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A study of quality management strategy for reused products

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ABSTRACT

To ensure the sustainability, industries have to move forward to product recovery strategies. Reuse is one of the most efficient strategies as it preserves natural resources while maintaining the functional properties of the product. To alleviate the concerns over the quality at the end of first life, laws are enacted to protect the consumers through mandatory warranty requirements. Offering warranty results in additional costs, this cost might be reduced through upgrade that improves the reliability of the item. Considering the age at the end of first life as stochastic, this paper proposes a profit model, relevant costs like upgrade and the minimal repair during the warranty period are included. Optimal upgrade level and warranty length are jointly derived so that the expected profit per used item for the producer can be maximized. Algorithm to search for the optimal solution is developed for a special case. Numerical examples are utilized to demonstrate the feasibility of the proposed approach and the sensitivity analyses regarding the important parameters that might impact the profit.

1. Introduction

Sustainability is one of the most important issues of the twenty-first century and presents a truly global challenge for everyone to make additional considerations about the material consumption and resource utilization. Since the producer have the greatest control over product design and marketing and therefore should have the greatest ability, EU has formulated a number of prescriptive directives having extended producer responsibility (EPR) as their core philosophy, which aims to put most of the responsibility of end-of-life considerations and the reduction of a product's overall ecological impact to producers [1]. That is why nowadays many countries are using political means to hold producers liable for the costs of managing their products at end of life. (Sierra Club [2]). To align with this perspective, industries have to move forward to product recovery strategies. One of the most efficient and environmentally viable strategies for producers to manage used product is reuse, as it conserves natural resources, saves costly production of the equivalent new goods, and protects the environment by preventing the used products otherwise becoming hazardous waste.

Despite these, the global scale of product recovery application is significantly disproportional to the total manufacturing output. One of the most critical issues regarding the viability of product recovery is the availability of markets. The concern over the reliability and safety at the end of first life hinders the development of the second-hand product market. Lack the knowledge of usage and maintenance history of the first user, quality will not be completely shown by the appearance of the item. However consumers may predict the quality of the item based on its warranty, which is considered as the assurance that the producers provide after evaluating the strength of the product [3]. That is why many countries have enacted laws to protect the consumer against early failure of the second-hand product through mandatory warranty requirements.

According to Anityasari et al. [4], functionality and reliability are the two quality dimensions that need to be addressed for reused products. Functionality represents the conditions of the product at the beginning of the second life. Reliability of a used item must be assessed based on the probability of its survival during the second life. One way of improving the reliability is through actions such as overhaul and upgrade. Upgrade actions allow the producer to sell the item at a higher price, slow down the product degradation so that the failure rate can be controlled and the warranty service cost can be reduced.

J.D. Power and Associates reported that the sales of certified pre-owned cars have increased 46 percent since 2000. A certified pre-owned vehicle must be inspected, refurbished and certified by the original manufacturer and warranty are included in the price of the product. IBM certified pre-owned equipment is refurbished and tested to IBM standards and comes with a 3-month limited warranty on all products. In order to be Caterpillar Certified Used equipment, every machine has to pass Cat's rigorous and detailed inspection program, and comes with a minimum of a 6-month power train warranty.

This paper considers a quality management policy for used products from the point of view of a producer with EPR. After the used product is reclaimed, actions like surface polishing, upgrade,

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or dispose may be conducted depending on the virtual age of the used item. Warranty will be offered to the customers of the second-hand product if the increase in the sale revenue can cover the warranty service cost. During the warranty period, any failure will be rectified through minimal repair at the expense of the producer. After minimal repair, the item is functional, but the failure rate remained unchanged. The objective is to obtain the optimal upgrade threshold level and the length of the warranty period such that the expected profit per used item for the producer is maximized, assuming the age of the used product is stochastic.

The remainder of this paper is organized as follows. In Section 2, literature is reviewed to set the background for the modeling of this paper. The mathematical models are developed in Section 3. The properties of the optimal policy are investigated for general and special case in Section 4. In Section 5 the impact of providing upgrade and warranty is illustrated through numerical examples. Finally, conclusions are drawn in the last section.

2. Literature review

A significant amount of academic research has been focused on modelling warranty policies. Murthy et al. [5] link the literature on warranty and discuss the different issues in warranty logistics. More specifically, Wu et al. [6] determine the optimal burn-in time and warranty length for non-repairable products under the fully renewing combination of free replacement and pro-rata warranty policy so that the total mean cost is minimized, and solutions are sought by using grid solutions approach. Wu et al. [7] propose a profit model, considering cost of production、 warranty、and inventory, the optimal price, warranty length and production rate are obtained by using the maximum principal.

Virtual age initiated by Kijima [8] can be understood as an aggregate index of the system as the chronological age often does not reflect the characteristic behavior of the system. Finkelstein [9,10] uses two approaches to define virtual age: statistical virtual age based on the fact that deterioration varies under different environment and informational-based virtual age comparing an observed level of degradation with some average population degradation. To mathematically describe the degree of upgrade, many methods were proposed in reliability study, including failure rate reduction, state transitions of a Markov chain, and age-reduction. The age-reduction method was introduced in 1981 by Nakagawa [11] and widely adopted in the research of imperfect maintenance policies (see Pham and Wang [12]).

Thousands of reliability improvement models have been proposed and studied. To name a few, Wang [13] summarizes, classifies, and compares various existing maintenance policies. Yeh and Lo [14] jointly decide the optimal number of preventive maintenance actions and the corresponding maintenance degree. Djamaludin et al. [15] develop a frame work to study preventive policies when the vender offers an initial period of warranty. However all of the above mentioned references are for the new product. Literature for warranty or maintenance policy of the second-hand product is scant. Yeh et al. [16] propose two periodical age reduction PM models for a second-hand product to obtain the optimal number of times of PM action and the optimal degree of each PM action such that the total expected maintenance cost is minimized. Chattopadhya and Murthy [17] develop models to estimate the expected warranty cost for second-hand products sold with free replacement or pro rata warranty policies without considering the upgrade action. Chattopadhyay and Murthy [18] deal with two models to decide on the reliability improvement strategies for items sold with free replacement warranty. Both of these papers take the point of a view of a consumer. Chattopadhyay and Murthy [19] proposed three new cost sharing warranty policies and developed stochastic model for the costs of these warranty policies of second-hand products. Pongpech et al. [20] determine the optimal upgrade level; the time epochs and degree of the failure rate reduction of preventive maintenance actions that minimized the total expected cost for the lease of the second-hand product. Saidi-Mehrabad et al. [21] decide on the reliability improvement strategies for various warranty policies from a dealer's point of view, but considering age and length of period warranty as fixed. Shafiee et al. [22] develop a stochastic model which results in the derivation of the optimal expected upgrade level under the given cost structure including purchase price, upgrade cost and warranty cost so that the dealer's expected profit per product is maximized. However minimal-perfect repair method is used as the reliability improvement approach and warranty length is assumed to be known.

3. Model formulation

Consider a manufacturer who is responsible for the reclamation of all used products. The expected useful life L of this product is assumed to be fixed and known. We assume the age of the used product at reclamation is stochastic with distribution function $F(x)$ in interval (a, b) with $0 \le a \le L \le b$, and the associate density function $f(x)$.

When a used product is reclaimed, virtual age of the item is evaluated through log book or maintenance history which producers are very likely to have. Price will be paid to the consumer if the age of the item is still within the range of expected useful life L. Following Chattopadhyay and Murthy [12], we consider the purchase cost to be $P(x) = k_1 S_0(1-x/L)$, where S_0 is the base value of a new item, $0 < k_1 < 1$ represents the immediate loss in resale value. The expected purchasing cost per used item is $\int_a^L p(x)f(x)dx$.

If the age of an item exceeds L, it will be discarded, which incurs a mean disposal cost of C_d, C_d could be revenue instead of cost whenever recycle is possible. The expected disposal cost is $C_d \int_L^b f(x)dx$.

If the age is less than a threshold value of $u > a$, a surface polishing is conducted to ensure the functionality and the optimal surface appearance, which incurs a mean cost of C_s. Otherwise, besides polishing, an upgrade action is also carried out to bring the age down to the threshold value u. The reason of using a threshold value rather than a fixed upgrade level is that it should be more practical from an implementation point of view. The cost of upgrade is assumed to be increasing as either age x or upgrade level $x-u$ increases, i.e., $C_u(x, u) = C_s + k_2(x-u)^{\psi} x^{\zeta}$ where $\psi \ge 0$ and $\zeta \ge 0$. The expected upgrade cost is $\int_u^L C_u(x, u)f(x)dx$.

The producer will provide warranty of length w, if the increase of the sale revenue can cover the warranty service cost. It is simply reasonably to assume the warranty period will last at most until the end of useful life L, which means w should not exceed $L-u$. Let $h(t)$ denote the failure rate, the expected number of failure $E(N)$ will be $\int_a^u [\int_x^{x+w} h(t)dt] f(x)dx + \int_u^L [\int_u^{u+w} h(t)dt] f(x)dx$. Within the warranty period, any failure incurs a mean cost of C_m, which includes minimal repair action to rectify the failure and the possible loss due to product failure. The expected warranty service cost will be $C_m E(N)$.

The sale revenue is assumed to be increasing as warranty length increases and as age decreases, i.e., $S(x, w) = S_0(1-A/L)(1 + k_3 w)^r$, where A equals to upgrade threshold value u or age x depending on if upgrading is necessary, $k_3 > 0$, $r \ge 0$ are the two parameters to ensure the flexibility of this function. The expected revenue is $\int_a^u S(x, w)f(x)dx + \int_u^L S(u, w)f(x)dx$.

Deducting all the relevant cost which includes the purchasing cost, polishing cost, upgrading cost and the warranty service cost