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Optimal strategies for manufacturing/remanufacturing system with the consideration of recycled products

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ABSTRACT

This paper analyzes the model of the recycled products which are considered with the minimum quality level in manufacturing/remanufacturing system. In this model, a constant demand is satisfied by manufacturing raw materials and remanufacturing recycled products which are up to the quality level. It is assumed that functions of recycling rate, buyback cost and remanufacturing cost are depend on the minimum quality level. The quality level of recycled products is set to be exponential distribution and then the model is established. The results show that when the buyback cost is low (the quality of the recycled products is low), the average total cost is low, though the remanufacturing cost is high. Namely, the companies are willing to recycle the used products with low quality level. Meanwhile, the optimal strategy of recycling, manufacturing and remanufacturing is investigated here. Through construction of a solution process on Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and numerical examples with sensitive analysis, the validity of the model has been proved.

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1. Introduction and literature review

In recent years, recycled products remanufacturing processing which is regarded as a senior form has increasingly been taken seriously due to the rising strict environmental legislation system and the ever growing environmental awareness. (Lindhqvist, 2001; Rubio, Chamorro, & Miranda, 2008; Spicer & Johon, 2004). However, remanufacturing process is profitable for businesses (Galbreth, 2006; Sang, 2008). Remanufacturing system has its unique advantage, unlike direct reuse, the product quality of remanufacturing will not be degraded and be sold as new products to reduce the total cost (Beamon, 1999). Yet in the remanufacturing system, the quality, quantities, recovery time of the products are uncertainties which are more complicated than the front forward logistics (Trebilcock, 2002).

In this paper, in the case of uncertainty of recycled products quality, the quality level of recycled products will affect the recycling rate, the buyback cost and remanufacturing cost. If quality level of recycled products is very low, then the recycling rate will be high and the buyback cost will be low. However, the remanufacturing process will be very complex and the remanufacturing cost will be high and the buyback cost will be high. If quality level of recycled products is very high, then the recycling rate will be low and the manufacturing process will be very simple, and the manufacturing cost is low.

Since EOQ model of recycled products was analyzed by Schrady (1967), numerous researches have been proposed by many scholars. Fleischmann, Bloemhof-Ruwaard, and Dekker (1997) set up simulation model of uncertain quality of recycled products. Salameh and Jaber (2000) and Chang (2004) investigated stochastic EOQ model with quality consideration. Singer, Donoso, and Traverso (2003) studied the game theory model of supply chain quality. Dobos and Knut (2006) assumed that if quality level of the recycled products was too low, the products could not be applied in the remanufacturing process, and put forward the optimal production strategy. Kibum, Iksoo, and Juyong (2006) studied the model of supply planning in reverse logistics system to maximize the total cost saving, determining the number to be produced on each remanufacturing facilities and the number to be purchased from subcontractors. Choi, Hwang, and Koh (2007) assumed that the recycling possibility of recycled products was fixed and present the different ordering and recycling strategies with various qualities. Sergio and Albert (2008) studied the optimal manufacturing remanufacturing strategies in the lean production conditions and the structure of the optimal strategies. The conclusion is that the mixed strategy (recovery and utilization are both between 0, 1) is optimal. Sang (2008) studied the quality and buyback costs of products, but based on an assumption that they were independent.

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Mukhopadhyay and Ma (2009) studied the optimal procurement and production decisions in the remanufacturing system assuming that the quality of recycled products and demand were uncertainty. Mutha and Pokharel (2009) studied the network design for reverse logistics and remanufacturing process using new and used parts. The designing of the network and the assigning abilities depend not on the quantity of recycled products but also on demand of remanufactured products and used parts. Lee, Gen, and Rhee (2009) studied a three-stage logistics network of remanufacturing system to minimize the total cost model of reverse logistics shipping cost and fixed opening cost of the disassembly centers and processing centers considering a multi-stage, multi-product and some of the conditions attached to disassembly center and processing center. Saadany and Jaber (2010) researched on the various recycled products, and buyback cost was depended on different quality level. Guo and Liang (2011) extended their previous research, and considered the relationship between the minimum quality level of the recycled products with buyback cost and remanufacturing cost, but based on an assumption that its quality level was uniformly distributed. Iwao and Kusukawa (2012) studied the optimal production planning and potential quality classification error with the various qualities of recycled products. Zanoni, Segerstedt, and Tang (2012) studied multi-product economic scheduling problem with manufacturing and remanufacturing simultaneously on the same production line. Remanufactured products are the same as the quality of manufactured products meeting the demand of the market. Aybek, Kemal, and Önen (2013) studied the impact of the quality of recycling in remanufacturing process, where the old and new parts are produced on the same machine with a negative impact by the impurity in the old parts. Xiao, Jing, and Chen (2014) studied a game model of a one-manufacturer and one-retailer supply chain to analyze the competition of price and lead time and develop the cooperation for make-to-order supply chains, in which the consumers are sensitive to the retail price and lead time.

This paper assumes that the constant demand is satisfied by manufacturing and remanufacturing process. In contrast to above researches, it is assumed that the recycling rates, buyback cost and remanufacturing cost are depended on different quality level of recycled products. The quality of returned items is exponential distribution. In fact, the distribution of the quality of the recycled product can be others, i.e., normal distribution or/and gamma distribution, etc. (Aybek et al., 2013; Galbreth, 2006; Li & Da, 2008). In theory, every distribution should be researched to prove the model, but we just select a kind of distribution (exponential distribution) to analyze the model in this paper. We take recycling rate, buyback cost and remanufacturing cost to be unknown, as the quality of recycled products is set to be random variable. Treating the minimum quality level of recycled products, the length of a cycle, the number of manufacturing lots and remanufacturing lots in a cycle as variables, the models with the goal of minimizing the average total cost are built. Meanwhile, we also put forward the optimal recycling, the optimal manufacturing and remanufacturing strategy. The purpose of the optimal recycling strategy (minimum quality level) is to manage the quality of the recycled products; the purpose of the optimal manufacturing and remanufacturing strategy (the length of a cycle, the number of manufacturing lots and remanufacturing lots) is to arrange the manufacturing and remanufacturing period and to reduce the average total cost.

2. Problem description and function definition

In order to model the manufacturing and remanufacturing system, the following assumptions and notations are listed.

2.1. Manufacturing and remanufacturing system

The manufacturing and remanufacturing process is displayed in Fig. 1. A cycle time contains several manufacturing runs and several remanufacturing runs. The demand of consumers for products is satisfied by manufactured inventory and manufactured inventory. Manufactured products are produced by raw materials purchasing from outside, while remanufactured products are produced by recycling the end-of-life products. The remanufacturing system is composed by three types of inventory, the raw material inventory, and the returning inventory, and the serviceable inventory containing manufactured products and remanufactured products.

2.2. Assumptions

(1) Demand rate is known and constant;
(2) The remanufacturing products are considered as new products;
(3) The quality of returned items is exponential distribution;
(4) Recycling rate of the used products is dependent on the required minimum quality level of returned products, and recycling rate does not exceed the demand rate;
(5) Buyback cost is affected by the quality level of recycled products;
(6) Remanufacturing cost is related to the quality level of recycled products;
(7) Raw materials is purchased once from outside in a cycle;
(8) There is no disposal of recycled products;
(9) The lead times is neglected in the manufacturing and remanufacturing processes;
(10) No shortage is allowed.

2.3. Notations

2.3.1. Input parameters

a	Parameter of the buyback cost function, $0 \leqslant a \leqslant 1$;
θ	Parameter of the buyback cost function;
b	Parameter of the recycling rate function, $0 \leqslant b \leqslant 1$;
φ	Parameter of the recycling rate function;
c	Parameter of the remanufacturing cost function, $0 \leqslant c \leqslant 1$;
δ	Parameter of the remanufacturing cost function;
D	Demand rate, [unit]/[time];
$(1/\beta)D$	Manufacturing rate ($\beta < 1$), [unit]/[time];
$(1/\gamma)D$	Remanufacturing rate ($\gamma < 1$), [unit]/[time];
h_s	Holding cost per unit time of serviceable stock, [$]/[unit][time];
h_r	Holding cost per unit time of returned stock, [$]/[unit][time];
h_{raw}	Holding cost per unit time of raw material stock, [$]/[unit][time];
S_R	Remanufacturing setup cost, [$];
S_M	Manufacturing setup cost, [$];
C_M	Manufacturing cost per unit, [$]/[unit];
C_{raw}	Purchasing cost for raw material per unit, [$]/[unit];
C_O	Ordering cost, [$]/[unit].

2.3.2. Parameters

$d = \alpha D$	Return rate, $0 \leqslant \alpha \leqslant 1$;
α	Marginal recycling rate, $0 \leqslant \alpha \leqslant 1$;

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