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Contents

Imprecise statistical methods for warranties based on accelerated life testing data

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Abstract

Recently, we have developed a novel statistical method for inference based on ALT data. The method quantifies uncertainty using imprecise probabilities, in particular it uses Nonparametric Predictive Inference (NPI) at the normal stress level, combining data from tests at that level with data from higher stress levels which has been transformed to the normal stress level. This has been achieved by assuming an ALT model, with the link between different stress levels modelled by a simple parametric link function, e.g. the power-law or the Arrhenius relation. We then derived an interval for the parameter of this link function, based on the application of classical hypothesis tests and the idea that, if data from a higher stress level are transformed to the normal stress level, then these transformed data and the original data from the normal stress level should not be distinguishable. We have already presented this approach with the assumption of Weibull failure time distributions at each stress level, and without such an assumption but using nonparametric hypothesis tests instead. In this talk, we will present an initial study of the use of the above mentioned methods to support decisions on warranties. A warranty is a contractual commitment between consumer and producer, in which the latter provides post-sale services in case of product failure. We will consider pricing basic warranty contracts based on the information from ALT data and the use of our novel imprecise probabilistic statistical method.

On Aspects of Statistical Inference for the Proportional Hazards Model Applied to Two Groups

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Abstract

The Proportional Hazards (PH) model is a semi-parametric model that has had an enormous impact on the development of survival analysis, particularly in medical research but also in reliability, risk, and many other fields. The PH model links survival of individuals with different covariates, with the key assumption that hazard rates of different individuals are proportional over time, with the proportionality constants depending on the covariates. A parametric model is assumed for this dependence. The parameters of this model can be estimated in several ways, the classical approach is by using the so-called 'Partial Likelihood', which links the ranks of the failures to the covariates. In this paper, we report on our ongoing research on aspects of statistical inference for the parameter estimation in the PH model, for the specific case with a single binary covariate, hence we have data on two groups, for example males and females in a medical context or units of two types in a reliability context. We investigate whether or not the partial likelihood is correct, and we compare its maximization with the idea of 'most likely data' for given parameter values. We also explore opportunities for imprecise statistical inference for the PH model, using estimation methods that result in sets of parameter values instead of single values. We briefly illustrate our findings with an example in a reliability context and we discuss related topics for future research.

References

[1] Cox, D. R. Regression Models And Life-Tables. Journal Of The Royal Statistical Society B.34, no. 2 (1972): 187-220.

Risk Prediction for Autonomous Systems

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Abstract

Over the last decade the use of automation (reproduction of actions without choice) in systems has increased dramatically and there is every expectation that this trend will continue into the future. At the same time there has been an increase in the number of autonomous machines that have the ability to make independent decisions and many have a self-learning, adaptive capability. The rapid development of the technologies has enabled autonomous cars to appear on city streets. The world's first self-driving bus appeared in China in 2015 and there are now others in Stavanger and Catalonia. UAVs (Unmanned Aerial Vehicles) have been employed in the military theatre for many years to avoid the risk to a human pilot, they are now increasingly utilised for civil applications. The ability of these machines to operate in hostile environments has also led to their use for sub-sea maintenance work. But are they safe?

How do you ensure that the risk posed by such machines is acceptable? How do you assess the risk that they will cause fatalities? This presentation will explore some of the challenges that have to be overcome and explain why the risk assessment methods which have been applied to ensure safe system operation since the 1970s are not suitable to make the same contribution for autonomous system safety.

Generalizing Banks' Smoothed Bootstrap Method for Right-Censored Data

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Abstract

In 1979, Efron introduced the bootstrap method, which has been widely used in applied statistics due to its capacity to quantify the variability of sample estimates [3]. This method uses simple random sampling with replacement from the original data set. In 1981, Efron generalized his method for data sets including right-censored observations [4]. Banks [1] introduced a smoothed version of Efron's bootstrap for real-valued data. It allows us to sample from the whole support of a distribution. We present a generalization of Banks' bootstrap for data sets including right-censored observations. Our method uses an assumption by Coolen and Yan [2]. We then compare our generalized Banks' bootstrap to Efron's bootstrap via simulations.

References

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[3] Efron, B. (1979). Bootstrap methods: another look at the Jackknife. The Annals of Statistics, 7(1), 1-26.

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Cryptographically Secure Multiparty Evaluation of System Reliability

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Abstract

The design of a system may be a trade secret, whilst at the same time component manufacturers are sometimes reluctant to release full test data (perhaps only providing mean time to failure data). In this situation it seems impractical to produce an accurate reliability assessment and satisfy all parties' privacy requirements. However, recent developments in cryptography, combined with the recently developed survival signature in reliability, allows almost total privacy to be maintained in a cryptographically strong manner in this setting. Thus, the system designer does not have to reveal their design and component manufacturers can retain test data in-house.

Frailty Modelling for Repairable Systems using Inverse Gaussian Model

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Abstract

The effect of ignoring heterogeneity in the analysis of multiple repairable systems' data have been clearly outlined in repairable systems literature. As a result, a wide class of models have been developed to this effect in reliability literature to analyse repairable systems with various degrees of repair efficiency such as imperfect repair using Heterogeneous Trend Renewal Process, and Non-Homogeneous Poisson Process assuming minimal repair. A common approach of accounting for the factors of heterogeneity is via including a frailty (random effect) term. Most of the existing studies have focused on accounting for frailties using the Gamma distribution mainly due to its mathematical tractability and popularity whereas there are other distributions with interesting properties that have not yet been explored in the literature. In this research, we investigated the effect of mis-specification of frailty distribution in the analysis of multiple repairable system's data within a proportional hazards framework. We assumed a Non-Homogeneous Poisson process model based on minimal repair effects. The Gamma and Inverse Gaussian extensions of the NHPP were assessed in a simulation study. The effects of frailty distribution mis-specification were examined by assessing the bias and efficiency of the estimates of the mean scale and shape parameters of the baseline hazard at different time periods. Plotted values and simulation results were provided assuming a power law intensity function then a real-world case study was conducted for illustrations.

Maintenance-free operation in railway corridors

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Abstract

Asset management is necessary for every service provider to be able to keep services running in a high standard. Every maintenance task is a complex, expensive and time-consuming operation which needs to be optimised. This is a problem in the railway industry, so a lot of research has been done in order to try to save money and decrease service disruptions using different kind of mathematical models. This work introduces Maintenance-Free Operation Periods (MFOPs) along with Petri Nets, which provide a framework to model the railway degradation and maintenance tasks bounding the maintenance periods of the system.

Quantifying system reliability

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Abstract

Together with the workshop participants, I will try to quantify the reliability of two important systems: my car and my colleague Louis. Many questions will arise. Do the tools exist to answer these?

The joint survival signature of coherent systems with shared components

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Abstract

The concept of joint bivariate signature, introduced by Navarro et al. [2], is a useful tool for studying the dependence between two systems with shared components. As with the univariate signature, introduced by Samaniego [3], its applications is limited to one type of components which restricts its practical use. In 2012, Coolen and Coolen-Maturi [1] proposed the concept of survival signature which is capable of dealing with multiple types of components. In this paper we present a survival signature for two systems with shared components, including one or multiple types components. Extending the results for more than two systems is also discussed.

References

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Validation of Wind Turbine Health History

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Abstract

Probabilistic record linkage is used to combine wind turbine maintenance records with a database of power outages, for the determination of the health history of wind turbines and for its validation. We explain how this health history is applied to fault troubleshooting and to prognostic modelling for condition based maintenance.

Offshore wind turbine reliability modelling and operational simulation

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Abstract

Wind energy is growing at a fast pace around the world. According to a report published by WindEurope, 55% of total power capacity installations in the EU came from wind in 2017. In this context, offshore wind plays a decisive role with countries such as the UK leading the development of large-scale offshore wind projects with a total expected generation capacity of approximately 16 GW in 2020. In the presented work, an integrated operation simulation framework for reliability modelling and performance evaluation of multi-megawatt direct drive wind turbines suitable for use in far offshore wind farms is proposed. The operation simulation employs several essential wind turbine data as inputs such as component reliability, i.e. failure rates and downtimes per failure, historical wind speed, turbine information, and repair cost per failure. The time-sequential Monte Carlo simulation is used to model the wind turbine and its components operations; then a wind power model and a levelised cost of energy estimation model are coupled with the Monte Carlo simulation to estimate the wind turbine operational and economic performance in its entire lifetime. From the analysis, the impacts of wind turbine components' reliability on its operation performance are estimated, and useful information related to the identification of critical components and economic assessment of future offshore wind turbines is provided.

Maintenance Planning under Failure Model Uncertainty

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Abstract

Maintenance planning is important in order to minimize the total costs and machine downtime. Preventive maintenance actions are planned to avoid from high costs of corrective maintenance. However, the failure time model for maintenance planning may involve uncertainties. Uncertainty in model parameters must be taken into account and updated with the recently obtained data. In this study, an optimal preventive maintenance planning model is built as a Markov Decision Process. The failure time distribution is assumed to be Weibull distribution with a known shape and an unknown scale parameter. Scale parameter of Weibull distribution is updated by using both censored and event data. The model proposes an optimal preventive maintenance time for the next maintenance cycle.

Evidence-Based Resilience Engineering of Dynamic Space Systems

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Abstract

The talk introduces the concept of design for resilience in the context of space systems engineering and proposes a method to account for imprecision and epistemic uncertainty. Resilience can be seen as the ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions. Mathematically speaking this translates into the attribute of a dynamical system (or time dependent system) to be simultaneously robust and reliable. However, the quantification of robustness and reliability in the early stage of the design of a space system is generally affected by uncertainty that is epistemic in nature. As the design evolves from Phase A down to phase E, the level of epistemic uncertainty is expected to decrease but still a level of variability can exist in the expected operational conditions and system requirements. The talk proposes a representation of a complex space system using the so called Evidence Network Models: a network of interconnected nodes where each node represents a subsystem with associated epistemic uncertainty on system performance and failure probability. Once the reliability and uncertainty on the performance of the spacecraft are quantified, a design optimisation process is applied to improve resilience and performance.

Imprecise Markov Reliability Analysis of Multi-State Systems

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Abstract

We present a method for reliability and availability assessment for systems with multi-state components. Evolution of component states are modelled as imprecise Markov chain processes. The set of transition rate matrices, governing the component state evolution, is inferred by robust Bayesian inference from a set of observations for each component type. These imprecise Markov chain models induce an imprecise model for the laws of system component states at any given time. Thus the reliability and availability assessments will be of the form of lower and upper probabilities. We show that these probability bounds can be calculated directly for coherent systems.

Time-dependant reliability analysis of wind turbines considering load-sharing using FTA and Markov chain

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Abstract

Due to the high failure rates and the high cost of operation and maintenance (O&M), this research on wind turbine reliability assessment was carried out to achieve the optimum redundancy allocation and reliability improvement of wind turbines, which is at the forefront of current research of wind turbines. In the literature, the redundancy components are taken as a parallel system, and the correlations among them are ignored, which leads to the excessive system's reliability and much higher costs. For this reason, this article explores the influences of load-sharing on system reliability. The whole system's reliability is quantitatively evaluated through the fault tree analysis (FTA) and the Markov chain method. Following this, to reduce the costs and improve the system's reliability, the optimisation of redundancy allocation problem considering the load-sharing is conducted, which maximise the system reliability and reduce the whole cost subjecting to the available system cost and space. The results produced by this methodology can show a cost-effectively, reliably and accurate reliability assessment of the whole wind turbine from a quantitative point of view, which helps significantly reduce the cost of wind turbines.

Generalizing Nonparametric Predictive Inference for Right-Censored Data to Two Future Observations

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Abstract

Nonparametric predictive inference (NPI) is a frequentist statistics method based on only few assumptions. It focuses explicitly on future observations and uses imprecise probabilities to quantify uncertainty. NPI has been developed for data including right-censored observations [1], but only considering a single future observation. For such data, the resulting inferences are lower and upper survival functions for one future observation. In practice, however, there may be strong reasons to be interested in multiple future observations, and it is important that in the NPI approach such multiple future observations are not conditionally independent given the data. First, in the development of NPI for multiple future observations with data including right-censored observations, we explore such inferences for two future observations. In this talk particularly, we present NPI lower and upper probabilities for the event that both future observations are greater than time t. Then we state the importance of this generalization for a range of applications in Statistics and Reliability. We briefly illustrate the use of our new inferences for system reliability by considering some small systems containing multiple components of the same type.

References

[1] Coolen F.P.A and Yan K.J. Nonparametric predictive inference with right-censored data. Journal of Statistical Planning and Inference, (1):25-54, 2004.

System reliability when components can be swapped upon failure

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Abstract

In some practical scenarios, component swapping can be used as alternative to the use of additional components to provide increased redundancy, the use of standby components, maintenance activities or increased component reliability, in order to enhance system reliability. In this research, we study the possibility to swap a component upon failure by another one in the system, which has not yet failed, in order to increase the functioning time of the system. The swap between components is logically restricted to components of the same type. The survival signature technique has been used to quantify the reliability of systems when there is a possibility to swap components upon failure. The effect of component swapping on a reliability importance measure for the specific components, and on the joint reliability importance of two components have been studied.

Swapping components, if possible, is likely to incur some costs, for example for the actual swap or to prepare components to be able to take over functionality of another component. The cost aspects have been studied under the assumption that a system would need to function for a given period of time, where failure to achieve this incurs a penalty cost. We compared different swap scenarios with the option not to enable swaps, focusing on minimum expected costs over the given period. Moreover, we study the cost effectiveness of component swapping from the perspective of renewal theory, so effectively over an unlimited time horizon. We assume that the system is entirely renewed upon failure, at a known cost, and we compare different swapping scenarios. We also considered the possibility to combine swapping with preventive replacement actions.

In addition, we extend the approach of component swapping and the cost effectiveness analysis of component swapping to phase mission system, considering two scenarios of swapping opportunities, namely, assuming that the possibilities of component swapping can occur at any time during the mission or only at switches of phases.

Optimal extended warranty pricing for a product under base warranty with selling price dependent on warranty period

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Abstract

A product?s quality is difficult to judge prior to its purchase. Therefore, price and warranty are used to aid customers. Warranty services, particularly, offer extra confidence when customers are making decisions to purchase a product. With intense rivalries in the commercial market, manufacturers are pressured to provide more flexible warranty options toward its customers. Thought, a base warranty is often offered alongside with the sales of an item for free. Extended warranty, on the other hand, is considered as an extra purchase. The extended warranties are offered to ensure extra insurance outside of the base warranty coverage. In our study, we propose a flexible extended warranty offering to the market. According to our research, many scholars have focused on modelling of base warranty and extended warranty separately. This paper aims to consider them both jointly. In our paper, the proposed mathematical model will determine optimal profit by considering mainly product lifecycle, product reliability, pricing and warranty period. The numerical examples will be given to demonstrate the features of the proposed maximizing profit model and to show all possible cases of the solution procedure.

Bayesian design and analysis of reliability demonstration tests using assurance

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Abstract

Manufacturers are required to demonstrate that products meet reliability targets. A typical way to achieve this is with reliability demonstration tests (RDTs), in which a number of items are put on test and the test is passed if a target level of reliability is achieved. There are various methods for determining the design RDTs, typically based on the size of a hypothesis test following the RDT or risk criteria. However, Bayesian approaches of this type often conflate the choice of sample size for the test and the analysis to be undertaken once the test has been conducted. Here we offer an alternative approach to RDT design and analysis based on the idea of assurance. This approach addresses each of the issues with Bayesian risk criteria and chooses the design to answer the question: what is the probability that the RDT will result in a successful outcome? We develop the assurance approach for the design and analysis of RDTs and propose appropriate prior distributions for the design and analysis of the test.

Pairwise comparison elicitation for probabilistic fault tree analysis, with application to spacecraft re-entry risk

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Abstract

We describe a method of elicitation for system risk that is described by a fault tree. Elicitation is conducted on the elementary event probabilities through a pairwise comparison and is then updated from the observation of any combination of elementary or intermediate events. The approach is illustrated with an application to the risk associated with the controlled re-entry of spacecraft from orbit that formed part of a project with the European Space Agency.

Probabilistic Reasoning in Structural Health Monitoring

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Abstract

In terms of an 'abstract' my intention would be to simply introduce data-based SHM and to discuss some of the machine learning/statistical tools used currently. I may also mention some of our current work on the interface between probabilistic risk analysis and SHM.