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Efficient Operation Policy in a Closed-loop Tire Manufacturing System with EPR

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Abstract. This paper deals with a closed-loop remanufacturing system with one manufacturer and one remanufacturer. The manufacturer sells new products bearing the 'Extended Producer Responsibility (EPR).' It is assumed that the manufacturer's collection rate of used products depends only on the buy-back cost, while that of the remanufacturer depends on the minimum allowed quality level of used products in addition to the buy-back cost. Through the development of mathematical models with the objective function of maximizing profit, we study an efficient operation policy of each party. The decision variables are the unit selling price of new products and remanufactured products, the unit buy-back cost of the used products of the manufacturer and remanufacturer, and the minimum allowed quality level. The validity of the model is examined through numerical examples and sensitivity analysis.

Keywords: Extended Producer Responsibility, Minimum Allowed Quality Level, Buy-back Cost

1. INTRODUCTION

1.1 Background

In the past decade, product recycling has been paid heightened attention due to several reasons. First, producers and consumers became more environmentally conscious, and started to realize that it is time to abandon the 'throw-away age.' Second, tighter legislation in some countries forced producers to take back products after use and either recover them or dispose of them properly. Third, some producers realized that recovery operations can lead to additional profits (Teunter and Vlachos, 2002).

Extended Producer Responsibility (EPR) is a strategy designed to promote the integration of environmental costs associated with products throughout their life cycles into the market price of the products. Under EPR, firms are obliged to meet a given take back quota for the end of used products, and certain amount of penalty will be charged if it is breached (OECD, 1999). 15 countries in Europe, including Germany, the United Kingdom, France and Hungary, four countries in Asia including Korea, Japan, Taiwan and Australia, and some countries in Latin America including Mexico and Brazil, have introduced the EPR system by now. There are several items that are controlled by extended producer responsibility, and the number of items is increasing as the industries become more complex and the laws and regulations on environmental issues are tightened. Tire is one of the most important items which need to be controlled among the EPR related items. Discarded tires have caused a disposal problem and continue to be accumulated throughout the world. In the United States, in particular, over 279 million discarded tires are being added to an estimated 2 billion tires currently stockpiled around the country. The discarded tires can present both health and environmental hazards. Improperly stored tires are potential breeding grounds for disease-carrying insects and rodents. Also, the tire fires can be difficult and expensive to extinguish and can cause air, soil and water quality problems (Jang *et al.*, 1998). As a result, the recycling of discarded tires is encouraged and forced by some governments. In Korea, the obligatory recy-

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cling rate of discarded tires has been increased from 0.737 to 0.748 in 2008 (Korean Environment and Resources Corporation).

The remanufactured (or recapped) tires are produced by adding new tread rubber by vulcanization on casing of used tire that worn down only tread layer and have no wound on carcass or bead layer. The procedure of the tire remanufacturing is basically composed of 4 steps: Casing inspection process, buffing process, building process, and curing process. First, in casing inspection process, the retreadability of used tires is determined by manual and computerized inspection systems. Second, in buffing process, the old tread is removed from the casing. The processes after the casing and buffing process are classified into two processes depending on the quality of each used tire: cold-cap process and hot-cap process. Cold-cap process is be needed when only tread part is worn out and hot-cap process is done when both tread and shoulder parts become worn out. Figure 1 shows the structure of a tire with the tread part and shoulder part and the recap process required.

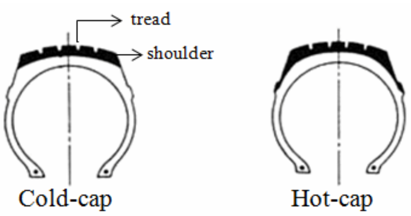

Figure 1. Cold-cap process and hot-cap process.

In cold-cap process, the new tread rubber is applied to a buffed casing in building process, and the rubber is vulcanized by heat and pressure over a period of time in curing process. In hot-cap process, the pre-cured tread-rubber is applied to a burred casing with a cushion gum in building process, and the cushion gum between pre-cured tread rubber and casing is vulcanized by heat and pressure in a chamber over a period of time in curing process. The remanufactured tires can be obtained after these four steps. Generally, the cost of hot-cap process is higher than that of cold-cap process.

1.2 Problem description

Figure 2 shows the closed-loop remanufacturing system this study deals with. It is assumed that a manufacturer sells new tires at the unit price of p_M bearing an obligatory take-back-quota, α, while paying the unit buy-back cost, c_{bM} for used tires. If the obligatory take-back-quota is breached, he has to pay the unit penalty cost, c_p, for unsatisfied take-back quota. The return rate of the used tire for the manufacturer is determined by c_{bM}. Also, a remanufacturer sells the remanufactured tires at the unit price of p_R, while paying c_{bR} per unit for used tires. The remanufacturer is assumed to purchase only those used tires that satisfy a minimum allowed quality level (q_m). In other words, used tires whose quality is higher than q_m can be bought by the remanufacturer. It is assumed that the return rate of the used tire of the remanufacturer is a function of c_{bR} and q_m. The quality of used tires is assumed to follow a beta distribution and closely related with the type of process it goes through for remanufacturing. Let q_c be the minimum quality level of used tires for cold-cap process and q_h the minimum quality level of used tires for hot-cap process where $0 \leq q_h \leq q_c \leq 1$. If the quality is in between q_c and q_h, it goes through the hot-cap process. If the quality is better than q_c, it goes through the cold-cap process.

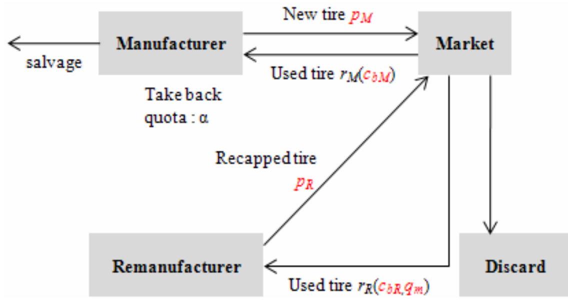

Figure 2. The framework of the system.

The remanufacturer can be a potential competitor of the manufacturer by cannibalizing the sales of new tires. On the other hand, the manufacturer has the benefits of being free from the take-back-quota if the remanufacturer actively collects used tires. Majumder and Groenevelt (2001) observed that communities and legislatures might as well encourage the local remanufacturers if they want to achieve a reduction of waste disposal. In this paper, an efficient operation policy of two parties is examined through the development of mathematical models with the objective of maximizing the profit. The solution procedure is presented based on the repeated game model and tabu search. There are five decision variables including the unit price of the new tire and the remanufactured tire, the unit buy-back cost of the manufacturer and remanufacturer, and the minimum allowed quality level of the used tires.

1.3 Previous studies

One of the earliest studies on reverse logistics was addressed in 1960's, by Schrady (1967). In his model, the demand and return rate is deterministic, and the manufacturing and remanufacturing rate is infinite (e.g. EOQ) with no waste disposal. He assumed a single manufacturing batch and multiple remanufacturing batches. Nahmias and Rivera (1979) developed a generalized model of the Schrady (1967) for the case of finite repair rate. A multiproduct extension of these models was investigated by Mabini *et al.* (1998). Teunter (2001) studied an EOQ type reverse logistics model with different inventory holding cost rates for manufactured and remanufactured items including the concept of waste disposal. These models considered the return rate as a given parameter. Richter and Dobos (1999) and Dobos and Richter (2000, 2003) studied a recycling model considering waste disposal where the return rate is a decision variable. Dobos and Richter (2004) studied the optimal return and disposal rate in multiple manufacturing and remanufacturing situation. In our study, unlike the models mentioned above, the return rate of used products is treated as a function of the decision variables, the unit buy-back cost for used products and the minimum allowed quality level. Salameh and Jaber (2000), Chang (2004) investigated stochastic EOQ models with quality consideration and reselling defective items. Hwang *et al.* (2008) dealt with a recycling system with minimum allowed quality level on returned products. Sergio and Albert (2008) studied the optimal manufacturing and remanufacturing policies in a lean production environment, where no inventory related costs is considered. The models mentioned above assumed that the remanufactured products are not distinct from the newly manufactured products (as-good-as-new policy), while in this study newly manufactured products and remanufactured products can have different retail prices. The remainder of this paper is organized as follows. Section 2 describes the assumptions and notations adopted in this study. In Section 3, mathematical models are developed for the problem and then a solution procedure is presented in Section 4. Numerical example and conclusions appear in Section 5 and 6, respectively.

2. NOTATIONS AND ASSUMPTIONS

2.1 Notations

D_M	demand rate of the new tire [unit]/[time]
D_R	demand rate of the remanufactured tire [unit]/[time]
c_M	unit manufacturing cost [$]/[unit]
c_c	unit cold-cap process cost [$]/[unit]
c_h	unit hot-cap process cost [$]/[unit]
c_p	unit penalty cost for unsatisfied take-back quota [$]/[unit]
c_s	unit salvage cost [$]/[unit]
$r(c_b)$	return rate of used tires
$r_M(c_{bM})$	return rate of used tires of manufacturer
$r_R(c_{bR}, q_m)$	return rate of used tires of remanufacturer
$f(x)$	density function of the quality level of used tires
α	obligatory recycling rate
q_c	the minimum quality level of used tires for cold-cap process where $0 \leq q_h \leq q_c \leq 1$
q_h	the minimum quality level of used tires for hot-cap process

parameters

a_M, a_R, b_M, b_R, γ	parameters of the demand function
b	parameter of the return rate

Decision variables

p_M	unit selling price of the new tire [$]
c_{bM}	unit buy-back cost for the manufacturer [$]
p_R	unit selling price of the remanufactured tire [$]
c_{bR}	unit buy-back cost for the remanufacturer [$]
q_m	the minimum allowed quality level ($0 \leq q_m \leq 1$)

In general, if you are willing to pay higher unit price for certain product, then you can expect to obtain more products. Exponential function as shown in Figure 3 is adopted to represent the relation between the buy-back cost and the return rate, $r(c_b)$.

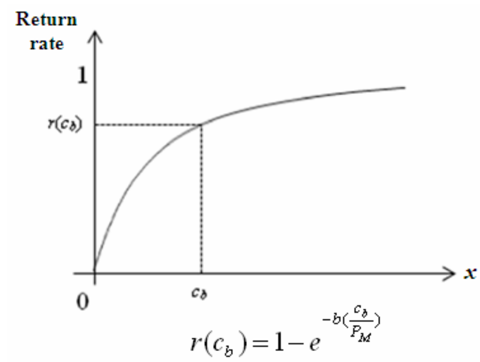

Figure 3. The return rate function of used tires.

Figure 4 shows the relation between the minimum allowed quality level q_m and the return rate of used tires. A smaller value of q_m implies that tires of poor quality are also bought back in order to produce more recapped tires. Beta distribution is adopted to express the quality distribution of used tires. The beta distribution is a family of continuous probability distributions defined on the interval [0, 1] with two positive shape parameters, typically denoted by a and b.

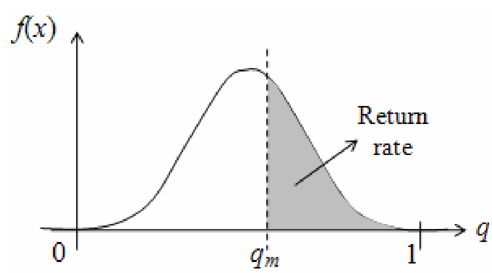

Figure 4. The return rate vs. the minimum allowed quality level.

2.2 Assumptions

1. The cost parameters are all known and constant.
2. Production rate of manufacturer and remanufacturer is large enough to satisfy the demand.
3. Demand rate of newly manufactured tire and remanufactured one is dependent on its selling price.

4. Return rate of manufacturer is dependent on the buy-back cost of used tire.
5. Return rate of remanufacturer is dependent on both the buy-back cost of used tire and the minimum allowed quality level.
6. Let q be the quality level of the used tire. q follows a beta distribution on the interval [0, 1] with $q = 1$ being the best quality while $q = 0$ the worst quality.
7. Unlimited storage capacity is available.
8. The used tires are remanufactured by cold-cap process when the quality is above q_c.
9. The used tires are remanufactured by hot-cap process when the quality is in between q_h and q_c.
10. Unit cold-cap process cost is cheaper than unit hot-cap process cost.
11. Penalty cost is imposed on manufacturer for the amount failed to observe obligatory recycling rate.
12. Obligatory recycling rate is known.

3. MATHEMATICAL MODEL

3.1 Return rate

Case 1) $c_{bM} \geq c_{bR}$

With $c_{bM} \geq c_{bR}$, the manufacturer's buy-back cost is equal to or higher than that of the remanufacturer. In this case we assume that the manufacturer dominates the remanufacturer in the used tire market with $D_M\ r_M(c_{bM})$ units of retrieval from the customers as expressed in Equation (1). $D_M\ (1\text{-}r_M(c_{bM}))$ represents the amount of used tires still owned by customers who are reluctant to sell their used tires at the price of c_{bM}. With c_{bR}, the remanufacturer is assumed to fail to purchase the used tires (Equation (2)) and consequently has to close his business.

● The return rate of manufacturer

$$r_M(c_{bM}) = r\,(c_{bM}) = (1 - e^{-b(\frac{c_{bM}}{p_M})}) \tag{1}$$

Note that the manufacturer gives no consideration to the quality in buying back the used tires.

● The return rate of manufacturer

$$r_R(c_{bR}, q_m) = 0 \tag{2}$$

Case 2) $c_{bM} < c_{bR}$

In this case, the remanufacturer has a priority over the manufacturer in buying back the used tires. Among $D_M\ r_R(c_{bR},\ q_m)$ units of the used tires, the remanufacturer is assumed to purchase only those tires that satisfy the minimum allowed quality level. Consequently, the manufacturer can purchase the used tires that fail the quality test among $D_M\ r_M(c_{bM})$. Therefore, we have the following expressions for the return rate.

● The return rate of manufacturer

$$\begin{aligned} r_M(c_{bM}) &= r(c_{bM}) \times \int_0^{q_m} f(x)dx \\ &= (1 - e^{-b(\frac{c_{bM}}{p_M})}) \times \int_0^{q_m} f(x)dx \end{aligned} \tag{3}$$

● The return rate of remanufacturer

$$\begin{aligned} r_R(c_{bR}, q_m) &= r(c_{bR}) \times \int_{q_m}^{1} f(x)dx \\ &= (1 - e^{-b(\frac{c_{bR}}{p_M})}) \times \int_{q_m}^{1} f(x)dx \end{aligned} \tag{4}$$

3.2 Demand function

When there is a price difference among products segments, it is known that more customers are willing to migrate to low priced segments as the price difference increases, Zhang and Bell (2007) modeled the demand leakage as a linear function of the difference between the prices. In our study, the lower price of the remanufactured tire is assumed to trigger demand leakage from the new tires to remanufactured tires. That is, if the price of remanufactured tire becomes much cheaper, then the demand for remanufactured tires will be higher. Based on the above discussion, the price dependent demand functions, D_M for the new tire and D_R for the remanufactured tire, are modeled as follows.

$$D_M(p_M, p_R) = a_M - b_M p_M - \gamma(p_M\text{-}p_R) \tag{5}$$

$$D_R(p_M, p_R) = a_R - b_R p_R + \gamma(p_M\text{-}p_R) \tag{6}$$

3.3 Profit function

3.3.1 Manufacturer's profit function

The manufacturer's profit function, π_M, consists of the sales profit, manufacturing cost, returning cost involving buying back cost and salvaging cost, and the penalty cost.

$$\begin{aligned} \pi_M &= (p_M - c_M)D_M - (c_{bM} + c_s)D_M r_M(c_{bM}) \\ &\quad - c_p \max\{0, D_M(\alpha - r_M(c_{bM}) - r_R(c_{bR}, q_m))\} \end{aligned} \tag{7}$$

Note that the manufacturer has to pay the salvaging cost for the used tires he purchased and also pays the penalty cost for the unsatisfied amount of take-back quota, if any.

3.3.2 Remanufacturer's profit function

The remanufacturer's profit function, π_R, consists of the sales profit, buying back cost, and the remanufacturing cost involving cold-cap and hot-cap process.

If $q_c \leq q_m \leq 1$, all the returned used tires go through only cold-cap process and the profit function becomes

$$\begin{aligned} \pi_R &= \{p_R - c_{bR}\}Q_R - c_c Q_R \\ &\text{where } Q_R = \min\{D_R, D_M r_R(c_{bR}, q_m)\} \end{aligned} \tag{8}$$

Q_R is the amount of remanufactured tires and equals the minimum of the demand of remanufactured tires and the amount of used tires purchased from the customers. For example, if the demand for the remanufactured tires is smaller than the amount of used tires purchased, then the remanufacturer will buy-back the used tires only as much as the demand amount.

If $q_h \le q_m \le q_c$, each of the returned used tires go through either hot-cap or cold-cap process depending on its quality. Thus the profit function can be written as

$$\pi_R = \{p_R - c_{bR}\}Q_R - \{c_c \frac{\int_{q_c}^{1} f(x)dx}{\int_{q_m}^{1} f(x)dx} + c_h \frac{\int_{q_m}^{q_c} f(x)dx}{\int_{q_m}^{1} f(x)dx}\}Q_R \quad (9)$$

$$\text{where } Q_R = \min\{D_R, D_M r_R(c_{bR}, q_m)\}$$

Note that if the quality of a returned used tire is below q_h and above q_c, it goes through the cold-cap process, and if it is above q_c, then it goes through the hot-cap process.

4. SOLUTION PROCEDURE

We find the solution of Equation (7), Equation (8) and Equation (9) utilizing the repeated game model and Tabu search.

4.1 Repeated game model

A repeated game is defined in game theory as an extensive form game which consists in some number of repetitions of some base game that is usually one of the well-studied 2-person games. Thus the participants expect that there will be future games of the same type. Benoit and Krishna (1985) showed that in a sufficiently long time horizon, the solution of one-shot game can be approximated by the solution in a perfect equilibrium of a repeated game. Jia *et al.* (2009) adopted the repeated game with Tabu search to obtain maintenance scheduling of generating units in competitive electricity markets. They reported that the optimal solution obtained by the complete enumeration method turned out to be the same as that obtained from the heuristic search algorithm. In this study, assuming that the values of the selling price, buy-back cost and the minimum allowed quality level of remanufacturer (p_R, c_{bR}, q_m) are known as an initially given solution, we find a near-optimal solution by Tabu search that maximizes the manufacturer's profit. Similarly, for the predetermined selling price and buy-back cost of manufacturer (p_M, c_{bM}), the remanufacturer decides the best selling price, buy-back cost and minimum allowed quality level with Tabu search. Repeating the above procedure we expect to find an equilibrium point of the decision variables that maximizes both parties' profits. The repeated game terminates when the value of each objective function converges, i.e., iteration stops when the following criterion is satisfied.

$$|\, n^{th}\, \pi_M - (n\text{-}1)^{th}\, \pi_M \,| < e \text{ and } |\, n^{th}\, \pi_R - (n\text{-}1)^{th}\, \pi_R \,| < e \quad (10)$$

where e is a very small positive real number.

The solution procedure is shown in Figure 5.

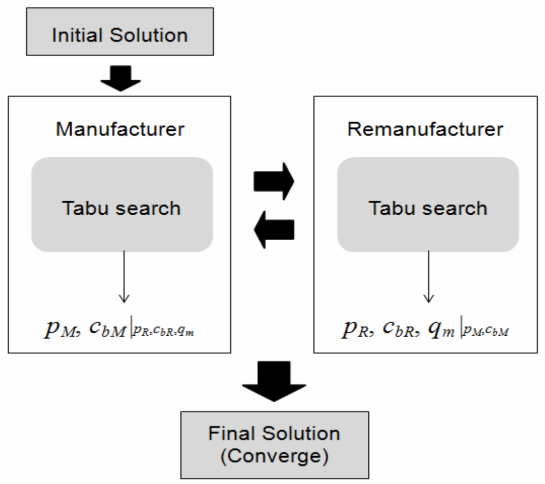

Figure 5. The solution procedure of the repeated game model.

4.2 Tabu Search

To find the best solution of each problem in the repeated game model, Tabu search algorithm is adopted. Tabu search is a meta-heuristic algorithm that can be used for solving a wide variety of classical and practical problems such as traveling salesman problem (TSP), job shop problem (JSP) and vehicle routing problem (VRP). The basic concept of Tabu search was introduced by Glover (1989, 1990a). Tabu search starts at some initial point and then moves to neighborhood point that gives the best value of the objective function at each iteration. This move continues until a certain stopping criterion has been satisfied. In Tabu search, the most important feature is the tabu list that consists of the latest move made. With tabu list, we can avoid revisiting the same point again, which may also restrict the next move to a better point. To overcome this limitation of tabu list, aspiration criterion exists. Although the movement to best neighborhood point is in the tabu list, we can visit this point if aspiration criterion is satisfied. A commonly used aspiration criterion is to allow a certain point in tabu list can be the next solution when it gives a remarkably better result than the currently-known best solution. In its simplest form, Tabu search requires the following ingredients

- Initial point
- Neighborhood point generation method
- Tabu list
- Aspiration criterion
- Stopping criterion

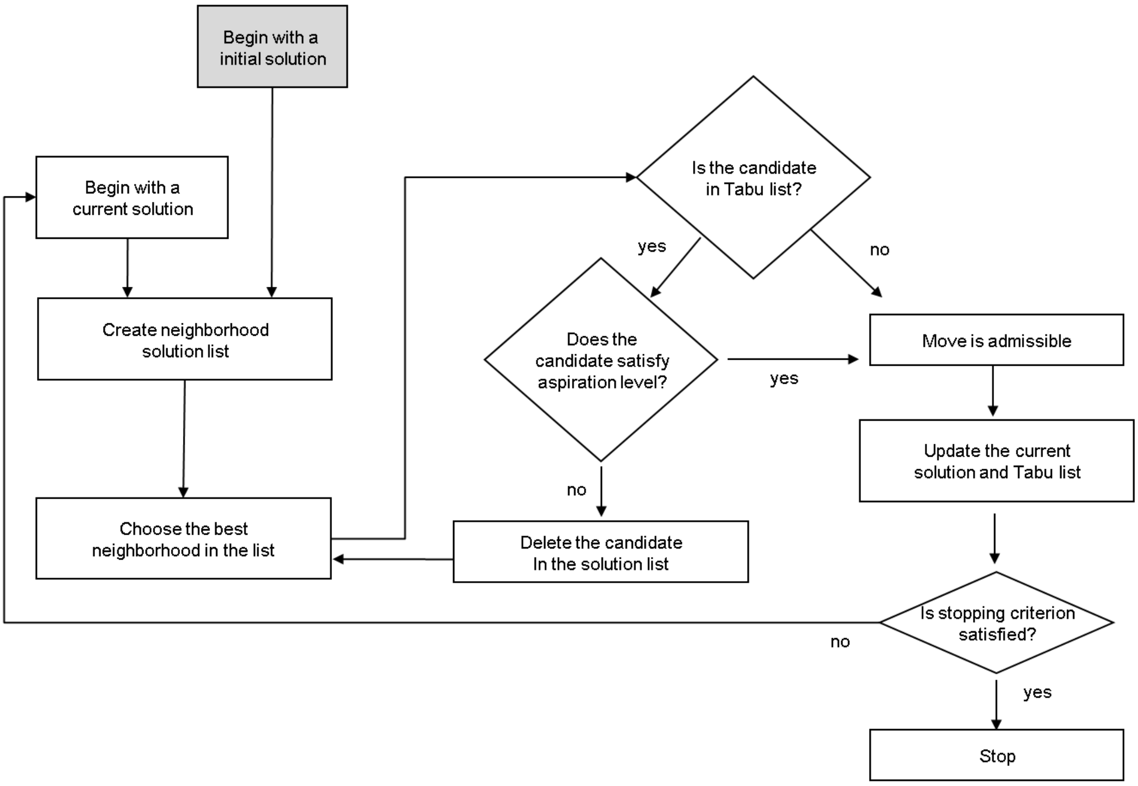

Figure 6. The basic procedure of Tabu search.

The basic procedure of tabu search is shown in Figure 6.

The algorithm starts at some initial point, say (p_R^0, c_{bR}^0, q_m^0), and it goes through a number of iterations. At each iteration, we randomly generate r directions to move and line search is performed along each direction. Among the r candidate neighborhood points, the non-tabu point that gives the best objective function value (maximum profit in this study) or tabu point that satisfies the aspiration criterion is selected as the next point and its associated direction is stored in the tabu list. This procedure is repeated until stop criterion is satisfied. As for the aspiration criterion in this study, we have an objective function value that is better than the currently-known best solution by more than 1%. In Tabu search, generally two kinds of stop criterion have been used (Glover, 1990b), i.e., one in terms of a total elapsed number of iterations and the other associated with the case of finding the last best solution again. This study adopted the first stop criterion.

Step 1: Initialization

Choose the number of random search directions to be used at each iteration (r)

Choose the maximum number of iteration (MAX_ ITER)

Choose an initial point $x^0 = (p_R^0, c_{bR}^0, q_m^0)$ or $x^0 = (p_M^0, c_{bM}^0)$

Let $TL = \emptyset$, Best value = $ATC(x^0)$, $j = 0$.

Step 2: Perform Line Search

2.1 Generate r random direction, $\mathbf{d}^1, \mathbf{d}^2, \cdots, \mathbf{d}^r$

Let λ^* and $\mathbf{d}^*$ be such that

$ATC(x_j + \lambda^* \mathrm{d}^*) = \max_{1 \le i \le r} ATC(x_j + \lambda^i \mathrm{d}^i)$

2.2 Check tabu list

If ($\mathbf{d}^* \in TL$)

or ($\mathbf{d}^* \in TL$ and $ATC(x_j + \lambda^* \mathbf{d}^*) >$ Best value),

go to step 2.3.

Otherwise, choose the second best solution and repeat step 2.2

2.3 Update current point

Let $x_{j+1} = x_j + \lambda^* \mathbf{d}^*$ and update tabu list.

If $ATC(x_j + \lambda^* \mathbf{d}^*) >$ Best value

then Best value = $ATC(x_j + \lambda^* \mathbf{d}^*)$

$j = j+1$ and go to step 3.

Step 3: Check stopping criterion

If j = MAX_ITER, stop.

Else, go to Step 2.

5. NUMERICAL EXAMPLE

In this setion an example problem is solved in order to illustrate the model and the proposed solution procedures. The values of the parameters of the example are as follows: a_M = 1,000,000, a_R = 200,000 b_M = 2,000, b_R = 3,000, γ = 1,000, b = 6, c_M = 100, c_c = 30, c_h = 60, q_c =

0.65, q_h = 0.20, c_p = 200, c_s = 10, and α = 0.6

5.1 Computational results

The computational results obtained by the repeated game model with Tabu search is shown in Table 1.

Table 1. The result from Tabu Search.

p_M	c_{bM}	p_R	c_{bR}	q_m
233.3	26.4	96.5	26.6	0.647
π_M		π_R		
39,064,444		1,858,987		

It can be observed that the unit buy-back cost of the manufacturer (c_{bM}) is slightly smaller than the unit buy-back cost of the remanufacturer (c_{bR}) while the selling price of the recapped tire is less than one half of the new one.

5.2 Sensitivity analysis

In the sensitivity analysis, we examine the effect of the obligatory take back quota on the profit, unit buy-back cost, and the unit selling price of the manufacturer and the remanufacturer.

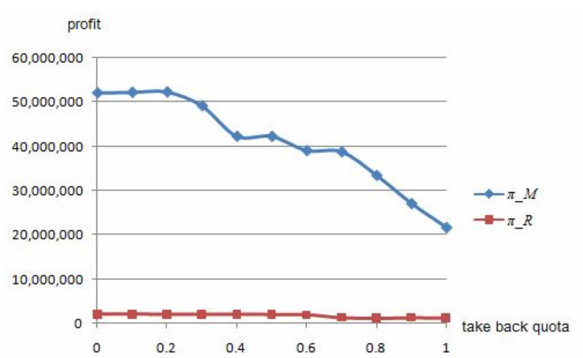

Figure 7. The profit vs. the take back quota.

Figure 7 shows the changes of the profit of both the manufacturer and remanufacturer for the various values of the obligatory take-back quota. It can be observed that the manufacturer's profit, π_M, decreases when the obligatory take back quota increases, while the remanufacturer's profit (π_R) seems invariant to the changes. Also, the manufacturer's profit starts decreasing rapidly when the quota reaches a certain value, i.e., 0.3 in this experiment. It could be interpreted as follow: In case of small valued quota the manufacturer tends rely on the remanufacturer's effort in collecting the used tires. He starts collecting the used tires only when the level of the quota becomes substantially, which incurs a reduction of the profit.

Figure 8 shows the relation between the unit buy-back cost of both the manufacturer and the remanufacturer and the obligatory take-back quota. The buy-back cost of both the manufacturer and remanufacturer tends to increase when the obligatory take back quota increases.

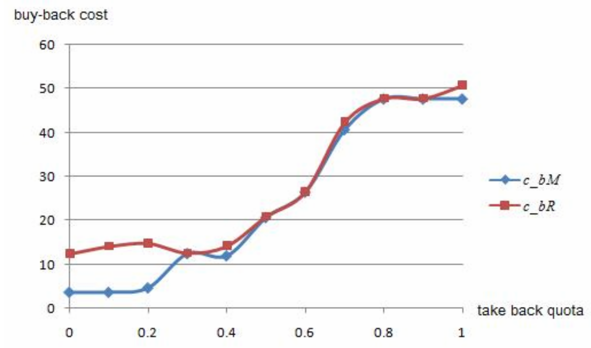

Figure 8. The buy-back cost vs. the take back quota.

Figure 9. The unit selling price vs. the take back quota.

Figure 9 shows the responses of the unit selling price of both the manufacturer and remanufacturer to the changing values of the obligatory take-back quota. Both the manufacturer's and remanufacturer's unit selling price tend to be stable up until it reaches 0.7.

For various values of the unit penalty cost, Figure 10 shows the behavior of the manufacturer and remanufacturer in terms of the return rate. The results can be utilized as a useful reference for the decision maker of government policy as follow. The penalty cost is only effective up to a certain point (i.e., approximately 80 in this example) in forcing the manufacturer to collect more used tires. Higher penalty cost only worsens the manufacturer's profit without gaining an additional environmental benefit.

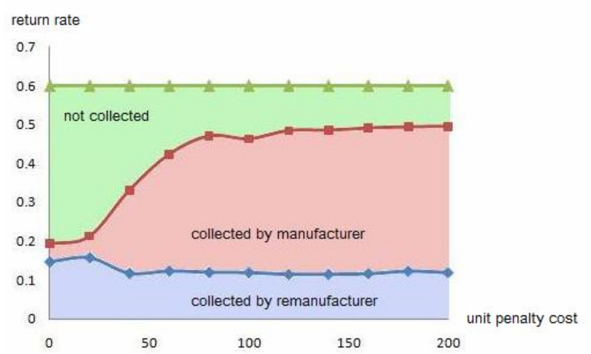

Figure 10. The return rate vs. the unit penalty cost.

Test results on the return rate vs. the take back quota are illustrated in Figure 11. Similar to the case of the penalty cost, it can be observed that an effective level of obligatory take back quota seems exist that forces the manufacturer to collect the used tires without substantially discouraging the business activity.

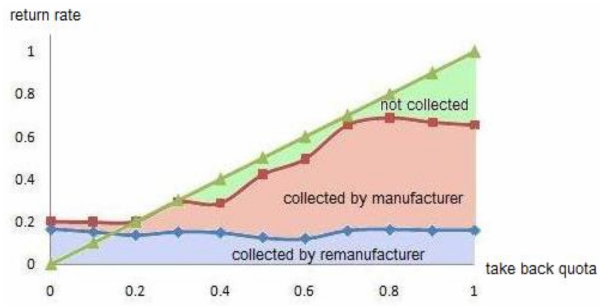

Figure 11. The return rate vs. the take back quota.

6. CONCLUSIONS

This paper deals with a closed-loop recycling system in the tire industry where there is one manufacturer and one remanufacturer. We adopt a linear demand function integrated with the demand leakage caused by the price difference. It is assumed that the return rate of the used tires for manufacturer is a function of the unit buy-back cost of used product, while that for the remanufacturer is a function of the unit buy-back cost and the minimum allowed quality level. The decision variables are the unit selling price and the unit buy-back cost of manufacturer and remanufacturer and the minimum allowed quality level for remanufacturer. A near-optimal solution is found based on the repeated game model and Tabu search. Through computational experiments we analyze the effects of the obligatory take back quota and penalty cost on environmental protection efforts and business activities. We do not believe that the model presented in this paper can be directly applicable to real world problem. Still, the determination of appropriate level of obligatory take-back quota and unit penalty cost is an important issue from the view point of government policy maker. It is hoped that the results of our study could be a useful reference in the formulation of future government policy in protecting our environment. The model could be extended to the case where the manufacturer also competes in the remanufactured market as well.

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