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Estimation of Reliability with Semi-parametric Modeling of Degradation

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Abstract

In many real life scenarios, stress accumulates over time and the system fails as soon as the accumulated stress or degradation equals or exceeds a critical threshold. For some devices, it is possible to obtain measurements of degradation over time, and these measurements may contain useful information about product reliability. In this paper, we propose a semi-parametric random effect (frailty) model for degradation path, and a method of estimating this path as well as the reliability. Consistency of the estimator under general conditions is established. Simulation results show superiority of the performance of the proposed method over a parametric competitor. The method is illustrated through the analysis of a real data set.

Keywords: Accelerated failure time, Crack propagation, Kernel function, Monotonic spline, Random effects, SEMOR, Shape invariant model.

1. Introduction

For systems that are designed to achieve high reliability, it is difficult to estimate system reliability with data consisting of a small number of failures, obtained from traditional life tests that record only time to failure. For many such systems, reliability depends on the dynamic balance between stress and strength, where stress accumulates over time. As for example, a vehicle axle fails when the depth of a crack has exceeded a critical level (Nakagawa, 2007, p. 2). Measurements on accumulated stress or degradation, taken over time, contain information about reliability of the unit. By harnessing this information, one can hope to achieve better specification of reliability even with data from a relatively small number of units (Lu and Meeker, 1993).

In designed experiments, systems are inspected at prefixed time points and current status of the systems along with measurements of accumulated stress are recorded. For such systems, failure can be defined in terms of a specified level of strength $s(t)$ at time t, and the reliability at time t is given by $R(t) = P[X(t) < s(t)]$, where $X(t)$ denotes the accumulated stress at time t (See Bhuyan and Dewanji, 2015). Sobczyk and Trbicki (1989) emphasized the importance of statistically designed experiments for estimation of the model parameters for analyzing fatigue crack data, modelled as