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Cost analysis of two-dimensional warranty for products with periodic preventive maintenance

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ABSTRACT

This study uses a bivariate approach, which simultaneously considers the time and usage of a repairable product, and takes into account periodic preventive maintenance to develop a two-dimensional warranty policy for the repairable product. The proposed model is based on the bivariate Weibull process to analyze the breakdown process of a repairable product simultaneously in terms of time and usage. A repairable product may be differently utilized by various customers. We consider two types of customers: (1) customers whose product warranty is terminated because the warranty time limit has reached first; (2) customers whose product warranty is terminated because the warranty usage limit has reached first, to perform cost analyses for determining an appropriate warranty policy. However, since it is often the case that the repairable product may be equally likely purchased by the two types of customers who are equivalently important to the product manufacturer; the optimal warranty policy would thus be the equilibrium solution of the cost analyses which pay the same attention to both types of customers in order to maximize the total profit of the manufacturer.

1. Introduction

Warranties are often offered with preventive maintenance (PM) to reduce the cost of possible breakdowns within the warranty term. In particular, two-dimensional warranties are more practical, since they consider two factors, such as age and usage of a product, in the warranty term, and can thus be adopted to avoid losses that may arise with only one dimension. Taking warranties in the automobile industry as an example, car manufacturers often suggest that owners undertake PM after every few months or a certain mileage, and the warranty terms are also typically provided in terms of these two dimensions. In general, periodic PM programs are easily manageable and essentially beneficial for both buyers and sellers. Manufacturers can arrange and perform PM periodically to slow the deterioration of their products within the warranty period, and thus reduce the warranty costs. On the other hand, consumers can send back the products to the manufacturers according to a preset PM schedule to maintain acceptable reliability, and use the item for a longer time. Therefore, this study considers two-dimensional warranties with periodic PM to determine the optimal warranty policy for deteriorating repairable products.

In general, the warranties provided by manufacturers to consumers can not only convey product quality and company image, but also stimulate product consumption and sales volume, and

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thus achieve the overall objective of maximizing profits. Regarding the adoption of warranty policies, manufacturers often offer renewable or nonrenewable ones with different maintenance replacement options, such as a minimal repair or a replacement when a breakdown occurs [33,7,44,50], and while this choice is affected by many factors, the usual aim is to minimize the warranty cost [52,23]. Among these factors, the deterioration of products is the primary consideration for the determination of warranty policies [17]. For instance, automobile vendors often offer a longer warranty period to indicate better quality, and thus different warranty policies can be one of their marketing strategies [29,30]. While offering warranties may increase the costs of manufacturers, it can also stimulate the purchasing intention of customers, and thus increase sales to enhance the profits of manufacturers [3,12]. Many companies thus prepare a warranty reserve to meet anticipated warranty expenses, and so the uncertainty of the cost of future repairs can be appropriately dealt with [41,39]. In addition, not every warranty claim incurs the repair cost. For instance, it is found that a certain percentage of products with warranty claims would be returned to customers due to the case of no trouble found (NTF) [4]. Consumers are also likely to claim warranties under the non-failed but reported (NFBR) situation in which the product fails owing to human factors instead of product defect. Moreover, the failed but not reported (FBNR) situation signifies that warranties are not claimed although products are out of order [45].

Many studies have examined one-dimensional warranties (e.g. [48,15]). However, the deterioration of many products may be influenced by two or more factors, and a two-dimensional warranty may be more appropriate in such cases [34,13,26,24]. For example, manufacturers in the automobile industry would set the two limits of accumulated time and mileages by which the warranty would be terminated if either one of them is reached. With regard to the two-dimensional warranty policies, research has focused on the determination of the warranty interval and the adoption of either a repair or a replacement after a breakdown [21,5,18,22,19,6,20]. In order to determine an appropriate warranty policy, manufacturers have to carefully examine the corresponding expenses [35,10,1], and the relationship that these with the product life and consumer utility [31].

Warranties with PM have been extensively studied [49,25,38,16]. Such maintenance is essential within the warranty term, as this can reduce the expense of repairs and replacements for manufacturers, and also extend product life for consumers. PM actions have been categorized [40,42], and the choice of the appropriate PM policy in terms of usage time and the frequency of maintenance has also been studied [2,36]. In particular, research on imperfect PM policies has been conducted for both repairable and non-repairable products [27,9,51].

Research on two-dimensional warranties often uses univariate methods, which consider that time and usage are stochastically proportional, to deal with the deterioration of repairable products. However, since the impacts of time and usage on deterioration may be different, this study uses a bivariate approach which simultaneously considers these two factors to develop a two-dimensional warranty policy which satisfies both the seller and buyer, with an aim of maximizing the profits of the manufacturer. The products of interest are those that offer two-dimensional warranties, such as automobiles and factory equipment which may breakdown due to more than one factor. This paper is organized as follows: Section 2 states the research problem of two-dimensional Warranty with PM, while Section 3 presents the development of the proposed approach. Section 4 demonstrates the effectiveness of the proposed approach by illustrating a numerical example, with sensitivity analyses also carried out to examine the important factors that may influence the results. Finally, Section 5 presents the concluding remarks of this work.

2. Two-dimensional warranty and preventive maintenance

Suppose a product is sold with a warranty term within which the cost of repair is paid by the manufacturer if any breakdown occurs, and the expense of maintenance is paid by the buyer if any PM is performed. This type of product is often deteriorating and repairable, such as automobiles and factory equipment. Suppose the manufacturer offers a two-dimensional warranty policy, $\Omega(K,L)$, that is, the warranty term would be terminated when the time reaches K or the usage reaches L. Since there is often a difference between the real time and usage time of a product, i.e., the usage time at time t, $T(t)$, may not be identical to t, and the real usage time of every user is often hard to estimate, this study supposes that the usage time is the possessing time for the product, that is, the accumulated time after purchasing is the usage time t. Suppose x refers to the usage degree of the product. In order to determine an appropriate warranty policy, the manufacturer would have to examine the historical repair claims records to obtain the distribution of time and usage for a possible breakdown, $f(t,x)$, which can describe the breakdown process of the product. Suppose that the breakdown process can be modeled by a non-homogeneous Poisson process (NHPP), in which the probability of a breakdown increase as time and usage increase.

Since warranties often influence demand, the warranty time elasticity on demand μ and the warranty usage elasticity on demand v can be obtained from the historical sales data to further estimate the sales volume, Q. In considering the fixed cost C_f, production cost C_m, and repair cost C_r, the optimal warranty time and usage which maximize the profit, i.e., K^* and L^*, can thus be determined. Note that the estimation of C_r requires taking account of the NTF case due to human factors, namely NFBR, which may incur a relatively small amount of inspection cost rather than a relatively large amount of repair cost. The ignorance of such a case may overestimate C_r, and as a result, a proper field survey and past engineering experiences concerning the claim handling process would be useful to achieve a sound estimation of average C_r per claim. Moreover, suppose periodic PM is adopted, i.e., the interval of two consecutive PM activities is fixed, and a PM activity can restore the product to a younger status, that is, with a younger virtual age $\nu(t)$. Suppose that the PM level m would result in a relationship $\zeta(m)$ between the virtual age and the actual age, which transforms the actual age t into the virtual one $\nu(t)$. Likewise, such a level would also have a usage reduction of $\xi(m)$, which transforms the actual usage x into the virtual one $\theta(x)$. Accordingly, the optimal warranty terms K^*_{PM} and L^*_{PM} with consideration of periodic PM can thus be obtained.

The assumptions of this study are as follows:

1. The product deteriorates over time and through usage, and the breakdown process can be described by an NHPP.
2. A minimal repair is performed when a breakdown occurs within the warranty term, that is, after the repair, the product would be restored to its condition immediately before the breakdown.
3. The PM activities are imperfect, and thus do not restore the product to an AGAN (as-good-as-new) condition [47], but rather to a specific better condition, with the virtual age younger than the actual one.
4. The repair cost is paid by the manufacturer. The PM cost is paid by consumers.

The notations used in this study are as follows:

t the time using the product
x the usage of the product
Ω the warranty policy, that is, $\Omega=\{K,L\}$