Chapter 1

Effective Optimization of Statistical Decisions for Age Replacement Problems under Parametric Uncertainty

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ABSTRACT

In this chapter, an innovative model for age replacement is proposed. The costs included in the age replacement model are not assumed to be constants. For effective optimization of statistical decisions for age replacement problems under parametric uncertainty, based on a past random sample of lifetimes, the pivotal quantity averaging (PQA) approach is suggested. The PQA approach represents a simple and computationally attractive statistical technique. In this case, the transition from the original problem to the equivalent transformed problem (in terms of pivotal quantities and ancillary factors) is carried out via invariant embedding a sample statistic in the original problem. The approach allows one to eliminate unknown parameters from the problem and to find the better decision rules, which have smaller risk than any of the well-known decision rules. Unlike the Bayesian approach, the proposed approach is independent of the choice of priors. For illustration, numerical examples are given.

INTRODUCTION

Age replacement strategies, where a unit is replaced upon failure or on reaching a predetermined age, whichever occurs first, provide simple and intuitively attractive replacement guidelines for technical units. Within theory of stochastic processes, the optimal preventive replacement age, in the sense of leading to minimal expected costs per unit of time when the strategy is used for a sequence of similar units over a long period of time, is derived by application of the renewal reward theorem, see, for example, Barlow

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Effective Optimization of Statistical Decisions for Age Replacement Problems

and Hunter (1960), Barlow and Proschan (1965, 1975). They discussed the problem of determining an optimal preventive replacement age $T$ to minimize the long-run average expected cost per unit time over the infinite horizon (the average cost in short). Since then, this basic model has been generalized and modified by many authors to handle more practical situations, as summarized in Ascher and Feingold (1984), Nakagawa (1981), and Valdez-Flores and Feldman (1989). In practice, this procedure is also used even though one realizes that the resulting optimal strategy may only be used for a few such cycles, for example, because the unit would normally undergo some technical updates within reasonable period of time, or one wishes to keep the option open to change the policy in light of new information that may occur during the process.

It should be noted that Barlow and Hunter (1960) considered only minimal repair and preventive replacement as maintenance activities. Minimal-repair and replacement are often used as practical maintenance activities of real reliability systems. A minimal repair is the maintenance activity to repair the failed system so that its function is recovered, without changing its age, while a replacement restores the entire system into the new condition so that it behaves as a new system. Further, replacement is classified into preventive replacement or failure (or corrective) replacement according as whether the system is in operation or in failure. Phelps (1983) introduced failure replacement as a maintenance activity, and discussed an optimal maintenance problem with minimal repair and failure replacement under the average cost criterion (since it was assumed in this model that the required costs for preventive and failure replacements are equal, the system should be replaced only when it is failed). Tahara and Nishida (1975) discussed the maintenance problem with both preventive replacement and failure replacement which have different costs. The above studies concern, in general, the classical age replacement model and its some modifications.

Mazzuchi and Soyer (1996) considered age replacement from Bayesian perspective, allowing the assumed parametric lifetime distribution to be updated, within the Bayesian framework, when new data from the process become available. Such procedures can be called ‘adaptive’, in the sense that the optimal preventive replacement time may change over time.

To deal with scarce information, as may regularly be the case in practice, one could attempt to base replacement decisions entirely on expert judgements, via elicitation of a lifetime distribution for the unit (Apeland & Scarf, 2003; Percy, 2002).

Coolen-Schrijnera and Coolen (2004) consider an age replacement problem using nonparametric predictive inference (NPI) for the lifetime of a future unit. Based on observed failure times, NPI provides lower and upper bounds for the survival function for a future lifetime, which are lower and upper survival functions in the theory of interval probability, and which lead to upper and lower cost functions, respectively, for age replacement based on the renewal reward theorem. Optimal age replacement times follow by minimizing these cost functions.

**Classical Age Replacement Model**

In the well-known classical model for age replacement (Barlow & Proschan, 1965, 1975), the failure time of the unit (component) is assumed to be an absolutely continuously distributed random variable $X \geq 0$ with known probability distribution, with cumulative distribution function (cdf) $F(x) = Pr(X \leq x)$, probability density function (pdf) $f(x)$, hazard rate $h(x) = f(x)/(1 - F(x))$, and expected value $E(X)$. It is assumed that $h(x)$ is monotonously strictly increasing, which is often considered to be a natural as-
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