) \): probability density function of lead time
- \( F(\cdot) \): 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: \( 0 < t \leq L_0 \)

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 case 1 is expressed as follow:

\[
TC_{case1}(Q) = \int_0^{L_0} \left( S + (L_0 - t)nq_s + \frac{h_sQ^2}{2P} \right) f(t) dt + \int_0^{L_0} \left( A + \frac{h_bQ^2}{2D} + R_1g_b \right) f(t) dt
\]

where

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

Case 2: \( L_0 < t \leq L_0 + Q/D \)

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:

$$T_{\text{case2}}(Q) = \int_{L_0}^{L_0+Q/D} \left( S + \frac{Q^2}{2P} + (t - L_0)Q \right) h_s f(t) dt + \int_{L_0}^{L_0+Q/D} \left( A + \frac{(t - L_0)^2}{2} + \frac{h_s(Q - (t - L_0)D)^2}{2D} \right) + R_2g_b f(t) dt$$

where

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

**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:

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

After concluding case 1 to case 3, the expected total cost of of per unit of time can be stated as follow:

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

where

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

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

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

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.
where

\[ \frac{\partial ETC(n)}{\partial n^2} = \frac{2(S + A)D}{n^2} + (n + 1)\lambda - 1 \frac{g_b\alpha}{neD} e^{-\frac{n\alpha D}{n^2}} > 0 \]

\[ n^* = \left( \sqrt{\frac{2(S + A)D + (\Delta_3\lambda - \frac{\Delta_4\lambda}{n})}{\Delta_3\alpha D}} + \frac{g_b\alpha}{\Delta_3 \alpha D} + \frac{g_b\alpha}{\Delta_4 \alpha D} \right) e^{-\frac{n\alpha D}{n^2}} \]

where

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

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 \( n \)

\[ n^* = \left( \sqrt{\frac{2(S + A)D + (\Delta_3\lambda - \frac{\Delta_4\lambda}{n})}{\Delta_3\alpha D}} + \frac{g_b\alpha}{\Delta_3 \alpha D} + \frac{g_b\alpha}{\Delta_4 \alpha D} \right) e^{-\frac{n\alpha D}{n^2}} \]

where

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

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 \( (L_0 = 0.0023 \text{ years}) \). The RTI capacity, \( \alpha \), is 500 kg. Inventory carrying charges for RTIs and finished products at the vendor’s and retailer’s side are \( h_s = 0.00045/\text{kg} \), \( h_b = 0.0005/\text{kg} \), \( g_s = g_b = 13.6 \) 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 \( \pi = 2.5 \) per unit short. Additionally, we need to decide multiple sets of \( (\Delta_3, \Delta_4) \) directly to calculate the expected total cost in an uncertain environment. All of the results would be presented in Table III.

Table I

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<th>VARIOUS PARAMETER FACTORS</th>
<th>( L_0 )</th>
<th>( \alpha )</th>
<th>( D )</th>
<th>( P )</th>
<th>( \pi )</th>
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Table II

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<th>( h_b )</th>
<th>( g_s )</th>
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<th>( S )</th>
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TABLE III

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<th>NUMERICAL EXAMPLE RESULTS</th>
<th>( \Delta_3 )</th>
<th>( \Delta_4 )</th>
<th>( \frac{1}{\bar{p}} )</th>
<th>( n )</th>
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(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 \( \Delta_3 \) and \( \Delta_4 \) 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.

(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 \( \Delta_3 = 750000 \), \( \Delta_4 = 1500000 \) and \( \Delta_3 = 1000000 \), \( \Delta_4 = 2000000 \).

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

REFERENCE


