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RECENT ADVANCES IN RELIABILITY AND QUALITY ENGINEERING

Editor

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To

Michelle, Hoang Jr. and David

PREFACE

Today's engineering systems have become increasingly complex to design and build while the demand for reliability, quality, and cost effective development continues. Reliability is one of the most important attributes in such critical systems as defense systems,0 aerospace applications, real-time control, medical applications, as well as commercial systems. Growing international competition has increased the need for all engineers and designers to ensure a level of quality and reliability of their products before release, and for all manufacturers and producers to produce products at their optimum reliability level at the lowest cost. Hence, the interest in reliability and quality has been growing in recent years.

This volume presents recent research in reliability and quality theory and its applications by many leading experts in the field. The subjects covered include reliability optimization, software reliability, maintenance, quality engineering, system reliability, Monte Carlo simulation, tolerance design optimization, manufacturing system estimation, neural network, software quality assessment, optimization design of life tests, software quality, reliability centered maintenance, multivariate control chart, methodology for the measurement of test effectiveness, imperfect preventive maintenance, Markovian reliability modeling, accelerated life testing, and system availability assessment. This volume will serve as a reference for postgraduate students and also prove useful for practicing engineers and researchers of reliability and quality engineering. The method proposed in Chapter 1 is devoted to the designing of control charts (mean, median, standard deviation, and range) for data having a symmetrical leptokurtic distribution. This method is based on the symmetrical Johnson S_u distributions.

Since computers are being used increasingly to monitor and control both safety-critical and civilian systems, there is a great demand for high-quality software products. Reliability is also a primary concern for both software developers and software users [Pham *et al.* (1999)]. Chapter 2 describes an NHPP software reliability model that integrates testing coverage and imperfect debugging by incorporating fault introduction phenomenon into software fault detection rate function. The model is also illustrated by using two sets of data collected from real applications. In Chapter 3, a software system is viewed as a hierarchy of programming and integration modules. Each programming module can be developed in-house or purchased (when available). The reliability of software modules developed in-house and of software hierarchies as a function of their cost is presented. This chapter also includes branch and bound schemes to compute the optimal reliability where only easier continuous nonlinear problems are solved.

Successful testing of a one-shot device usually results in its destruction. This occurs quite often in the inspection of military weapons as well as industrial products. Chapter 4 discusses general test plans that satisfy both sample size and power requirements. An algorithm for generating these plans is also obtained. There are many situations that the process may be in control when the characteristics are considered separately but out of control when considered jointly with the multivariate control chart. In Chapter 5, multivariate control charts are discussed which are based on Hotelling's T^2 statistic. Chapter 6 presents the preparedness maintenance model for multi-unit systems with imperfect maintenance and economic dependence. The optimum opportunistic preparedness maintenance policies to optimize the system operating performance are then obtained.

Chapter 7 describes the use of Monte Carlo simulation to provide estimates of reliability functions for use in classical variational methods. The variational principle is derived from the forward and backward Kolmogorov equations. Chapter 7 also demonstrates a number of practical ways in which the efficiency of the simulation and variational processing procedure can be further improved. Chapter 8 presents a Bayesian approach to the periodic and the sequential imperfect preventive maintenance with minimal repair at failure. The optimal policies that minimize the expected cost rate under a Weibull hazard function are discussed. A case study of the K Steelworks is also presented to illustrate the results. Chapter 9 deals with life tests based on multi-stage decision making. The decision making of which action, namely accepting, rejecting or deferring to the next stage, is done at each stage. This chapter also deals with the multi-stage life test with step-stress life acceleration at each stage and presents a design procedure for the multi-stage accelerated life test using the cumulative exposure model.

Reliability centered maintenance (RCM) is a systematic process for preserving a system's function by selecting and applying effective maintenance tasks. Chapter 10 reports an application of RCM techniques to enhance the maintenance efficiency and effectiveness of light rail vehicle equipment at the Light Rail Division of Kowloon–Canton Railway Corporation. An RCM team was set up during the implementation of RCM to rethink and redesign maintenance procedures. For robust tolerance design, tightening systems' variations can lead to better customer satisfaction but it may result in a higher cost to the manufacturer. The focus of environmental protection concern is now shifting to pollution prevention, from documentation of pollutant patterns and identification of remediation technology. Chapter 11 presents a tolerance design optimization model incorporating environmental concepts. The model can be used to minimize the total societal loss, including a loss to the environment, by selecting the best level settings of the tolerance limits.

Chapter 12 discusses two stochastic software safety assessment models based on the existing software reliability models: the reliability assessment model with safety and the availability-intensive safety assessment model. These models can be used to predict the software safety and reliability measurements. Chapter 13 discusses variable stream and sample size group control charts in which both the number of streams selected for sampling and sample size from each of the selected streams are allowed to vary based on the values of the preceding sample statistics. The Markov chain process is used to derive the formulas for evaluating the performances of the proposed charts. Chapter 14 describes a model to estimate the total number of faults inserted into a software system, its residual fault content at any given time, and the efficacy of the testing activity in executing the code containing the newly inserted faults. This study also shows that changes in the relative complexity can be used to estimate the rates at which faults are inserted into a system between successive revisions.

Chapter 15 presents the classification and regression trees algorithm to practitioners in software engineering and draws practical lessons learned on building classification trees for software quality modeling. A case study of a very large telecommunications system is used to illustrate the algorithm to build software quality models.

Chapter 16 investigates the impact of software design on reliability assessment by describing a novel approach to software reliability assessment which combines the strengths of formal verification and program testing. The approach in this chapter provides a better understanding of the consequences of design decisions and a better insight into the problem domain. Chapter 17 discusses the radial basis function neural network method for empirical modeling and illustrates the method through a well-known temperature controller circuit application. In Chapter 18, a mathematical programming framework for assisting decision-makers in determining the optimal subset of maintenance activities to perform prior to the next mission is discussed. This process allows the decision-maker to consider the time, reliability and cost issues.

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Piscataway, New Jersey
October 1999

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Dr. Hoang Pham is currently Associate Professor in the Department of Industrial Engineering at Rutgers University, New Jersey, USA. Before joining Rutgers in 1993, he was Senior Engineering Specialist at the Boeing Company, Seattle, USA, and the Idaho National Engineering Laboratory, Idaho Falls, USA. He received the BS in Mathematics and BS in Computer Science, both with high honors, from Northeastern Illinois University, MS in Statistics from the University of Illinois at Urbana-Champaign, and MS and PhD in Industrial Engineering from the State University of New York at Buffalo.

He is Editor-in-Chief of the International Journal of Reliability, Quality and Safety Engineering. He was Guest Editor for the IEEE Transactions on Reliability, IEEE Communications Journal, Journal of Systems and Software, and International Journal of Modelling and Simulation. He is an editorial board member of several international journals and has been Conference Chair of many international reliability conferences. He is the General Chair of the Seven International Conference on Reliability and Quality in Design, Washington, D.C., USA.

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CONTENTS

Chapter 1

CONTROL CHARTS FOR DATA HAVING A SYMMETRICAL DISTRIBUTION WITH A POSITIVE KURTOSIS

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1. Introduction

The designing of a "classical" control chart (Shewhart, EWMA, CUSUM) supposes that the probability density function of the quality characteristic X has to be normal or approximately normal. However, in some situations, it has been shown that this condition does not hold [Jacobs (1990)]. In order to design control charts when the underlying population is non-normal (without increasing the sample sizes), different approaches may be used:

- Use classical Shewhart control charts anyway. Many authors studied the effect of non-normality on Shewhart control charts: [Burr (1967), Schilling and Nelson (1976), Balakrishnan and Kocherlakota (1986), Chan, Hapuarachchi and Macpherson (1988)]. One important conclusion of these studies is that classical Shewhart control charts give good results unless the population is highly skewed.
- Assume that the distribution of the underlying population is known and then derive specific control limits which verify the type I error α. Such an approach was chosen by Ferrell (1958), Nelson (1979). Ferrell assumed a log-normal distribution for the underlying population and proposed control limits for the geometric midrange and the geometric range, whereas Nelson assumed a Weibull distribution and derived control limits for the median, range, scale, and location.
- Use distribution free control charts that provide a type I error close enough to the theoretical one. This approach was first considered by Cowden (1957) who proposed to split the skewed distribution into two parts at its mode, and to consider the two new distributions as two half-normal distributions having the same mean, but different standard deviations. Another very similar approach, the Weighted Variance control chart (WV control chart), was proposed by Choobineh and

Ballard (1987) who suggested to split the skewed distribution into two parts at its mean, instead of its mode, and then compute the standard deviations of the two new distributions using the semivariance approximation of Choobineh and Branting (1986). Finally, we can cite the recent works of Seppala (1995) who suggests to use the "Bootstrap" in the computation of control limits, Willemain and Runger (1996) who proposes to use the notion of "Statistically Equivalent Blocks" to design nonparametric control charts, and Castagliola (1997) who proposes an extension of the Weighted Variance method called the "Scaled Weighted Variance" method.

- Transform the data in order to make them quasi-normal. This approach was chosen by Pyzdek (1992), Farnum (1997) who used the Johnson system of distributions as a general tool for transforming the data to normality.

The method proposed in this paper, which follows the last approach, is devoted only to the designing of "classical" control charts (mean, median, standard deviation, range, EWMA, CUSUM, etc.) for data having a symmetrical distribution with a positive kurtosis (leptokurtic distribution). This method is based on the properties of the symmetrical Johnson S_U distributions which will be examined in the following section.

2. The Symmetrical Johnson S_U Distributions

Let us focus on transformations of form $Z = a + bg(Y)$ of the random variable Y, where a and $b > 0$ are two parameters, where g is a monotone increasing function, and where Z is a $(0, 1)$ normal random variable. It is very easy to show that the random variable Y has the following characteristics:

- cumulative distribution:

$$F_Y(y) = \Phi[a + bg(y)]$$

- inverse cumulative distribution:

$$F_Y^{-1}(\alpha) = g^{-1}\left[\frac{\Phi^{-1}(\alpha) - a}{b}\right]$$

- density function:

$$f_Y(y) = bg'(y)\phi[a + bg(y)]$$

- noncentral moments of order s:

$$m_s(Y) = \int_{-\infty}^{+\infty} \left[g^{-1}\left(\frac{z-a}{b}\right)\right]^s \phi(z)dz \qquad (1)$$

If c and $d > 0$ are two additional parameters such that $Y = (X - c)/d$, then we can straightforwardly deduce the characteristics of the random variable X, i.e., $F_X(x) = F_Y[(x - c)/d]$ and $F_X^{-1}(\alpha) = c + dF_Y^{-1}(\alpha)$. There are a large number of possibilities for choosing an adequate function g. Johnson (1949) has proposed a very popular system of distributions based on a set of three different functions:

- $g_L(Y) = \ln(Y)$ and $d = 1$. The distributions defined by this function, called Johnson S_L distributions, are defined on $[c, +\infty]$.
- $g_B(Y) = \ln[Y/(1-Y)]$. The distributions defined by this function, called Johnson S_B distributions, are defined on $[c, c+d]$.
- $g_U(Y) = \ln(Y^2 + \sqrt{Y^2+1}) = \sinh^{-1}(Y)$. The distributions defined by this function, called Johnson S_U distributions, are defined on $]-\infty, +\infty[$.

Johnson has proved in his paper that (a) for every skewness coefficient $\gamma_1 = \mu_3/\mu_2^{3/2}$ and every kurtosis coefficient $\gamma_2 = \mu_4/\mu_2^2 - 3$ such that $\gamma_2 \geq \gamma_1^2 - 2$ there is one and only one Johnson distribution, (b) the S_B and S_U distributions occupy nonoverlapping regions covering the whole of the skewness-kurtosis plane, and the S_L distributions are the transitional distributions separating them (see Fig. 1).

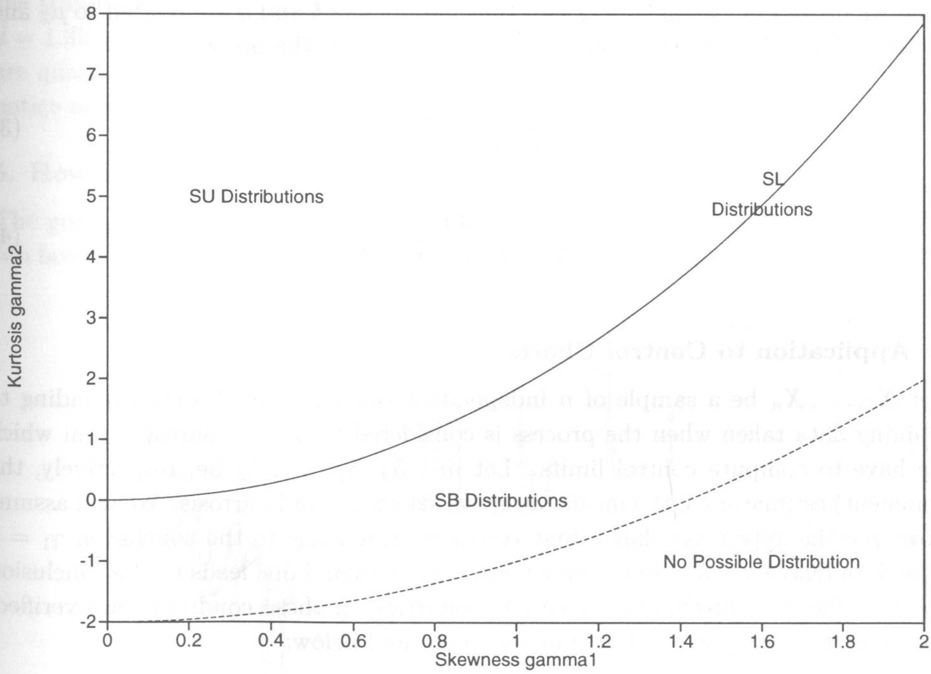

Fig. 1. The (γ_1, γ_2) plane for the Johnson distributions.

If we look at this figure, we can see that among the symmetrical Johnson distributions ($\gamma_1 = 0$) the S_U distributions are leptokurtic while the S_B ones are platykurtic. For this reason, we will now focus more precisely on Johnson S_U distributions which are symmetrical (about the mean $m_1(X) = m_1$). It is clear that a necessary and sufficient condition for a Johnson S_U to be symmetrical is that $a = 0$ and $c = m_1$. Consequently, the characteristics of a symmetrical Johnson S_U random variable X are: