



Abstract Booklet

The 11th Seminar on **Reliability Theory and its Applications**

Department of Statistics
University of Isfahan

14–15 May 2025



In the Name of God



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Preface

We are delighted to host the “11th Seminar on Reliability Theory and its Applications” on 14–15 May 2025 in the Department of Statistics at the University of Isfahan. On behalf of the organizing committee, we warmly welcome all participants and trust that this seminar will provide engaging discussions and the exchange of valuable scientific ideas. We are grateful to the many individuals and institutions whose support has made this event possible, including our colleagues in other universities, researchers, and postgraduate students whose contributions enrich this event. In particular, we wish to thank the Research Council of the University of Isfahan, the “Center of Excellence on Ordered Data, Reliability, and Dependency”, the Islamic World Science Citation Center (ISC), the Iranian Statistical Society, the scientific and the organizing committees of the seminar, our peer reviewers, and the staff of the Department of Statistics at the University of Isfahan for their kind cooperation.

Mahdi Tavangar (Scientific Chair)

Somayeh Ashrafi (Organizing Chair)

May, 2025

Seminar Topics:

- Reliability of systems and networks
- Maintenance and repair models of systems
- Reliability analysis based on degradation data
- Accelerated lifetime tests
- Statistical inference and analysis of lifetime data
- Software reliability
- Warranty models and field data
- Ageing concepts
- Dependency concepts and copula functions
- Risk analysis in reliability
- Bayesian methods in reliability
- Stochastic orderings
- Data mining in reliability
- Shock models
- Survival analysis
- Statistical quality control
- Reliability in fuzzy environments
- Case studies in industry
- Big data in reliability
- Artificial intelligence in reliability

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Maintenance Policy for a k -Out-of- n System

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Abstract

In the context of reliability, a set of technical, engineering, administrative, and managerial actions applied throughout the life cycle of a system is known as a maintenance policy. It is used to make management decisions to maintain a specific operating condition of a system or to restore a failed system to an operational condition. Based on the system's structure, how to use it, and the optimization of the objective functions, researchers have introduced various maintenance policies. The k -out-of- n system is one of the most popular and widely used systems in practice, and it functions if at least k ($1 \leq k \leq n$) of the n components function successfully. Recently, several studies have been conducted on developing maintenance policies for k -out-of- n systems. This talk is based on joint work with Safaei et al. (2022, 2023), in which we proposed some types of maintenance strategies, including income from the sale of second-hand components.

Keywords: Age replacement policy, k -out-of- n system, Long-run average cost, Maintenance policy

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An Approach to Modeling the Mean Residual Time

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Abstract

There has been increasing interest in employing the mean residual lifetime (MRL) as a key index for failure prognosis. But, it is not flexible enough to accommodate condition monitoring information required for maintenance decision-making. The primary innovation of this work lies in computing the mean residual time based on the expected time to reach a defective state, rather than waiting for complete system failure. Further in this study, the characterization problem of the proposed reliability index is addressed and its monotonicity properties are analyzed.

Keywords: Mean residual lifetime, Failure prognosis, Parallel system configuration, System inspection

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Mission abort policy for k -out-of- n systems subject to degradation

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Abstract

In this paper, we consider k -out-of- n :F systems with degraded components such that if the value of degradation of each component become larger than a predetermined level, then component's failure occurs. In order to increase the system's survival probability, a decision to abort a mission or to continue operation is executed. The proposed policy is that when a specific number of component's failure occurs, the mission is aborted. The mission success probability and also system survival probability are obtained as two important metrics for mission-based systems. An optimization model with consideration of minimizing the expected cost are also presented.

Keywords: Mission abort, k -out-of- n system, Mission success

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Stochastic Comparisons of Extremes with Dependent and Heterogeneous Observations from a General Two Parameters Distribution

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Abstract

In this paper, we carry out stochastic comparisons of lifetimes of two series (and two parallel) systems consisting of dependent and heterogeneous components. The underlying dependence model for component lifetimes is supposed to be an Archimedean copula. Also, we assume a general two parameters distribution for the lifetime distribution of components. Sufficient conditions are developed to get the usual stochastic ordering between two systems. An example is given to illustrate the theoretical findings.

Keywords: Stochastic comparisons, Majorization, Archimedean copula

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Best Unbiased Prediction of Order Statistics in Generalized Extreme value Distribution

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Abstract

Assume that some order statistics from a generalized extreme value distribution are missing. We aim to impute the missing values. We compute the Best Unbiased Prediction (BUP) of these missing values. Additionally, we examine and compare the performance of the derived predictor with several alternatives through comprehensive simulations for various extreme value indexes, sample sizes, and the number of missing values. We observe that generally, the method BUP demonstrates better performance.

Keywords: Extreme value distribution, Missing order statistics, Extreme value index, Prediction.

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A New Test Based on Linear Ordered Rank Statistics

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Abstract

In this paper we consider the problem of hypothesis testing the equality of two distribution functions against the distribution functions are ordered with respect to usual stochastic order and the hazard rate order. The proposed statistical test is based on the linear combination of ordered rank statistics. The exact null and alternative distributions of the proposed test statistic are derived and are then used to generate the critical value.

Keywords: Non-parametric test, Stochastic ordering, Rank statistic, PHR model, Order statistic

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Postponed Preventive Maintenance for k -out-of- n Systems Subject to External Shocks

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Abstract

In this paper, we study an $(n - k + 1)$ -out-of- n system exposed to shocks that arrive according to a counting process, where each shock potentially causes component failures. We propose a postponed preventive maintenance (PM) strategy in which the decision to perform maintenance at a scheduled time depends on the observed number of failed components. If the failure count is below a threshold, the PM action is postponed to a later time. For the presented PM policy, the mean cost function per unit of time is obtained, and the optimal decision parameters that minimize the mean cost function are determined. Numerical examples demonstrate the applicability and effectiveness of the proposed maintenance strategy.

Keywords: Nonhomogeneous Poisson process, Mean cost function, Emergency repair.

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Analysing Random Maintenance Data by Repair Alert Model for Discrete Lifetimes

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Abstract

This paper presents an examination of repair alert models for analyzing discrete lifetimes coming from maintenance programs. The study considers the negative binomial distribution for component lifetimes. Furthermore, we address the challenges associated with parameter estimation for the negative binomial distribution and compute some approximate confidence intervals for the selected distribution based on the Akaike Information Criterion. Findings are illustrated by analyzing a real dataset.

Keywords: Maximum likelihood estimation, Random sign censoring, Repair alert model.

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A Q-Learning Approach to Maintenance Policy Optimization for Series Systems with Degradation and Common Shocks

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Abstract

This paper addresses the optimization of maintenance strategies for a two-component series system subjected to both natural degradation and common shock-induced degradation. The system is modeled with degradation processes for each component, where natural degradation follows a homogeneous gamma process, and shock-induced degradation is governed by a homogeneous Poisson process with shared shocks affecting both components. The objective is to develop an optimal maintenance policy using Q-learning, a reinforcement learning technique, to minimize maintenance costs while preventing system failure. The maintenance strategy includes corrective, preventive, and opportunistic maintenance actions, with the decision-making process based on the degradation levels of both components observed during periodic inspections. The proposed method is evaluated through simulations to assess the effectiveness of the Q-learning-based policy in reducing overall costs and ensuring system reliability.

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Results show that the optimal policy balances the costs of inspections, maintenance actions, and system downtime, providing significant cost savings compared to traditional maintenance approaches. The approach demonstrates the potential of reinforcement learning in dynamic maintenance optimization for complex systems subject to degradation and external shocks.

Keywords: Condition-based maintenance, Opportunistic maintenance, Common cause failure, Degradation modeling, Q-learning.



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Optimizing Maintenance Scheduling in a Scrap-Based Steel Production Line Using Reinforcement Learning

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Abstract

This paper suggests a Reinforcement Learning (RL)-based optimization method for shredder machine maintenance and inspection planning in a steel production line with scrap as raw material. The method incorporates Remaining Useful Life (RUL) into decision-making for proactive maintenance considering real production conditions like production rate, buffer level, and RUL. The production line is represented as a multi-component system with dependencies and uncertainties, and a simulation platform used to estimate performance. The result indicates that the incorporation of RUL improves maintenance effectiveness in terms of reducing downtime and operation costs. With this approach, it is demonstrated that Reinforcement Learning, based on RUL data, can significantly enhance maintenance control in production systems.

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Keywords: Reinforcement learning, Maintenance optimization, Scrap-based steel production line, Remaining useful life, Multi-component system



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Smart State-Dependent Maintenance with Deep Reinforcement Learning

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Abstract

We present a novel maintenance optimization framework for single-unit systems subject to both gradual degradation and non-fatal random shocks. Unlike conventional approaches, our method combines: (1) A virtual age-based degradation model that captures accelerated aging due to continuous wear and shock-induced damage, and (2) A dynamic imperfect repair mechanism with state-dependent improvement factors that adapt to real-time system conditions. The maintenance decision-making process is modeled as a continuous-state Markov Decision Process (MDP) with three actions: do nothing, perform imperfect repair, or replace the system. To efficiently handle the high-dimensional state space and complex interactions between degradation and shocks, we employ Deep Reinforcement Learning (DRL), training the decision-maker using a Deep Q-Network (DQN). Numerical experiments show that our framework achieves significant reductions in long-term maintenance costs compared to traditional improvement factor policies while simultaneously improving system reliability. This research contributes to predictive maintenance

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by introducing an adaptive, data-driven approach for systems experiencing multi-mode degradation.

Keywords: Degradation modeling, Maintenance optimization, Imperfect repair, Improvement factor, Markov decision process (MDP), Deep reinforcement learning (DRL)



Efficiency of Ranked Set Sampling in Mean Residual Lifetime Estimation

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Abstract

The mean residual life (MRL) function is a fundamental concept in survival analysis and reliability. In addition to characterizing the survival distribution, its clear interpretability makes it particularly useful for conveying survival information to non-statisticians. Ranked set sampling (RSS) is a sampling technique designed for situations where obtaining precise measurements of sample units is costly or challenging, while ranking them without relying on exact values is more feasible and cost-effective. However, its practical application is limited by the requirement that each sample unit must be assigned a unique rank. To address this challenge, Frey introduced an innovative variation of RSS, called RSS-t, that integrates tie structure into the ranking process for improved effectiveness. In this paper, we use the RSS-t technique to estimate the MRL function. Then, we compare the proposed estimators with their counterparts in simple random sampling

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(SRS) and standard RSS using Monte Carlo simulation. Our results show that incorporating tie information enhances statistical inference for the MRL function, reducing the sample size required to achieve a predetermined precision.

Keywords: Mean residual life, Monte Carlo simulation, Non-parametric estimation, Ranked set sampling, Ties information



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Mission Abort Strategy for Multi-Component Systems Using Survival Signature

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Abstract

Survivability of important real-world systems such as satellites, aircraft, and submarines is vital as their failures can lead to significant economic losses and operational risks. An effective approach to enhance system survivability and reduce failure probability is to implement a mission abort policy. The mission is halted and recovery measures are initiated when the risk of system failure exceeds a certain level. This paper discusses a coherent system consisting of independent, heterogeneous components with a mission abort policy. Under survival signatures, we develop a probabilistic model to evaluate system survivability. With the help of elaborate illustrative examples, we compare different abort rules.

Keywords: Mission abort policy, Survival signature, System reliability, Heterogeneous components.

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On the Redundancy Allocation Approaches to Coherent Systems

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Abstract

Redundancy allocation is recognized as a critical strategy in reliability engineering, which aims to increase reliability and further guarantee the continuous operation of complex designed systems. This approach involves adding spare components or sub-systems to the system that act as backup in the event of failure of the main components. In this lecture, a review of existing studies on redundancy allocation from various perspectives is presented. It is consisting of papers that compare the redundancy at component and system levels. Next, the findings in the articles related to the location of the redundant components as well as the number of redundancies dedicated to improving system performance are also reviewed. On the second part, we investigate an optimization method for the optimal number of redundancies for a coherent system consists of different types of components.

Keywords: Redundancy allocation, Active redundancy, Cold redundancy, Stochastic orders, Majorization orders.

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Burg Entropy: Extension and an Application to Binary Classification of Malaria Cell Images

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Abstract

In this paper, we first establish some results for Burg entropy based on escort and generalized escort distributions. Then, we propose relative Burg divergence measure, cumulative residual Burg entropy (CRB), and cumulative residual relative Burg (CRRB) entropy measures. We apply the proposed CRRB measure to malaria cell image analysis, demonstrating its effectiveness in quantifying image similarity and segmentation performance. Comparative results with Otsu's thresholding and K -means clustering highlight the efficacy of our approach in classification tasks.

Keywords: Burg entropy, Shannon entropy, Binary classification, Malaria cell disease

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Binary Classification of Heart Disease Data Based on Cumulative Residual Discrete χ^2_α Divergence

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Abstract

In this paper, we propose cumulative residual discrete χ^2 divergence and cumulative residual discrete generalized χ^2_α divergence measures, and establish some theoretical results for three mixture survival models. We further apply the proposed cumulative residual discrete χ^2_α divergence measure to a binary classification task using heart disease data. Our numerical experiments demonstrate the effectiveness of the proposed measure as a robust tool for quantifying classification performance. The performance of our approach is benchmarked against ten machine learning models, including Logistic regression, decision tree, random forest, support vector machine (SVM), K-nearest neighbors (KNN), naïve Bayes, linear discriminant analysis (LDA), AdaBoost, and gradient boosting, based on accuracy, precision, recall, and F1-score.

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Keywords: χ^2 divergence, Survival function, Classification, Machine learning



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Causal Inference on the Differences of the Restricted Mean Residual Lifetime

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Abstract

In biomedical studies, the difference in restricted mean residual lifetime can be used as an appropriate quantity for comparing different treatment groups with respect to their survival times. In observational studies where the factor of interest is not randomized, covariate adjustment is needed to take into account imbalances in confounding factors. An estimator is obtained for the average causal treatment difference using the restricted mean residual lifetime as target parameter. Specifically, treatment-specific additive hazards model is used to account for confounding factors. Large sample properties of the proposed estimator are also established.

Keywords: Additive hazards model, Average causal effect, Restricted mean residual lifetime

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Analyzing the Doubly Geometric Process with Flexible Interarrival Times: A Tool for Modeling Failure and Reliability Data

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Abstract

The doubly geometric process is widely applied in practical problems, including reliability and failure data analysis. Recently, a lot of scholars have been interested in the doubly geometric process. It is an advanced stochastic model that extends the traditional geometric process by incorporating two distinct scaling factors. Although this process offers greater flexibility in data modeling than the geometric process, it involves more complexity in parameter estimation. This study focuses on estimating the parameters for the doubly geometric process with log-normal interarrival times. The unknown parameters of the process are estimated using the maximum likelihood technique. The estimator's asymptotic properties are also obtained. Simulation results and practical applications are presented to validate the effectiveness of the proposed process.

Keywords: Geometric process, Doubly geometric process, Log-normal distribution, Maximum likelihood estimation

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A New Design of a Combined Control Chart Based on Exponentially Weighted Moving Average for Normal Quality Variables

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Abstract

The production of high-quality products can be effectively achieved through the application of statistical quality control methods, particularly control charts. These tools facilitate precise monitoring of production processes and enable the rapid identification of any deviations. In this study, we focus on designing combined control charts by integrating Double Exponentially Weighted Moving Average (DEWMA) charts and Double Moving Average (DMA) charts. These combined charts are specifically developed to monitor quality characteristics that follow a normal distribution. The performance of these charts is evaluated using the Average Run Length (ARL) index under various parameters. The results demonstrate that the proposed charts significantly outperform traditional control charts in detecting small shifts in the process.

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Keywords: Quality control, Control chart, Double Exponentially Weighted Moving Average (DEWMA), Average Run Length (ARL), Normal distribution



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Optimized Maintenance Planning Under Random Delayed Interventions: An RL-Based Approach

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Abstract

In this article, we introduce a framework based on reinforcement learning (RL) for optimizing Condition-Based Maintenance (CBM) with inherent random delays. The degradation of the system is represented using a Gamma Process, and decision-making is executed through a Q-learning algorithm. A significant challenge in these systems is managing intervention delays, where an action taken does not produce immediate results. Unlike earlier research that treated the delay as a fixed amount, this study considers it a random variable, making the optimization process more realistic. The simulation study investigates the optimization of railway track maintenance strategies, focusing on the identification of cost-effective intervention policies at each inspection while accounting for both track degradation levels and stochastic intervention delays. The simulation results demonstrate that the

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proposed RL-based methodology achieves a significant reduction in long-term maintenance costs compared to a fixed-threshold strategy. Specifically, cost reductions of approximately 19% and 45% were observed for scenarios with intervention delays shorter than and longer than the inspection interval, respectively.

Keywords: Condition-based maintenance optimization, Intervention delay, Reinforcement learning, Q-learning



Reliability of Complex k -Out-of- $n:d$ Systems

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Abstract

A system including n independent subsystems is considered that each subsystem contains d dependent components. It is assumed that system works if and only if at least k subsystems are functioning. The Gumbel copula function is used to model dependency among the components. The system reliability is evaluated and graphical results are presented. It was shown that ignoring dependency among components causes bias in reliability evaluation. Eventually, some conclusions are stated.

Keywords: Coherent system, Dependency, Gumbel copula, Reliability

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Analyzing Rayleigh-Poisson Model for Censored Data with Informative Random Removals

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Abstract

An important challenge when using progressive Type-II right censoring is determining a removal scheme. This can be fixed in advance or chosen randomly based on some discrete probability distributions. In this paper, we propose a new approach where the experiment itself influences the removal scheme, leading to the implementation of an informative censoring plan. For this purpose, we consider the Rayleigh Poisson distribution for lifetime data, along with two types of distributions for random removals: the truncated Poisson distribution and the discrete truncated Rayleigh distribution. Then, we obtain the maximum likelihood estimators and compare our new approaches with the patterns of removal obtained from the discrete binomial distributions via a Monte Carlo simulation study in terms of their biases, mean squared errors, and values of expected total time on the experiment.

Keywords:

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Optimal Age Replacement in k -Out-of- n : G Systems with Random Replacement Time

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Abstract

In this paper, an optimal age replacement policy has been studied for a k -out-of- n : G system, where the planned replacement time is a random variable with a distribution belonging to the proportional hazard rate family. It is supposed that the life-time of the system components has a Weibull distribution. The expected cost rate function is used as the optimization criterion. The results have been given analytically and numerically.

Keywords: Expected cost rate function, k -out-of- n : G system, Optimization, Proportional hazard rate, Weibull distribution

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