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A Mathematical Model for Waste Management in Reverse Supply Chain

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Abstract

Reverse supply chain problem is one of the issues in supply chain which as well explore wastes management in relation to customer. In reverse supply chains, wastes can be recycled and reproduced and benefiting from profitability of new products which is produced from it. In this study, residuals, after transferring by customer, send to production station, sorting station and different manufacturing processes (melting, forging, clamping, painting …) for reproduction. After completion of all different manufacturing processes, several diverse products resend to customers. Here, with respect to different cost factors and also pricing concept and reproduced parts, we evaluate the mathematical model of optimizing manufacturing cost. The solution will be useful for strategic decision making in municipalities.

Keywords
Reverse supply chain; waste management; pricing; mathematical optimization.

1. Introduction
An effective, efficient and robust supply chain is a sustainable competitive advantage for countries and firms and helps them to cope with increasing environmental turbulences and more intense competitive pressures. A supply chain is a network of supplier, production, distribution centers and channels between them organized to acquire raw materials, convert them to finished products, and distribute final products in an efficient way to customers. Supply chain network design is one of the most important strategic decisions in supply chain management. In general, network design decisions include determining the numbers, locations and capacities of facilities and the quantity of flow between them (Amiri, 2006).

In recent decades, many companies such as Kodak, Xerox and HP have focused on remanufacturing and recovery activities and achieved significant successes in this area (Uster et al., 2007). Meade et al. (2007) classify driving forces led to increased interest and investment in reverse supply chain into two groups: environmental factors and business factors. The first group includes environmental impacts of used products, environmental legislations and growing environmental consciousness of customers. Business factors are related to economic benefits of using returned products and liberal return policies for gaining customer satisfaction. Reverse supply chain network design includes determining the numbers, locations and capacities of collection, recovery and disposal centers, buffer inventories in each site and the quantity of flow between each pair of facilities. The design and establishment of the supply chain network is a strategic decision whose effect will last for several years, during which the parameters of the business environment (e.g. demand of customers) may change (Meepetchdee and Shah, 2007). Implementation of reverse logistics especially in product returns would allow not only for savings in inventory carrying cost, transportation cost, and waste disposal cost due to returned products, but also for the improvement of customer loyalty and futures sales. Recycling problem can affect not only a cost performance of recycling of a company, but also whole strategy of the company including production strategy and purchase policy. To deal with this problem, the government should treat it in one industry. In the Korea, the extended product responsibility is in force system from 2003 that the obligation is given as a producer as it recycles more than a constant amount of the waste that can be recycled (Biehl et al., 2007; Koo and Evans, 2007; Lieckens and Vandaele, 2007). Reverse logistics is defined by the European working group on reverse logistics (REVLOG) as ‘‘the propose of planning, implementing and controlling flows of raw materials, in process inventory, and finished goods, From the point of use back to point recovery or point of proper disposal”. In a broader sense, reverse logistics refers to the distribution activities involved in product returns, source reduction, conservation, recycling, substitution, reuse, disposal, refurbishment, repair and remanufacturing (Stock, 1992). Concerning reverse logistics, a lot of researches have been made on various fields and subjects such as reuse, recycling, remanufacturing logistics etc. In reuse logistics models, Kroon and Vrijens (1995) reported a case study concerning the design of a logistics system for reusable transportation packages. The authors proposed a MIP (mixed integer programming), closely related to a classical un-capacitated warehouse location model.

In recycling models, Barros et al. (1998) proposed a mixed integer program model considered two-echelon location problems with capacity constraints based on a multi-level capacitated warehouse location problem. Pati et al. (2008) developed an approach based on a mixed integer goal programming model (MIGP) to solve the problem. The model studies the inter-relationship between multiple objectives of a recycled paper distribution network. The objectives considered are reduction in reverse logistics cost. This study proposed reverse logistics network of remanufacturing process. The objective of this study is to minimize all shipping costs occurred by remanufacturing process. In remanufacturing models, Kim et al. (2006) discussed a notion of remanufacturing systems in reverse logistics environment. They proposed a general framework in view of supply planning and developed a mathematical model to optimize the supply planning function. The model determines the quantity of products parts processed in the remanufacturing facilities subcontractors and the amount of parts purchased from the external suppliers while maximizing the total remanufacturing cost saving. Jayaraman et al. (1999) presented a mixed integer program to determine the optimal number and locations of remanufacturing facilities for the electronic equipment. They developed heuristic concentration procedures combined with heuristic expansion components to handle relatively large problems. Lee et al. (2007) proposed the reverse logistics network problem (rLNP) minimizing total reverse logistics various shipping costs. This paper offers an efficient MILP model for multi-stage reverse logistics network design that could support recovery and disposal activities.

This paper is organized as follows. The model notations and mathematical model for remanufacturing system are proposed in Section 2. Section 3 provides an analysis of the model using an illustrative example and some insights into the proposed model and finally, concluding remarks and some possible future works are given in Section 4.

2. Problem definition and formulation

The reverse logistics network discussed in this paper is a multi-stage logistics network including customer, collection, disassembly, refurbish and disposal centers.

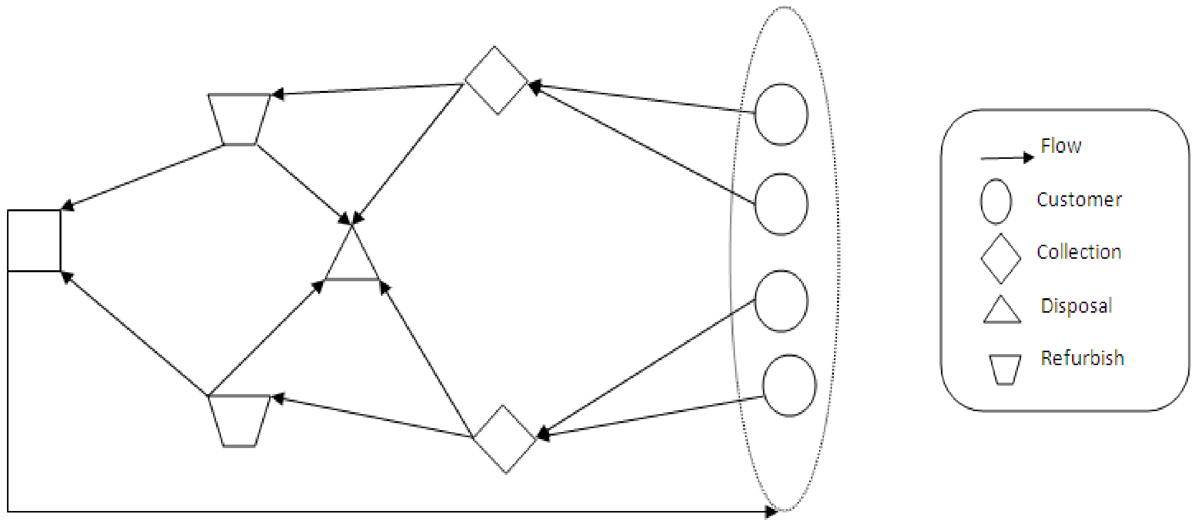

Fig.1. Structure of reverse supply chain network

As illustrated in Fig. 1, in the reverse flow, returned products are collected in collection centers and after inspecting the recoverable products are shipped to disassembly facilities, and scrapped products are shipped to disposal centers. With this strategy, excessive transportation of returned products (especially scrapped products) is prevented and the returned products can be shipped directly to the appropriate facilities. The disassembled parts from products in disassembly facilities are shipped to refurbish and disposal centers through a push system. After the refurbish process, the refurbished parts are delivered to customers as new parts. A predefined percentage of demand of each customer zone is assumed to result in return products and a predefined value is determined as an average disposal rate. The average disposal rate is associated with the quality of returned products; because high quality returns have a capability for recovery process (remanufacturing and de-manufacturing) and low quality returns should be entered to a safe disposal process. Under the above situations, the remanufacturing company is interested in minimizing total remanufacturing cost so that eventually it can maximize total profit. to achieve the goal, while meeting part demands from manufacturing plants, the company should determine how many returned products should be thrown into the remanufacturing process such as refurbishing and disassembling for 'as new' condition. The other issues to be addressed by this study are to choose the location and determine the number of collection, disassemble, refurbish and disposal centers and to determine the quantity of flow between network facilities. The following notation is used in the formulation of proposed model.

Indices:

i	Index of collection/inspection center $i = 1, \ldots, I$
j	Index of disassembly center $j = 1, \ldots, J$
k	Index of refurbish center $k = 1, \ldots, K$
m	Index of disposal center $m = 1, \ldots, M$
n	Index of customer $n = 1, \ldots, N$
p	Index of product $p = 1, \ldots, P$
l	Index of part $l = 1, \ldots, L$

Parameters:

d_{np}	Demand of customer n for refurbished products p
r_{np}	Returns of used products p from customer n
s_l	Average disposal fraction part l
re_{ijp}	Exit of returned product p from collection center i to disassemble center j
cc_{ip}	Capacity of handling returned products p at collection/inspection i

cs_{jp} Capacity of handling recoverable products p at disassembly center j
cr_{kl} Capacity of handling refurbished parts k at refurbish center k
cd_{ml} Capacity of handling scrapped parts l at disposal center m
π_{lp} The number of disassembled parts l from products p
a_{ip} set-up cost of collection/inspection center i for returned product p
b_{jp} set-up cost of disassembly center j for recoverable product p
c_{kl} set-up cost of refurbish center k for part l
o_{ml} set-up cost of disposal center m for part l
e_{nip} Shipping cost per unit of returned products p from customer n to collection/inspection center i
q_{ijp} Shipping cost per unit of recoverable products p from collection / inspection center i to disassembly center j
t_{jkl} Shipping cost per unit of parts l from disassembly center j to refurbish center k
v_{jml} Shipping cost per unit of parts l from disassembly center j to disposal center m
α_{ip} The idle cost of collection/inspection center i for product p
β_{jp} The idle cost of disassembly center j for product p
γ_{kl} The idle cost of refurbish center k for part l
λ_{ml} The idle cost of disposal center m for part l
ci_{ip} The inspection cost of returned products p in collection/inspection center i
ca_{jp} The disassembly cost of recoverable products p in disassembly center j
cp_{kl} The refurbish cost of disassembled parts l in refurbish center k
ch_{ml} The disposal cost of disassembled parts l in disposal center m

Decision variables:

QE_{nip} Quantity of returned products p shipped from customer n to collection/inspection center i
QQ_{ijp} Quantity of recoverable products p shipped from collection/inspection center i to disassembly center j
QT_{jkl} Quantity of parts l shipped from disassembly center j to refurbish center k
QV_{jml} Quantity of parts l shipped from disassembly center j to disposal center m

$$X_{ip} = \begin{cases} 1 & \text{if a collection center i is set}-\text{uped} \\ 0 & \text{otherwise} \end{cases} \qquad \forall\, i, p$$

$$Y_{jp} = \begin{cases} 1 & \text{if a disassembly center j is set}-\text{uped} \\ 0 & \text{otherwise} \end{cases} \qquad \forall\, j, p$$

$$G_{kl} = \begin{cases} 1 & \text{if a refurbish center k is set}-\text{uped} \\ 0 & \text{otherwise} \end{cases} \qquad \forall\, k, l$$

$$\delta_{ml} = \begin{cases} 1 & \text{if a disposal center m is set}-\text{uped} \\ 0 & \text{otherwise} \end{cases} \qquad \forall\, m, l$$

Using above indices and parameters, the mathematical formulation for this problem can be stated as follows.

$$\min Z = \Bigg\{\sum_{i=1}^{I}\sum_{p=1}^{P}(a_{ip} * X_{ip}) + \sum_{j=1}^{J}\sum_{p=1}^{P}(b_{jp} * Y_{jp}) + \sum_{k=1}^{K}\sum_{l=1}^{L}(c_{kl} * G_{kl}) + \sum_{m=1}^{M}\sum_{l=1}^{L}(o_{ml} * \delta_{ml}) + \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{p=1}^{P}(ci_{\mathrm{ip}} + e_{nip}) * \big(QE_{nip}\big) + \sum_{\mathrm{i=1}}^{\mathrm{I}}\sum_{\mathrm{j=1}}^{\mathrm{J}}\sum_{\mathrm{p=1}}^{\mathrm{P}}(ca_{\mathrm{jp}} + q_{ijp}) * \big(QQ_{\mathrm{ijp}}\big) + \sum_{\mathrm{j=1}}^{\mathrm{J}}\sum_{\mathrm{k=1}}^{\mathrm{K}}\sum_{\mathrm{l=1}}^{\mathrm{L}}\big(cp_{kl} + t_{jkl}\big) * (QT_{\mathrm{jkl}}) + \sum_{\mathrm{j=1}}^{\mathrm{J}}\sum_{\mathrm{m=1}}^{\mathrm{M}}\sum_{\mathrm{l=1}}^{\mathrm{L}}(ch_{\mathrm{ml}} + v_{\mathrm{jml}}) * \big(QV_{\mathrm{jml}}\big) + \sum_{i=1}^{I}\sum_{p=1}^{P}\alpha_{ip} * (X_{ip} * cc_{\mathrm{ip}} - \sum_{\mathrm{n=1}}^{\mathrm{N}} QE_{nip}) + \sum_{\mathrm{j=1}}^{\mathrm{J}}\sum_{\mathrm{p=1}}^{\mathrm{P}}\beta_{jp} * (Y_{jp} * cs_{\mathrm{jp}} - \sum_{\mathrm{i=1}}^{\mathrm{I}} QQ_{\mathrm{ijp}}) + \sum_{\mathrm{k=1}}^{\mathrm{K}}\sum_{\mathrm{l=1}}^{\mathrm{L}}\gamma_{\mathrm{kl}} * (G_{kl} * cr_{\mathrm{kl}} - \sum_{\mathrm{j=1}}^{\mathrm{J}} QT_{\mathrm{jkl}}) + \sum_{\mathrm{m=1}}^{\mathrm{M}}\sum_{\mathrm{l=1}}^{\mathrm{L}}\lambda_{ml} * (\delta_{ml} * cd_{\mathrm{ml}} - \sum_{\mathrm{j=1}}^{\mathrm{J}} QV_{\mathrm{jml}}) \qquad (1)$$

subject to:

$$\sum_{i=1}^{I} QE_{nip} \geq r_{\mathrm{np}} * d_{\mathrm{np}} \qquad \forall p \in P, n \in \mathrm{N} \qquad (2)$$

$$re_{\mathrm{ijp}} * \sum_{n=1}^{N} QE_{nip} = \sum_{\mathrm{j=1}}^{\mathrm{J}} QQ_{\mathrm{ijp}} \qquad \forall \mathrm{i} \in \mathrm{I}, p \in \mathrm{P} \qquad (3)$$

$$QT_{\mathrm{jkl}} = (1 - s_{\mathrm{l}})\sum_{p=1}^{P}\sum_{i=1}^{I}\pi_{\mathrm{lp}} * QQ_{\mathrm{ijp}} \qquad \forall l \in L, k \in K, j \in J \qquad (4)$$

$$QV_{\mathrm{jml}} = s_{\mathrm{l}}\sum_{p=1}^{P}\sum_{i=1}^{I}\pi_{\mathrm{lp}} * QQ_{\mathrm{ijp}} \qquad \forall l \in L, m \in M, j \in J \qquad (5)$$

$$\sum_{n=1}^{N} QE_{nip} \leq cc_{\mathrm{ip}} * X_{ip} \qquad \forall \mathrm{i} \in \mathrm{I}, \mathrm{p} \in \mathrm{P} \qquad (6)$$

$$\sum_{i=1}^{I} QQ_{\mathrm{ijp}} \leq cs_{\mathrm{jp}} * Y_{jp} \qquad \forall j \in J, p \in P \qquad (7)$$

$$\sum_{j=1}^{J} QT_{\mathrm{jkl}} \leq cr_{\mathrm{kl}} * G_{kl} \qquad \forall k \in K, l \in L \qquad (8)$$

$$\sum_{j=1}^{J} QV_{\mathrm{jml}} \leq cd_{\mathrm{ml}} * \delta_{ml} \qquad \forall m \in M, l \in L \qquad (9)$$

$$QE_{nip}, QQ_{\mathrm{ijp}}, QT_{\mathrm{jkl}}, QV_{\mathrm{jml}}, \geq 0 \qquad (10)$$

$$X_{ip} \in \{0, 1\} \qquad (11)$$
$$Y_{jp} \in \{0, 1\} \qquad (12)$$
$$G_{kl} \in \{0, 1\} \qquad (13)$$
$$\delta_{ml} \in \{0, 1\} \qquad (14)$$

Objective function (1) minimizes the total cost, which includes set-up costs, transportation costs, operation costs and idle costs of facilities. This means that our model tries to minimize both the costs from remanufacturing process and the utilization of remanufacturing facilities at the same time. Constraint (2) ensures that the demands of all customers are satisfied and returned products from all customers are collected. Constraint (3) represents the balance equation for the products that are entered to disassembly center and are exited from collection center. Constraints (4)-(5) assure the flow balance at disassembly, refurbish and disposal centers. Equations (6)-(9) are capacity constraints on facilities. Constraint (10) checks for the non-negativity of decision variables and the last four Constraints check for binary variables.

3. An Example

Using a numerical example, we will illustrate how the model works in the proposed framework and gain some insights into the proposed model. A small set of stochastic data is prepared. We assume that there are three types of products and five types of parts from those products, too three collection/inspection sites, five disassembly sites, four refurbish sites, three disposal sites and five customer. Rate of return of used products p from customer n, rate of Exit returned product p from collection center i to disassemble center j and Average disposal fraction parts be considered 0.3, 0.8 and 0.5, respectively. The capacity of collection/inspection and disassembly sites is set to be in range of [500, 1000] units of product and the capacity refurbish and disposal sites in range of [5000, 10000] units of part. The set-up cost of the facilities are set to be in range of [100, 200] dollars, transportation cost of products and parts between facilities are set to be in range of [1, 10] dollars, idle cost of the facilities are set to be in range of [1, 20] dollars and operation costs are set to be in range of [5, 20] dollars. We used the LINGO 9.0 for solving our mixed-integer programming model on a PC.

Table1. Demand of customer n for refurbished products p

d_{np}			
n \ p	1	2	3
1	100	140	100
2	160	100	200
3	700	90	160
4	90	170	200
5	130	140	130

Table 2. The number of disassembled parts l from products p

π_{lp}			
l \ p	1	2	3
1	16	10	13
2	12	14	12
3	8	13	19
4	11	6	19
5	5	14	5

Table 3. Shipping cost per unit of returned products p from customer n to collection/inspection center i

e_{nip}									
p	1			2			3		
n \ i	1	2	3	1	2	3	1	2	3
1	9	3	4	2	4	6	9	8	8
2	8	10	7	4	7	6	6	2	10
3	9	5	3	8	9	8	2	9	6
4	7	9	6	4	10	6	2	5	5
5	5	10	7	3	5	4	4	2	4

The results are shown in Tables 4–11. Table 4 shows the number of collected products from customers at collection/inspection site. Table 5 shows the number of recoverable products at disassembly site. Table 6 shows the number of refurbished parts at refurbished site. Table 7 shows the number of scrapped parts at disposal site. X_{ip}, Y_{jp}, G_{kl}, δ_{ml} Decision variables are determined the number of optimal quantity sites.

Table 4. Quantity of returned products p shipped from customer n to collection/inspection center i

QE_{nip}									
p	1			2			3		
n \ i	1	2	3	1	2	3	1	2	3
1	0	0	30	0	0	42	0	30	0
2	0	0	48	0	0	30	0	60	0
3	0	0	211	0	0	27	0	48	0
4	0	0	27	0	0	51	0	60	0
5	0	0	39	0	0	45	0	42	0

Table 5. Quantity of recoverable products p shipped from collection/inspection center i to disassembly center j

QQ_{ijp}															
P	1					2					3				
i \ j	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	192	0	0
3	0	0	284	0	0	0	0	156	0	0	0	0	0	0	0

Table 6. Quantity of parts l shipped from disassembly center j to refurbish center k

QT_{jkl}																				
l	1				2				3				4				5			
j \ k	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4300	4300	4300	4300	3948	3948	3948	3948	3974	3974	3974	3974	3854	3854	3854	3854	2282	2282	2282	2282
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7. Quantity of parts l shipped from disassembly center j to disposal center m

QV_{jml}															
l	1			2			3			4			5		
j \ M	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4300	4300	4300	3948	3948	3948	3974	3974	3974	3854	3854	3854	2282	2282	2282
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8. The number of collection/inspection sites

X_{lp}			
l \ p	1	2	3
1	0	0	0
2	0	0	1
3	1	1	0

Table 9. The number of disassembly sites

Y_{jp}			
j \ p	1	2	3
1	0	0	0
2	0	0	0
3	1	1	1
4	0	0	0
5	0	0	0

Table 10. The number of refurbish sites

G_{kl}					
k \ l	1	2	3	4	5
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1

Table 11. The number of disposal sites

δ_{ml}					
m \ l	1	2	3	4	5
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1

4. Conclusions

In this paper, we address reverse logistics network problem for treating a remanufacturing problem which is one of the most important problems in the environment situation for the recovery of used products and materials. Based on this system, we proposed a general framework in view of supply planning and developed a mathematical model to optimize the supply planning function. The model determines the quantity of products/parts processed in the remanufacturing facilities while minimizing the total remanufacturing cost. We presented a numerical example to analyze and validate the model by using a small set of stochastic data.

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Biography

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