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# Inventory Management Practices Approach to Reverse Logistics

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**Abstract.** In the last few years growing interest has been dedicated to supply chain management. Modeling complexity is added to supply chain coordination problem by accounting for reverse logistics activities. The objective of this paper is to extend inventory model of manufacturing factory with respect to the production of raw material of forward logistics and recycling material of reverse logistics. The proposed model is applied to a plastic recycling process plant located in Taiwan. The case study improvement scheme shows when the recycling rate of recycling material increases from 15% to 50%, the total inventory cost of manufacturing factory decreases by 12.82%, safety stock volume decreases by 41.19% and the reorder quantity is down by 50.96%. This paper finds whether the results of the model can reach the economic profit through quantitative analysis and encourages companies integrate reverse logistics into the supply chain system.

**Keywords:** Reverse Logistics, Remanufacture, Inventory Management

## 1. INTRODUCTION

Normally, reverse logistics include recycling and repairing the spare parts of the machines as well as the recycling, reduction and reusing of common resources. Meanwhile, considering the service level and lead time, this research wants to gain the optimal economic order quantity and safety stock quantity when the recycling rate increases from 10% to 50% under the circumstance that the demand and lead time are uncertainty.

In recent years, there are many problems and models coexisting in the current supply chain system in the field of reverse logistics. This research chooses this kind of material which needs rigorous monitoring in order to deeply understand the control and management principles of stock, and will establish inventory model of reverse supply chain and further to discuss the inventory management problem of reverse logistics in the whole supply chain system. We conclude the purposes of our research:

1. Establish a three-level inventory management model of supply chain, which includes supplier, manufacturer and recycling center and this inventory model can help them to manage stock and minimize the total cost of the whole supply chain.
2. According to the inventory model established, we can calculate the effect of the recycling rate change in reverse logistics on the total inventory cost of supply chain, and the effect of lead time of common raw materials ordering at all levels and the lead time of using recycling materials on inventory cost of all levels.
3. In this research, the raw materials of manufacturer in the whole supply chain system come from two aspects: one is the raw material from supplier and the other is the recycling material from recycling center. As to the whole supply chain, we use demand quantity of all levels as input variables and the outputs called optimal inventory level are optimal service level, optimal order point and optimal order quantity in the expectation of minimizing total cost of whole supply chain.

## 2. LITERATURE REVIEW

In the complex supply chain, the inventory mana-

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gement is rather difficult and may give great impact on client service level and systematic cost of supply chain. Some inventory management models of supply chain use mathematic equation to find out the best solution, and some use simulation to imitate the actual dynamic situation of supply chain. In the whole supply chain system, service level and inventory level are two important indexes. Academic research results show decreasing the uncertainty of demand will lead to better service level and decreasing uncertainty of lead time will lead to better inventory level.

Van der Laan *et al.* (1996) analyzed an ($s$, $Q$) inventory model in with used products can be remanufactured to new ones, and presented an ($s$, $Q$) model for inventory control under remanufacturing and disposal. Although an exact analysis for his model is possible, they developed approximations with perform reasonably well against much less numerical effort. They have shown that disposal is necessary rise to very high values because of the variability in the return streams.

Silver *et al.* (1998) proposed multi-level ($s$, $Q$) inventory theory: ($s$, $Q$) inventory policy is often used as inventory control method of supply chain management. It is a sustainable inventory system. When inventory that can be used (net inventory+inventory on order) decreeases to the reorder point $s$, $Q$ is the fixed inventory which shall be ordered and is called Economic Order Quantity (EOQ). The EOQ's of supplier, manufacturer and recycle center are different and $s$ depends on the lead time enacted. The total stock cost of supply chain includes: 1. ordering cost, 2. inventory holding cost, 3. security holding cost, 4. backorder cost. These four costs are the important factors shall be considered in the inventory theory.

According to the research paper of Council of Logistics Management, the definition of reverse logistics is as follows: It is a kind of logistic activity through source reduction, recycling, substitution, reuse and disposal and it is mainly responsible for the product withdrawing, maintenance and reproducing, goods reprocessing, regeneration and waste disposal as well as hazardous materials management. There are three main operation models of reverse logistics: 1. Reuse 2. Remanufacture 3. Repair and brought forward the mechanism of disposal.

Cachon (1999) studied supply chain demand variability in a model with one supplier and $N$ retailers that face stochastic demand. His research shows that the supplier's demand variance will decline as retailers' order interval is lengthened or as their batch size is increased. Lower supplier demand variance can certainly lead to lower inventory at the supplier. He finds that reducing supplier demand variance with scheduled ordering policies can also lower total supply chain costs.

In the last few years growing interest has been dedicated to supply chain management. Modeling complexity is added to supply chain coordination problem by accounting for reverse logistics activities. Stefan Minner (2001) combined the problem of the problem of safety stock planning in a general supply chain with the integration of external and internal product return and reuse. He analyzed pure safety stock cost effect of reverse logistics activities, the avoidance of disposal cost together with reduced external material supply quantities are other cost determinants that make reverse logistics attractive. From a strategic point of view, when (re-)designing supply chains with respect to reverse logistics processes, additional safety stock requirements have to be traded off with disposal and purchase cost saving. But even if there is no material cost advantage of product recovery, synchronized materials coordination that enable a safety stock reduction may exist and make this option profitable.

Decroix and Zipkin (2005) considered an inventory system with an assembly structure. In addition to uncertain customer demands, the system experiences uncertain return from customers. Some of the components in the returned products can be recovered and reused, and these units are returned to inventory. They find that holding and backorder costs tend to increase when the average return rate, the variability of returns, or the number of components recovered increases. Whether product recovery reduces total system costs depends on the magnitude of the additional holding and backorder costs relative to potential procurement cost savings.

The pressure on manufacturing organizations to adopt benign processes and to develop greener products has increased significantly over the last decade. Vachon (2007) examined the linkage between green supply chain practices and the selection of environmental technologies; the results suggest that environmental collaboration with suppliers is positively associated with greater investment in pollution prevent technologies.

Reverse logistics is considered to be the key for remanufacturing and sustainable development. It has gained increasing attention in the last decade and has been a new frontier of strategic management. Chan (2007) put reverse logistics forward is probably due to environmental impacts on non-returnable materials, and reports a case study of using returnable packaging materials between a manufacture and an original equipment manufacturer supplier.

Arijit, Bijan, and Sanat (2007) proposed a distance-based multi-criteria consensus framework on the concepts of ideal and negative-ideal solutions is presented for the ABC analysis of inventory items. Unit cost, lead time, consumption rate and cost of storing of raw materials have been considered for the case study, they use a simulation model to compare the proposed model with that of the traditional ABC classification technique.

Remanufacturing refers to the process of accepting inoperable units, salvaging good and repairable components from those units, and then re-assembling good units to be re-issued into service. Depuy *et al*. (2007) presented a methodology for production planning within facilities involved in the remanufacture of products. They developed a probabilistic form of standard material requirements planning (MRP) for generating a component purchase schedule to avoid shortages in periods with a low probability of meeting demand.

Guo *et al.* (2010) investigated a manufacturing/remanufacturing system with the consideration of required minimum quality of end-of-used products. For remanufacturing, only the used products that satisfy a required minimum quality level will be recycled. Thus, the returning rate is a function of the required minimum quality level. The mathematical models with the objective of minimizing the average total cost are constructed, through construction of a solution process based on Tabu Search algorithm and calculating examples, the validity of the models is illustrated.

Jonsson and Mattsson (2008) focused on the use of material planning methods to control material flow to inventories of purchased items. In particular, the way of determining and the review frequency of safety stocks and lead times have great importance for the planning performance of MRP methods, while the determination and review of order points, review frequencies and run-out times were important for re-order point methods.

Louly, Dolgui, and Hnaien (2008) developed an efficient exact model to aid in MRP parameterization under lead time uncertainties, more precisely to calculate planned lead times when the component times are random. The aim is to find the values of planned lead times which minimize the sum of average component holding cost and the average backlogging cost.

In the recent years, as a result of environmental legislation and increasing interest in economics, many producers have been forced to implement the PTB (Products Tack Back) program. Ouyang and Zhu (2009) employed the basic ($R$, $Q$) model to control a single-item single-echelon inventory system with return flow, they derive a simple approximate algorithm to determine the optimal control parameters.

## 3. RESEARCH SCOPE AND FRAMEWORK

The reverse supply chain system discussed in this research includes three systems in supplier, manufacturing factory and recycling center. Three suppliers provide one kind of product to one manufacturing factory and the recycling center, it is responsible for the recycling of reused goods in the manufacturing factory, then deliver these reused goods to remanufacturing department through classification, compression and packaging, and finally carry out the manufacturing process of fusil and processing.

Basic research hypothesis of (s, Q) inventory management model:

1. Inventory model adopts (s, Q) system, when the inventory decreases to $s$, $Q$ is complemented.
2. Demand volume is market sales and normal distribution, and changes together with the time but not too much change.
3. Inventory of the management model can be independent each other.
4. The backorder lead time of raw material and recycling material are changing.
5. Suppose the recycling products are can be reused.
6. There are the normal distribution of demand rate, and lead times of the backorder of raw material and recycling material.

The role of supplier: producing new raw materials and providing to manufacturer, material item is the combination of single items provided by different suppliers. Suppliers are responsible for the transportation of materials; the material supply bill is balanced every month.

The role of the manufacturer: According to the difference of productive capacity, materials demand are provided by different suppliers and inside recycling centers to do goods to the production of manufacturer. At the same time, the production mechanism is obliged to the contract of suppliers and the supply falls short of demand. Manufacturer material demand and market sales response in line with production plan, recycling and reproducing are also adopted in the manufacturing of nonconfirmed products.

The role of recycling center: According to the manufacturing mechanism of various recycling manufacturers, clean, classify, compress and wipe off impurity the recycling materials, finally package them and respectively deliver to various re-manufacturers. The material item provided is the combination of single items from manufacturers. The recycling factory is responsible for the transportation of materials. The material supply bill is balanced every month. In this article, there is a specialized recycling center in the factory.

## 4. MODEL BUILDING

### 4.1 Symbole illustration

$D$, $D_S$, $D_g$, $D_m$ : Annual demand volume, the production period in one year is 12 months and production days every month is 30 days, ton/year.

$D_s$ is the demand of raw material supply usage in manufacturing factory.

$D_g$ is the demand of recycling material usage in manufacturing factory.

$D_m$ is the demand of raw material supply and recycling material usage in manufacturing factory.

$Q$, $Q_s$, $Q_g$, $Q_m$ : Economic order quantity refers to the optimal quantity of ordered every time, ton/times.

$Q_s$ is the economic order quantity of raw material supply usage in manufacturing factory.

$Q_g$ is the economic order quantity of recycling material usage in manufacturing factory.

$Q_m$ is the economic order quantity of raw material supply and recycling material usage in manufacturing factory.

$C, C_S, C_g, C_m$ : Order cost, material cost when company order at one time, \$/times.

$v, v_S, v_g$ : Unit variable cost: additional cost when producing one more unit. For example, in this research, the dye materials put into the plastic products are the variable expenditure, called margin cost. It accounts for 2.5% of the material cost.

P: Material cost: Unit price of normal material sold by supplier, \$/ton.

$P_g$ : Purchasing cost of recycling material in recycling center which accounts for 65% of raw material price.

r: Annual unit inventory holding cost: include the cost of stock space, equipment and maintenance, \$/ton/year.

$\sigma_{dLt}$ : Lead time standard deviation.

d: Monthly unit demand volume~N(750, 30.125), ton/month.

$\sigma_d$ : Monthly demand standard deviation.

$k$ : Stock safety coefficient (see Appendix):

$$k = \sqrt{2\ln\frac{DB}{\sqrt{2\pi}Qr}} \tag{1}$$

$B, B_S, B_g, B_m$ : Unit backorder cost represents annual lost money when out of stock or lost stock when purchasing other materials to replace the normal materials, \$/ton/year.

$R_g$ : Recycling rate represents the use rate of recycling material.

$C_R, C_{Rm}$ : Recycling cost, the required expenditure when recycling one unit material which including material unit price, setting and transportation, \$/ton.

Pr: Unit manufacturing trade price is \$1445/ton.

$P_S$ : 1- backorder probability.

## 4.2 Inventory model in manufacturing factory

Modeling complexity is added to supply chain coordination problem by accounting for reverse logistics activities. We extend inventory model of manufacturing factory with respect to the production of raw material of forward logistics and recycling material of reverse logistics was shown as following:

4.2.1 Inventory cost model of raw material providing Total cost of supplier

$$STC = \frac{D_S}{Q_S}C_S + \left(\frac{Q_S}{2} + \sigma_{dLt}\right)v_S r + \frac{B_S v\sigma_{dLt}G_u(k)D_S}{Q_S} \tag{2}$$

Including order cost $\frac{D_S}{Q_S}C_S$ , inventory holding cost $\left(\frac{Q_S}{2} + \sigma_{dLt}\right)v_S r$ . Where $\sigma_{dLt}$ is standard deviation of a lead time from raw material providing by supplier.

Backorder cost $\frac{B_S v\sigma_{dLt}G_u(k)D_S}{Q_S}$ (3)

Backorder probability (see Appendix):

$$G_u(k) = \frac{Q}{Bv\sigma_{dLt}}(1 - P_S) \tag{4}$$

In order to find out minimal inventory cost, the first order derivative with respect to Q to gain $Q_S$ , which is the economic order quantity of purchasing normal materials from suppliers.

$$Q_S = \sqrt{\frac{2D_S(C_S + B_S v\sigma_{dLt}G_u(k))}{vr}} \tag{5}$$

The optimal quantity of raw materials or semi-manufacturing products ordered every time. Decreasing order quantity will increase order times in the certain demand volume. Thus, the stock cost of inventory will decrease with the average stock volume. On the other hand, the order cost will increase with the order times. On the contrary, decreasing order times will increase order quantity and when order cost is dawn, the stock cost rises. It is obvious that the purpose of inventory decision making is to identify that the sum of these two costs is the economic order quantity.

4.2.2 Inventory cost model of producing recycling material in recycling center:

$$GTC = \frac{D_g}{Q_g}C_g + \left(\frac{Q_g}{2} + \sigma_{dLt}\right)v_g r + \frac{B_g v\sigma_{dLt}G_u(k)D_g}{Q_g} + R_g\frac{D_g}{Q_g}C_r \tag{6}$$

In order to find out minimal inventory cost, the first order derivative with respect to Q which equals to 0, the economic order quantity $Q_g$ of recycling material is:

$$Q_g = \sqrt{\frac{2D_g(C_g + B_g v\sigma_{dLt}G_u(k) + R_g C_r)}{vr}} \tag{7}$$

4.2.3 Inventory cost model of raw material supply and recycling material usage in manufacturing factory

$$\begin{aligned} MTC = \sum_{i=1}^{k}\sum_{j=1}^{k}\left(P_{si+gi}D + \frac{D_m}{Q_{si+gj}}C_m + \left(\frac{Q_{si+gj}}{2} + \sigma_{dLt}\right)vr\right) \\ + \frac{B_m v\sigma_{dLt}G_u(k)D_m}{Q_{si+gj}} + R_m\frac{D_m}{Q_{si+gj}}C_m \end{aligned} \tag{8}$$

In order to find out minimal inventory cost, the first order derivative with respect to Q then let it equals to 0. The economic order quantity of raw material supply and recycling material usage in manufacturing factory $Q_m$ is:

$$Q_m = \sum_{i=1}^{k}\sum_{j=1}^{k}\left(Q_{si} + Q_{gi}\right) = \sqrt{\frac{2D_m(C_m + B_m v\sigma_{dLt}G_u(k) + R_m C_m}{vr}} \tag{9}$$

## 5. EXAMPLE AND MODEL TESTING

Using an example to illustrate the inventory model of reverse supply chain involved above. Make an example of a high density polyethylene (HDPE) plastic processing plant in the central of Taiwan, the origin of the raw materials are from Formosa Plastic Mailiao plant, Formosa Plastic Linuan plant and Gao-Xiong polymer plant. In the producing process, recycling internal HDPE, and reproducing by fusil, then reusing. Recycling materials also can be purchased from other recycling factories that produce same materials. The remanufacturing materials can be used by the company itself or can be sold to factory A, B, C to produce HDPE in the purpose of extruding molding goods.

Through the original data of HDPE plastic processing industry are catch from the processing factory in central of Taiwan, we know the average annual demand volume of raw material is 9000 ton/year. The origin of the raw material is from two aspects: one is the manufacturing quantity of raw material supplier; the other is the manufacturing quantity of recycling center. Suppose the inventory productivity of these two aspects is far more than the demand rate, it means the supply and demand is stable. Suppose the standard deviation of a lead time, $\sigma_{dLt}$, from supplier and recycling center is negligible. Annual demands above Ds, Dg are changing with the recycling rate.

The recycling product in this research is HDPE called high-density polyethylene, and the finished products are plastic bags and bottles. The manufacturing and recycling process of a high density polyethylene processing system is show as Figure 1.

### 5.1 Decision making and parameter validation

From the original data, the service level is 96.5%, the lead time of raw material is 7 days, the service level of recycling material and product were in control, the lead time of the recycling material is 1.2 days and the recycling material accounts for 15% of total materials. In another year, the recycling rate depends on the midseason and off-season. In the midseason, the recycling rate is 15% and the off-season is 50%. Table 1 shows the lead time and recycling rate of midseason and off-season. Using material requirement plan table 3 to validate whether there is out of stock or not.

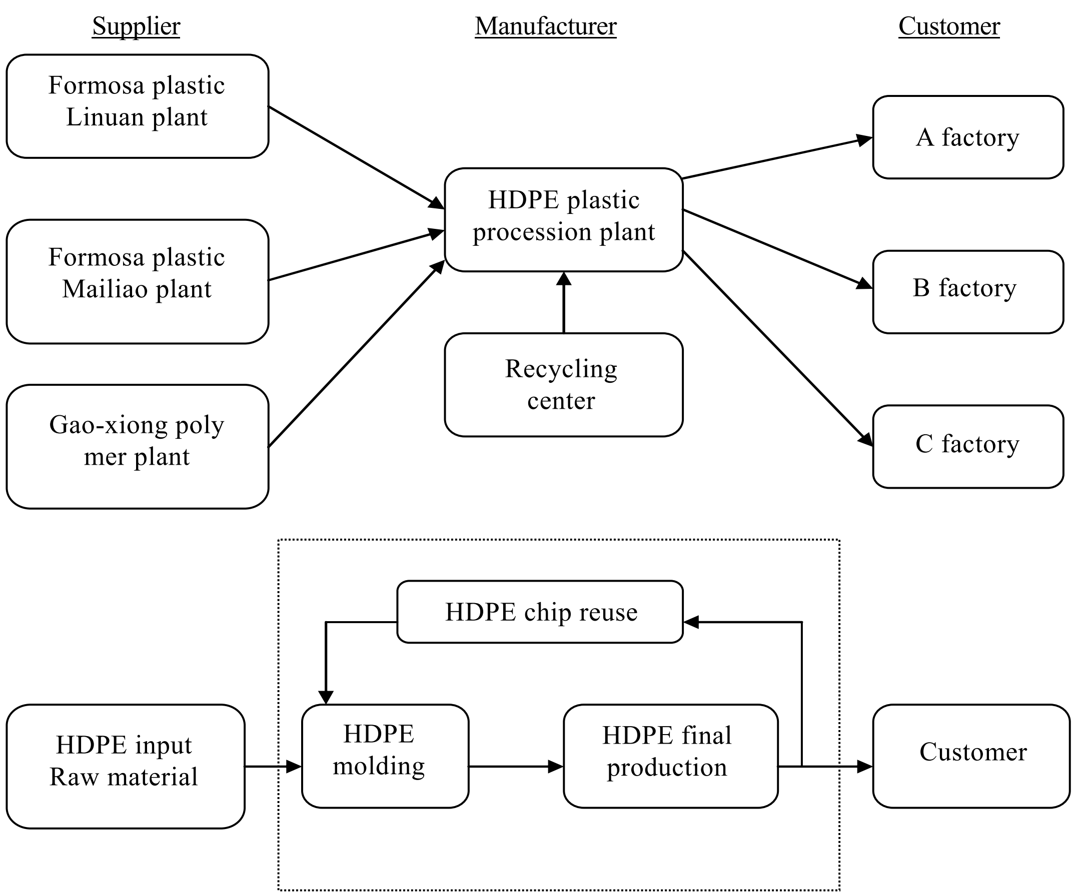


**Figure 1.** Manufacturing and recycling process of a high density polyethylene (HDPE) processing factory in central of Taiwan.

### 5.2 Improvement scheme

**a**. Increase the recycling rate of normal material to 50%.
**b**. Increase the service level of normal material to 98%.
**c**. Decrease the lead time of normal material to 2 days.
**d**. Combine the three schemes above.

### 5.3 Result analysis

1. According to the research restrictions, scheme ***a***, ***ab***, ***b***, are not up to the assumptions. From Table 3, the stock levels of various schemes are gained. From Table 2 to validate material requirement plan to gain the optimal stock level of scheme ac is 77.32% without the situation of backorder. At that time, the safety stock is 176.09 ton, filling vacancies in the proper order of safety stock is 3 times and the order quantity is 219.21 tons. Off-season with high stock and mid-season with low stock. Scheme ***bc*** and ***d*** have the loss of backorder.
2. In Table 2, the demand (sale) forecasting value is in the safety range from -4 to +4 and presenting normal distribution. The demand forecasting is acceptable for there is no overestimation and underestimation.
3. From Table 3, when the recycling rate increases to 50% and the lead time decreases to 2 days, the optimal inventory level is $Q_S + Q_g = 667.74$ unit order quantity, at this time, the inventory service level of normal material is 96.5%, the total outlay cost is $4,985,368.15, the upper limit of stock quantity of product line is $Q_m + SS = 843.83$, while the order quantity of scheme ***c*** is 624.11. When not considering increasing recycling rate, the optimal order scheme is gained.
4. This research analyzes the inventory model of manufacturing factory combining the normal material of forward logistics with the recycling material of reverse logistics to lead to the conclusion: Scheme ***ac*** shows when the recycling rate of recycling material increases from 15% to 50%, the total cost of inventory decreases by 12.82%, the safety stock volume decreases by 41.19% and the reorder quantity decreases by 50.96%, as showed in Table 3.

## 6. CONCLUSION AND DISCUSSION

1. From the case study, when the recycling rate increase to 50% and the lead time decrease to 2 days, then the optimal inventory level and service level were improved significantly.
2. After analyzing inventory model of manufacturing

**Table 1.** Data of recycling and manufacturing processing plant in midseason and off-season.

| Date(month) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| midseason LT | 2(1) | 5(1) | 3(0.5) | 6(1) | 5(2) | 4(1.5) | 4(1) | 2(1.5) | 3(0.5) | 4(1) | 5(1.5) | 4(2) |
| off-season LT | 5(1) | 2(1) | 6(1) | 3(0.5) | 4(1.5) | 5(2) | 2(1.5) | 4(1) | 4(1) | 3(0.5) | 4(2) | 5(1.5) |
| midseason d | 643.8 (110.4) | 615.2 (157.5) | 568.4 (148.3) | 585.6 (185.2) | 554.8 (142.6) | 569.1 (125.7) | 598.3 (155.8) | 625.7 (175.1) | 587.6 (147.6) | 608.6 (129.9) | 625.5 (165.6) | 617.4 (156.3) |
| off-season d | 350.8 (440.5) | 365.4 (408.6) | 312.2 (395.4) | 308.4 (398.3) | 312.9 (395.7) | 328 (384.5) | 354.1 (431.8) | 355.2 (448.6) | 321.6 (422.2) | 346.5 (376.8) | 330.7 (411.5) | 364.2 (436.1) |

Note: d: monthly unit demand volume, ton/month.

**Table 2.** Material requirement plan for this example.

| Date(month) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sale forecasting | 710 | 710 | 754.72 | 765.32 | 733.57 | 718.79 | 713.19 | 712.81 | 753.01 | 780.94 | 762.99 | 741.16 |
| Primary stock | 400 | 357.74 | 234.18 | 127.92 | 88.06 | 49.1 | 8.24 | 139.57 | 21.41 | 61.44 | 161.47 | 105.91 |
| Actual demand | 710 | 791.3 | 774 | 707.6 | 706.7 | 708.6 | 712.5 | 785.9 | 803.8 | 743.8 | 723.3 | 742.2 |
| Order quantity planned Q | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 | 667.74 |
| Order quantity | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 | 219.21 |
| Safety stock | 0 | 0 | 0 | 0 | 0 | 0 | 176.090 | 0 | 176.090 | 176.09 | 0 | 0 |
| Backorder | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Final stock | 357.74 | 234.18 | 127.92 | 88.06 | 49.1 | 8.24 | 139.57 | 21.41 | 61.44 | 161.47 | 105.91 | 31.45 |

Note: The calculation of cost in Table 2 is:

1. Raw material: Ps*Ds+ Pg*Dg 2.Order cost: $\frac{D_S}{Q_S}C_S + \frac{D_g}{Q_g}C_g$

3. Holding cost: $\frac{Q_S}{2}v_S r + \frac{Q_g}{2}v_g r$ 4.Backorder cost: Tons of out of stock $\times B_m$ .

**Table 3.** The change of recycling rate, service level and lead time for this example.

| Project | original | a | ab | ac | b | bc | c | d |
|---|---|---|---|---|---|---|---|---|
| Ds (Dg) | 7650 (1350) | 4500 (4500) | 4500 (4500) | 4500 (4500) | 7650 (1350) | 7650 (1350) | 7650 (1350) | 4500 (4500) |
| Rg (%) | 15 | 50 | 50 | 50 | 15 | 15 | 15 | 50 |
| Ps (%) | 96.5 | 96.5 | 98 | 96.5 | 98 | 98 | 96.5 | 98 |
| LT(day) | 7 | 7 | 7 | 2 | 7 | 2 | 2 | 2 |
| Qs | 666.40 | 451.24 | 265.55 | 339.79 | 418.31 | 422.43 | 498.63 | 265.78 |
| Qg | 125.48 | 327.95 | 310.62 | 327.95 | 114.06 | 114.06 | 125.48 | 312.18 |
| $Q_m$ | 791.88 | 779.19 | 576.17 | 667.74 | 532.37 | 536.49 | 624.11 | 577.96 |
| **S**afety **s**tock(SS) | 299.47 | 249.54 | 249.54 | 176.09 | 299.47 | 206.26 | 206.26 | 176.09 |
| ROP | 446.97 | 348.92 | 348.92 | 219.21 | 446.97 | 253.76 | 253.76 | 219.21 |
| Stock weight (%) | 100 | 94.26 | 75.66 | 77.32 | 90.60 | 82.44 | 76.09 | 69.09 |
| Raw material cost | 5,713,425 | 4,974,750 | 4,974,750 | 4,974,750 | 5,713,425 | 5,713,425 | 5,713,425 | 4,974,750 |
| Order cost | 285.18 | 258.68 | 417.49 | 332.28 | 441.06 | 437.05 | 372.09 | 416.99 |
| Holding cost | 4,810.59 | 3,386.48 | 2,055.40 | 2,593.104 | 3,038.439 | 3,067.76 | 3,616.284 | 2,057.86 |
| **S**afety **s**tock cost | 0 | 0 | 24,869.78 | 7,521.241 | 34,109.63 | 29,366.27 | 14,683.14 | 22,563.73 |
| Safety stock backorder | 0 | 0 | 7 | 3 | 8 | 10 | 5 | 9 |
| Backorder cost | 0 | 0 | 0 | 0 | 0 | 1909.5 | 0 | 1885.25 |
| Backorder times | 0 | 0 | 0 | 0 | 0 | 76.38 | 0 | 75.41 |
| Recycle cost | 40.34 | 171.52 | 181.09 | 171.52 | 44.38 | 44.38 | 40.34 | 180.18 |
| Total cost | 5,718,561 | 4,978,566 | 5,002,273 | 4,985,368 | 5,751,058 | 5,748,249 | 5,732,136 | 5,001,854 |

factory with respect to the production of raw material of forward logistics and recycling material of reverse logistics, scheme ***ac*** shows when the recycling rate of recycling material increases from 15% to 50%, the total inventory cost of manufacturing factory decreases by 12.82%, safety stock volume decreases by 41.19% and the reorder quantity is down by 50.96%.

3. This research validates whether the results of the model can reach the economic profit through quantitative analysis and encourages companies integrate reverse logistics into the supply chain system.
4. Among the inventory control methods, this research makes validation step by step with ($s$, $Q$) sustained inventory system, and finds out the optimal inventory level.
5. As there are so many inventory control subjects, the optimal recycling rate, service level, lead time and the impact of overall recycling effect produced by all levels of supply chain members can be considered in the future.

## REFERENCES

Arijit Bhattacharya, Bijan Sarkar, and Sanat K. Mukherjee (2007), Distance-based consensus method for ABC analysis, *International Journal of Production Research*, **45**(15), 3405-3420.

Cachon, G. P. (1999), Managing supply chain demand variability with scheduled ordering policies, *Management Science*, **45**(6), 843-856.

Chan, H. K. (2007), A pro-active and collaborative approach to reverse logistics-a case study, *Production Planning and Control*, **18**(4), 350-360.

DeCroix, G. A. and Zipkin, P. H. (2005), Inventroy management an assembly system with product or component retuen, *Management Science*, **51**(8), 1250-1265.

Depuy, G. W., Usher, J. S., Walker, R. L., and Taylor, G. D. (2007), Production planning for remanufactured products, *Production Planning and Control*, **18**(7), 573-583.

Guide Jr., V. D. R. and Srivastava, R. (1997), An evaluation of order release strategies in a remanufacturing environment, *Computer Operations Research*, **24**(1), 37-47.

Guo, J., Ko, Y. D., and Hwang, H. (2010), A manufacturing/remanufacturing system with the consideration of required quality of end-of-used products, *Industrial Engineering and Management Systems*, **9**(3), 204-214.

Jonsson, P. and Mattisson, S.-A. (2008), Inventory management practices and their implications on per-

ceived planning performance, *International Journal of Production Research*, **46**(7), 1787-1812.
Louly, M. A., Dolgui, A., and Hnaien, F., Optimal supply planning in MRP environments for assembly systems with random component procurement times, *International Journal of Production Research*, **46** (9), 5441-5467.
Ouyang, Huiqing and Zhu, Xiangyang (2009), A simple algorithm for the basic (*R*, *Q*) inventory control model with return flow, *Asia-Pacific Journal of Operational Research*, **26**(3), 383-398.
Silver, E. A., Pyke, D. F. and Peterson, R. (1998), *Inventory management and production planning and scheduling*, 3rd ed, J. Wiley.
Stefan, Minner, (2001), Strategic safety stocks in reverse logistics supply chain, *International Journal of Production Economics*, **71**, 417-428.
Vachon, Stephan (2007), Green supply chain practices and the selection of environmental technologies, *International Journal of Production Research*, **45** (18-19), 4357-4379.
Van der Laan, E., Dekker, R., Salomon, M., and Ridder, A. (1996), An (s, Q) inventory model with remanufacturing and disposal, *International Journal Production Economics*, **46**(2), 339-350.

## APPENDIX

Derivate the safety coefficient of stock:

Probability density function with normal distribution: $f(x)=\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(x-\mu)^2}{2}}$ (A-1)

mean value $\mu=0$, variance $\sigma^2=1$, expressed by $X \sim N(\mu,\sigma^2), -\infty < X < \infty$,

suppose $\mu_0 = x-\mu$, then, $E(\mu_0)=0, \sigma_\mu = 1$, the function can be rewrote as follows: $f_u(\mu_0)=\frac{1}{\sqrt{2\pi}}e^{-\frac{\mu_0^2}{2}}$ (A-2)

Substitute safety stock coefficient into A-2: $f_u(k)=\frac{1}{\sqrt{2\pi}}e^{-\frac{k^2}{2}}$ (A-3)

The function of backorder with normal distribution

$$G_u(k)=\int_k^\infty (u_0-k)\frac{1}{\sqrt{2\pi}}e^{\frac{-u_0^2}{2}}duo \quad \text{(A-4)}$$

$$G_u(k)\sim(0,1)\ G_u(k)=\int_k^\infty(\mu_o-k)e^{-\frac{\mu_0^2}{2}}duo=\int_k^\infty(\mu-k)f_u(u_0)du_0=\int_k^\infty u_0 f_u(u_0)du_0 - kp_u \ge (k) =$$

$$f_u(k) - kp_u \ge (k),\ G_u(-k)=G_u(k)+k,\ \frac{\partial G_u(k)}{\partial k}=-f_u(k) \quad \text{(A-5)}$$

Therefore the first order derivative with respect to total cost, we gain the out of stock probability of the order lead time:

$$\frac{\partial TC(k)}{\partial k}=\sigma_{dLt}vr+\frac{B\,v\sigma_{dLt}D}{Q}\frac{\partial G_u(k)}{\partial k}=0, \frac{\partial G_u(k)}{\partial k}=-f_u(k),$$

Such that $f_u(k)=\frac{1}{\sqrt{2\pi}}e^{-\frac{k^2}{2}}=\frac{Q\ r}{D\ B}$ then $k=\sqrt{2\ln\frac{DB}{\sqrt{2\pi}Qr}}$ (A-6)

Economic order quantity of suppliers: suppose the inventory productivity of supply origin is much higher than the demand rate, the economic order quantity is the economic production quantity:

$$STC=\frac{D_S}{Q_S}C_S+(\frac{Q_S}{2}+K_S\sigma_{dLT})vr+\frac{B_S v\sigma_{dLT}G_u(k)D_S}{Q_S} \quad \text{(A-7)}$$

$$\frac{\partial STC(Q^*)}{\partial Q}=-\frac{D_S}{Q_S^2}(C_S+B_S v\sigma_{dLT}G_u(k))+\frac{vr}{2}=0$$

$$Q_S=\sqrt{\frac{2D_S(C_S+B_S v\sigma_{dLT}G_u(k))}{vr}} \quad \text{(A-8)}$$

About the recycling center:

$$GTC = \frac{D_g}{Q_g} C_g + (\frac{Q_g}{2} + k_g \sigma_{dLT}) v \; r \; + \frac{B_g v \sigma_{dLT} G_u(k) D_g}{Q_g} + R_g \frac{D_g}{Q_g} C_r) \quad \text{(A-9)}$$

$$Q_g = \sqrt{\frac{2D_g(C_g + B_g v \sigma_{dLt} G_u(k) + R_g C_r}{vr}}$$

About the manufacturing factory:

Manufacturing factory $MTC = \sum_{i=1}^{k} \sum_{j=1}^{G} (P_{si+g_j} D + \frac{D_m}{Q_{si+g_j}} C_m$

$$+ (\frac{Q_{si+g_j}}{2} + k_m \sigma_{dLt}) vr + \frac{B_m v \sigma_{dLt} G_u(k) D_m}{Q_{si+g_j}} + R_m \frac{D_m}{Q_{si+gj}} C_m) \quad \text{(A-10)}$$

$$Q_m = \sum_{i=1}^{k} \sum_{j=1}^{G} (Q_{Si} + Q_{gj}) = \sqrt{\frac{2D_m(C_m + B_m v \sigma_{dLt} G_u(k) + R_m C_m)}{vr}} \quad \text{(A-11)}$$

Service level is:

$P_S$ = 1- (one year expected out of stock/ one year demand volume) =

1-backorder probability, Pb =1-P($R_L$ > ROP) = $1 - \frac{(D/Q)(\sigma_{dLT} G_u(k))}{D} = 1 - \frac{\sigma_{dLT} G_u(k)}{Q}$

Backorder probability: $G_u(k) = \frac{Q}{Bv\sigma_{dLT}}(1 - P_S)$ (A-12)