SUSTAINABLE COMPUTING AND OPTIMIZATION

COMPUTATIONAL INTELLIGENCE IN SUSTAINABLE RELIABILITY ENGINEERING

Edited by

S. C. Malik, Deepak Sinwar, Ashish Kumar, S. R. Gadde, Prasenjit Chatterjee and **Bui Thanh Hung**

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Computational Intelligence in Sustainable Reliability Engineering

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Sustainable Computing and Optimization

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Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

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Edited by

S. C. Malik

Department of Statistics, M.D. University, Rohtak, India

Deepak Sinwar

Department of Computer and Communication Engineering, Manipal University, Jaipur, India

Ashish Kumar

Department of Mathematics and Statistics, Manipal University, Jaipur, India

S. R. Gadde

Department of Statistics, The University of Dodoma, Tanzania

Prasenjit Chatterjee

Department of Mechanical Engineering, MCKV Institute of Engineering, West Bengal, India

and

Bui Thanh Hung

Faculty of Information Technology, Artificial Intelligence Laboratory, Ton Duc Thang University, Ho Chi Minh City, Vietnam

Scrivener Publishing

WILEY

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The editors would like to dedicate this book to their parents, family members, friends and readers.

Contents

Preface

With the design of every new product, the world is witnessing the continuous development brought on by cross-disciplinary technologies. Instead of taking raw materials and sending them through a real manufacturing process that repeatedly combats tolerances, errors, and energy consumption to arrive at the final product, the assembly details can be directly input into the computation model in order to obtain the material characteristics as output to reduce effort and process costs. To ensure maximum reliability of product development, it is desired that the manufacturing process be driven by optimization. However, even though optimization has previously been applied for various fields, over the past two decades, computational optimization has become very popular for industrial optimizations. Computational intelligence-based optimization is one of several computational techniques that help achieve sustainability in product design and development phases. Among computational intelligence-based techniques, metaheuristic optimization is found to be specifically suitable for industrial optimizations. There are mainly two types of metaheuristic approaches; single-solution based and population based. As per the applications in the field of industrial optimization, this book mainly focuses on population-based (swarm intelligence) metaheuristic approaches.

Swarm intelligence is an important sub-area of optimization that helps develop sustainable materials at nano-, micro-, meso- and macro-levels by identifying the optimum values for different parameters. With the exponential rise in demand for sustainable materials for various purposes, optimization has played an important role over the last few years. Not only is materials data available for researchers and scientists, but sufficient processing resources are also available, which need to be optimized through AI techniques.

Traditional techniques employed by researchers are often cumbersome, expensive and lack sustainability. Hence, there is always a need for having recourse to time-efficient, fail-safe, cheaper intelligent technologies to address problems and ensure long-term sustainability. Since the existing literature available in this respect is nonexistent, this book is proposed to serve as a treatise and knowledge base for the community to inspire them to adapt environment-friendly and sustainable solutions for the future.

This book focuses on developing advanced computational intelligence algorithms for the analysis of data involved in reliability engineering, material design, and manufacturing with the objective of ensuring sustainability. It reveals applications of different models of evolutionary algorithms in the field of optimization with the objective of solving problems to help the manufacturing industries. Some special features of this book include a comprehensive guide for utilizing computational models for reliability engineering, state-of-the-art swarm intelligence methods for solving manufacturing processes and developing sustainable materials, high-quality and innovative research contributions, and a guide for applying computational optimization to reliability and maintainability theory. A chapter-wise summary of the information presented herein follows.

Chapter 1 presents a stochastic model for reliability indices of a computer system with priority and server failure. The model is analyzed by using the semi-Markov process and regenerative point technique. The reliability indices, such as mean time to system failure (MTCSF), availability, busy period of the server due to hardware repair and software upgradation, expected number of treatments given to the server, expected number of hardware repair, and software upgradation, are obtained for arbitrary values of the parameters. The profit analysis of the system model has also been carried out to discern the usefulness of the system under different parametric situations.

Chapter 2 presents a study that optimizes the availability of a turbine unit (TU) of a steam turbine power plant (STPP) using mathematical modeling and a genetic algorithm. The mathematical model is developed using the Markovian birth-death process (MBDP) and Chapman-Kolmogorov differential equations derived for the proposed model. The analytical solution of the mathematical model is derived for a particular case by considering exponential distribution for random variables associated with failure and repair rates. By using a nature-inspired algorithm (NIA), namely a genetic algorithm (GA), an effort is made to attain the global solution of the TU.

Chapter 3 covers the development of the Laplacian artificial bee colony (LABC) algorithm for effective harmonic estimator design. For designing the estimator, a hybrid approach based on least square error minimization with the help of a new version of the artificial bee colony algorithm is proposed. The proposed version employs a Laplacian factor-based update equation in the scout bee phase. For proving the modification meaningful, first the proposed algorithm is tested on several standard benchmark problems, and then it is applied to the estimator design problem. Results reported in on both parts indicate that the proposed modification is meaningful and the performance of the LABC algorithm is comparable with that of many other state-of-the-art algorithms.

Chapter 4 discusses the applications of the cuckoo search algorithm in reliability optimization, which is a novel nature-inspired algorithm that is used to solve complex optimization problems. The algorithm depends on the brood-parasitic strategy of cuckoo species. The usage of Lévy flights is used to produce new candidate resolutions. It can improve the relationship between exploration and exploitation towards the potential of searching. It can also be used in solving engineering problems such as embedded systems, distribution of networks, and scheduling problems. In this chapter, a study of the reliability of the software at static and runtime is performed and the results are also discussed.

Chapter 5 carries out a performance evaluation of the series-parallel computer system with a Gumbel-Hougaard copula family. To analyze the reliability of the system, the partial differential equations are derived from the system's schematic diagram in which reliability measures of system strength, such as reliability, availability, mean time to failure (MTTF), and cost function, are computed. The MTTF of devices, such as workstation, hub, and router, obeys exponential distribution whereas the corresponding repair time follows two different distributions, namely general and copula distribution. The findings of the study are depicted with the help of suitable diagrams and tabular representations.

Chapter 6 covers the applications of artificial intelligence (AI) in sustainable energy development and utilization. To combat the energy and environmental crises, clean and renewable fuels like biofuels are popular as petrodiesel replacement fuels. Biofuels can be obtained from different feedstocks and are successfully tested in diesel engines. However, several parameters influence the output results during their production and engine testing. The accurate prediction of end results is considered challenging with the traditional techniques. Therefore, AI techniques have emerged as being the most successful in solving nonlinear problems and achieving a high success rate in prediction. In this chapter, different AI techniques that have been successfully used in finding a feasible solution for complex problems in biodiesel production and engine testing are discussed in detail.

Chapter 7 introduces a new joint reliability achievement worth (JRAW), joint reliability reduction worth (JRRW), and joint reliability Fussell-Vesely (JRFV) measure for three multistate components of a multistate system. This is a new approach to detect the joint effect of a group of components in improving system reliability. The differencing technique is used in the proposed measures. A steady-state performance level distribution restricted to the component's states is used to evaluate the proposed measures. The universal generating function (UGF) technique is applied for the evaluation of proposed joint importance measures with suitable examples.

Chapter 8 presents some inferences about inverse Rayleigh distribution based on joint progressive Type-II censoring. The maximum likelihood estimation and the corresponding asymptotic confidence interval estimation are used as the classical estimation methods. The Bayes estimates are calculated under the squared error loss function (SELF) using Tierney-Kadane's approximation and Metropolis-Hastings algorithm, along with the construction of Bayes estimates highest posterior density credible intervals. A Markov chain Monte Carlo simulation study is carried out to compare different estimation methods and a real-life problem is discussed for illustrative purposes.

Chapter 9 deals with component reliability estimation through competing risk analysis of fuzzy lifetime data. In many cases, the lifetimes of systems are not precisely observed, or they are reported in "vague" terms. This imprecision or vagueness in data can be dealt with more accurately by incorporating fuzzy concepts. In this chapter, a competing risk analysis of lifetime data is performed by considering lifetimes as fuzzy numbers. Using different membership functions, the authors provide procedures for maximum likelihood and a Bayesian estimation of component reliability. They also evaluate bootstrap confidence intervals and the highest posterior density intervals. To observe the impact of various membership functions on the considered estimators, a comprehensive simulation study has been carried out. Finally, a real data set of small electric appliances has been analyzed.

Chapter 10 discusses the cost-benefit analysis of a redundant system with the provision of refreshment. Sometimes, due to some system-oriented snags and glitches, system performance may be hindered that can be overcome by repair. The goal of this chapter is to look at the survey of cost-benefit of a two-unit system with a single unit that can operate the system and another unit held as a spare in case of server failure, with refreshment provided to the server on demand.

Chapter 11 introduces a few novel inequalities of fuzzy measures and establishes the bounds in terms of triangular discrimination. Some new relations between new and existing fuzzy divergence measures are obtained with the help of the properties of a convex function and a new f-divergence measure. The utility of new fuzzy divergence measures in multi-criteria decision-making problems is also presented for better understanding.

Chapter 12 discusses the contribution of refreshment provided to the server during the job of repairing a cold standby system. The concept of probabilities of state transitions is presented followed by mean sojourn time and mean time to failure of the system. When calculating steady-state availability, a busy period of the server due to repair of the failed unit and a busy period of the server due to refreshment is computed followed by estimated visits made by the server. Novel conclusions are drawn based on considering particular cases and profit analysis.

Chapter 13 deals with stochastic modeling and availability optimization of a heat recovery steam generator using a genetic algorithm. The study presented in this chapter proposes a novel mathematical model for a heat recovery steam generator (HRSG) system to assess its availability. For this purpose, a state transition diagram is developed using the Markov birth-death process by considering all time-dependent failure and repair rates as exponentially distributed. The Chapman-Kolmogorov differential-difference equations are derived for the proposed model. The availability of the proposed model is optimized using a genetic algorithm to attain the global solution.

Chapter 14 investigates the reliability and maintainability of a piston manufacturing plant. For this analysis, data on time to repair and the number of failures was collected over two years. A descriptive analysis of the subsystems was performed along with trend and serial correlation testing. The best-fitted repair and failure time distributions among Weibull, normal exponential and lognormal distributions were investigated. The useful parameters corresponding to best-fitted distribution were estimated using U-statistics methodology and non-homogeneous Poisson process–power law process (NHPP-PLP). The reliability, availability, and hazard rates of the entire plant were calculated. The results were stored in numerical and graphical order concerning time to highlight the importance of the study. The model is useful not only in assessing the anticipated time for planning a maintenance schedule of a plant but also in terms of identifying the occurrence of failures in manufacturing plants.

Editors
Prof. S. C. Malik
Department of Statistics
M.D. University, Rohtak, India
Dr. Deepak Sinwar
Department of Computer and Communication Engineering
Manipal University Jaipur, India

Dr. Ashish Kumar
Department of Mathematics and Statistics
Manipal University Jaipur, India
Prof. S. R. Gadde
Department of Statistics
The University of Dodoma, Tanzania
Dr. Prasenjit Chatterjee
Department of Mechanical Engineering
MCKV Institute of Engineering, West Bengal, India
Dr. Bui Thanh Hung
Faculty of Information Technology, Artificial Intelligence Laboratory
Ton Duc Thang University, Ho Chi Minh City, Vietnam
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Finally, the editors take this opportunity to thank all the readers and expect that this book will continue to inspire and guide them in high end researches.

The Editors

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Reliability Indices of a Computer System with Priority and Server Failure

S.C. Malik*, R.K. Yadav and N. Nandal

Department of Statistics, M.D. University, Rohtak, India

Abstract
A stochastic model for a computer system has been described by considering theconcepts of failure of service facility, priority, and redundancy. The computer system comprises hardware and software components, which work together to perform the desired goals. The failure of the components is assumed as independent, which follow some probability distributions. There is a single server that has the responsibility to rectify the snags that occur during the operation of the components. The server is subjected to failure while performing jobs related to software upgradation but can resume the same after getting treatment. The server repairs the hardware components at failure while the software components are upgraded from time to time on a need basis. The preference to the software upgradation is given over the hardware repair. The computer system is considered as a single unit and an additional identical unit (redundant) is provided in order to meet out the emergency requirements. The distributions for repair time, treatment time and upgradation time are considered as negative exponential. The system model is analyzed by using semi-Markov process and regenerative point technique. The reliability indices, such as MTCSF, availability, busy period of the server due to hardware repair and software upgradation, expected number of treatments given to the server, expected number of hardware repair and software upgradation are obtained for arbitrary values of the parameters. The profit analysis of the system model has also been carried out to see the usefulness of the system under different parametric situations.

***Keywords*:** Computer system, cold standby, failure of service facility, reliability indices, priority, software upgradation

**Corresponding author*: sc_malik@rediffmail.com

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1.1 Introduction

The entire responsibility for completing a task by a computer system lies on its constituents called h/w and s/w components. Therefore, the failure of any one component makes the computer system fail. These failures give rise to data loss, error in computer programs, natural disasters, economy loss, etc. Thus, it becomes very essential to maintain the reliability of the components of the computer system in order to provide effective services to the users. Friedman and Tran [4] gave the reliability techniques for combined hardware/software systems. The reliability modeling of hardware/software system has been discussed by Welke *et al.* [19]. Lai *et al.* [12] analyzed the availability of the distributed software/hardware system model.

The other way to intact the reliability of a computer system is to provide unit wise redundancy in it. The unit wise redundancy means to make a provision of another identical computer system which can be used as and when required at the failure of operating computer system. This provision of unit-wise redundancy may be made in cold standby or warm standby or in hot standby modes. The researches available in reliability theory indicate that the provision of cold standby redundancy in a system is much better than that of the others so far as reliability of the system is concerned. Sridharan & Mohanavadivu [18] and Meng *et al.* [15] analyzed the two unit cold standby systems. The stochastic analysis of cold standby system with two stage repair and waiting time has been carried out by El-Said and Sl-Sherbeny [3]. Bao and Cui [1] studied reliability for a cold standby Markov repairable system with neglected failures. Kumar *et al.* [5] checked the behavior of cold standby system with maximum repair time stochastically. Kumar and Goel [10] obtained profit of a two-unit cold standby system for general distribution. In the development of computer system model, the cold standby redundancy (unit wise/component wise) technique has also been used by the researchers, including Malik & Anand [13] and Munday & Malik [16].

Further, the idea of priority in repair discipline has been suggested by the researchers which can help in making the system more profitable to use and also to avoid unnecessary expenses on undesirable repair activities. In this direction, many authors, including Kumar & Malik [6], Kumar *et al.* [11], Kumar & Saini [8] and Kumar & Yadav [9], have worked and developed system models stochastically under different repair and maintenance strategies. But they failed to address the application of this idea in the stochastic modeling of computer systems.

The studies referred in this paper has no proof to authenticate the proper functioning of the service facility while conducting repair activities like s/w upgradation and h/w repair. In the computer system, upgradation of software means an improvement (newest version) in existing software, which is unable to meet out the assigned job. They considered the failure of the service facility negligible. But in realistic environment, the breakdown of the server is possible while repairing or upgrading the components of the operating systems. However, some authors including Bhardwaj & Singh [2], Nandal & Rathee [17] and Kumar & Saini [7] have tried to develop the system models by considering the failure of service facility. For the computer system, the service facility (server) can be the repairman or Internet or an individual (manually), which does h/w repair and s/w upgradation. The failure of service facility available for the repair of the computer system cannot be ignored as there may be the chances of its failure due to interruption in Internet connection or slow Internet speed or less knowledge of individual (manually) about that software. The failure of service facility has been considered by Yadav & Malik [20] and Malik *et al.* [14] while constructing stochastically the reliability models for a computer system.

The purpose of this chapter is to develop a stochastic model for a computer system by considering the ideas of failure of service facility, priority, and redundancy. The computer system comprises hardware and software components, which work together to perform the desired goals. The failure of the components is assumed as independent which follow some probability distributions. There is a single server who has the responsibility to rectify the snags, which occur during operation of the components. The server is subjected to failure while performing jobs related to software upgradation but can resume the same after getting treatment. The server repairs the hardware components at failure while the software components are upgraded from time to time whenever required. The preference to the software upgradation is given over the hardware repair. The computer system is considered as a single unit and redundancy in it with the identical unit is provided in order to meet out the emergency requirements. The distributions for repair time, treatment time and upgradation time are considered as negative exponential. The system model is analyzed by using semi-Markov process and regenerative point technique. The reliability indices, such as MTCSF, availability, busy period of the server due to hardware repair and software upgradation, expected number of treatments given to the server, expected number of hardware repair, and software upgradation, are obtained for arbitrary values of the parameters. The profit analysis of the system model has also been carried out to examine the usefulness of the system. The behavior of some reliability indices is presented graphically for arbitrary values of the parameters.

1.2 Some Fundamentals

Here, we shall describe in brief the following fundamentals.

1.2.1 Reliability

In broad term, reliability is considered as the probability of no failure of the system. If "T" is the lifetime of the system, then the system reliability is defined as:

$$R(t) = P_r[T > t] = \int_t^\infty f(u)du = 1 - F(t) = \overline{F}(\mathrm{t})$$

Where $f(t)$ is a probability density function of life time "T" and $F(t)$ is the cumulative density function of life time "T" or unreliability of the system, and $R(t)$ is the probability that the item does not fail in the time interval (0 , 1], and is still functioning at time "t."

1.2.2 Mean Time to System Failure (MTSF)

The expected time before the system completely fail is called mean time to system failure. Let $f(t)$ be the failure density function, then

$$MTSF = E(T) = \int_0^\infty tf(t)dt, \text{where, T is the time to failure}$$

$$= \lim_{t\to\infty}\int_0^t R(t)dt = \lim_{s\to 0} R^*(s), \text{where } R^*(s) \text{ is the Laplace transform of } R(t).$$

1.2.3 Steady State Availability

The probability that the system is operating successfully at time "t" is called availability of the system which is given by

$$\text{Availability } A(t) = \frac{\text{SystemUpTime}}{\text{SystemUpTime} + \text{SystemDownTime}}$$

The expected fraction of time that the system operates satisfactorily in the long run is known as steady state availability. Thus, steady state availability is

$$A(\infty) = \lim_{t \to \infty} A(t)$$

1.2.4 Redundancy

Redundancy is a common approach to improve the reliability and availability of a system. The provision of parallel paths (or alternative means) in a system for performing a given task such that all means must fail before causing the system failure, is called redundancy. It is mainly of two types: active redundancy and standby redundancy. The redundancy in which all spare units operate simultaneously is known as active redundancy, while the standby redundancy is that in which failed unit is replaced manually or automatically by its similar spare unit, and this process will continue until all the spare units (standby) have been exhausted.

For example, the system of power supply through electric transformer and generator is a case of standby system where a generator is kept as a spare (called redundant) and can be switched on as and when power supply through electric transformer is interrupted.

1.2.5 Semi-Markov Process

The semi-Markov process is a process in which transition from one state to another is governed by the transition probabilities of a Markov process but the time spent in each state before a transition occurs is a random variable depending upon the last transition made.

Mathematically, we assume that the process is time homogeneous, i.e.,

$Pr\{X_{n+1} = j, t_{n+1} - t_n < t | X_n = i\} = Q_{ij}(t), i, j \in s$ is independent of n, then there exist limiting transition probabilities.

Here, $Q_{ij}(t)$ is the cdf of passage time from regenerative state S_i to a regenerative state S_j or to a failed state S_j without visiting any other regenerative state in (0, t]

$$p_{ij} = \lim Q_{ij}(t) = \Pr\{X_{n+1} = j | X_n = i\},$$

then $\{X_n$, n = 0, 1, 2, … … ..$\}$ constitute a Markov chain with state space E and transition probability matrix (t. p. m.)

$$P = [p_{ij}]$$

1.2.6 Regenerative Point Process

Regenerative stochastic process was defined by Smith (1955) and has been crucial in the analysis of complex system. In this, we take time points at which the system history prior to the time points is irrelevant to the system conditions. These points are called regenerative points. Let $X(t)$ be the state of the system of epoch. If t_1, t_2, … .. are the epochs at which the process probabilistically restarts, then these epochs are called regenerative epochs and the process $\{X(t), t = t_1, t_2, … … …\}$ is called **regenerative process**.

1.3 Notations and Abbreviations

MTCSF	Mean Time to Computer System Failure
SMP	semi-Markov process
RPT	regenerative point technique
MST	mean Sojourn time
O/Cs	the unit is operative/in cold standby
a/b	probability of hardware/software failure
$x_1/x_2/\mu$	hardware/software/server failure rates
HFUr/HFWr	the failed hardware is under/waiting for repair
HFUR/HFWR	the failed hardware is continuously under/waiting for repair from prior state
SFUg/SFWg	the failed software is under/waiting for upgradation
SFUG/SFWG	the failed software is continuously under/waiting for up-gradation from prior state
SUt	the failed server (service facility) is under treatment
SUT	the failed server (service facility) is continuously under treatment from prior state
h(t)/H(t)	pdf/cdf of hardware repair time