Conference Abstracts

(Presented According to Order in Conference Program)

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Russell House
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Columbia, South Carolina, USA

Conference Abstracts

Session Number	**02 (Plenary)**
Session Title	**State of Survival Analysis**
Time and Day	**9:00–9:45, Thursday**
Place	**Russell House Ballroom**
Session Organizer	Organizers
Session Chair	**William J. Padgett**, University of South Carolina

A Quick Tour of Modern Survival Analysis

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Abstract: We will give a brief review on survival analysis including one-sample, two-sample, regression, multivariate survival, model checking, prediction problems. We will then discuss some newly developed techniques for analyzing survival data and some potentially interesting problems for future research.

Key Words: None provided.

Session Number	**03 (Invited)**
Session Title	**Dynamic Models of Failure Time Data**
Time and Day	**10:00–11:30, Thursday**
Place	**Room 203, Russell House**
Session Organizer	**Odd Aalen**, University of Oslo, Norway
Session Chair	**Odd Aalen**, University of Oslo, Norway

Modelling, estimation and inference with time-varying effects in survival analysis

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Abstract: Models and methodology that deal with time-varying effects is needed in many practical settings. In medical studies where treatment effects are of interest it is often expected that these

treatment effects will be time-varying, resulting, e.g., in an initially strong effect that wears off during the duration of the study. I present some approaches for dealing with time-varying effects in the context of proportional hazards models or additive hazards models. An important hypothesis when time-varying effects are studied is to decide if a covariate effect is significantly time-varying. I show a theoretically justified approach for answering such questions. One important aspect of the suggested methodology is that the testing of time-varying effects can be carried out in terms of successive tests. The theoretical foundation for the work is a study of the semi-parametric proportional and additive hazard models.

Key Words: Additive hazard models, inference, proportional hazards, semi-parametric models, time-varying effects, test for proportionality.

Hazard as a stochastic process: A Levy process model of individual frailty

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Abstract: Classical frailty models are based on a frailty term that is already present at time 0 and remains unchanged throughout the entire life span of the individual. A consequence of this is that the hazard of an individual is, at any time, perfectly correlated with its hazard at time 0. A more flexible approach would be to let the hazard develop over time as a non-negative stochastic process. Several features of this process, like the rate of increase, the speed of the development, the variability etc. could be controlled by parameters and covariates of the individual. From a technical point of view it would be an advantage to obtain explict formulas relating individual hazards with the observable population hazard, thus facilitating estimation. We present a model for the individual hazard rate based on non-negative Lévy processes. The model includes many standard frailty distributions as special cases, like gamma distributions, power variance function (PVF) distributions and compound Poisson distributions. Examples of explicit parametric hazard functions occurring in this framework will be shown.

Key Words: Frailty, Lévy process, compound Poisson distribution, PVF distribution

On a dynamic approach to the analysis of multivariate failure time data

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Abstract: Multivariate survival data may be analysed from several points of view. The simplest one is the marginal approach which largely ignores the dependencies. A more detailed modelling of the multivariate aspect may be found in the frailty approach, where one assumes that some unobserved latent variable creates the dependence within families or groups (or whatever hierarchical structure is considered). In the dynamic approach, which shall be studied here, no unobserved variables are postulated. Instead a purely empirical approach is taken, where the likelihood of future events is studied in terms of past observations. If there is dependence between individual measurements this will show up in regression analysis where information on the past is included among the independent variables. Using a nonparametric approach for the analysis avoids making unneccesary assumptions about how the dependence changes over time. We will apply counting process theory, whereby covariates that are functions of past observations can be treated similarly to ordinary covariates. It should also be noted that, for each individual, a real counting processes with several events is observed, as opposed to traditional applications of counting processes in survival analysis where each individual process yields at most one event.

Key Words: Counting processes, additive hazard models, dynamic covariates, multivariate survival data

Session Number	**04 (Invited)**
Session Title	**Bayesian Methods in Survival Analysis and Reliability**
Time and Day	**10:00–11:30, Thursday**
Place	**Room 205, Russell House**
Session Organizer	**Lynn Kuo**, University of Connecticut
Session Chair	**Lynn Kuo**, University of Connecticut

Bayesian Analysis of Competing Risks

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Abstract: Competing risks analysis considers the situation when two or more risks are acting simultaneously on a subject or a system. I will review two different approaches to analysis of competing risks and describe flexible Bayesian models for analysis of competing risks and masked competing risks. Application of these Bayesian models will be illustrated in several examples and model selection issues will be examined.

Key Words: Markov chain sampling, model selection

Bayesian Analysis of Nonproportional Hazards Models for Survival Data

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Abstract: In the analysis of censored survival data the Cox proportional hazards model (1972) is most popular among the practitioners. However, in many real-life situations the proportionality of the hazard ratios does not seem to be an appropriate assumption. To overcome such a problem, a class of nonproportional hazards models is proposed. The class is general enough to include several commonly used models, such as proportional hazards model, proportional odds model, and accelerated life time model, and it also has several attractive theoretical and computational properties. Bayesian analysis based on a semiparametric version of the model has been carried out. The propriety of the posterior has also been established under some mild conditions. Finally, a detailed analysis for data from prostate cancer and melanoma studies is presented.

Key Words: Cox Model; Gibbs sampling; Piecewise exponential model; Proportional odds model; Posterior distribution; Semiparametric model.

Network Reliability Assessment in a Random Environment

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Abstract: In this paper we consider networks that consist of components operating under a randomly changing common environment. Our work is motivated by power system networks that are subject to fluctuating weather conditions over time that effect the performance of the network. We develop a general setup for any network that is subject to such environment and present results for network reliability assessment under two repair scenarios. We also present Bayesian analysis of network failure data and illustrate how reliability predictions can be obtained for the network.

Key Words: Network reliability, power systems, random environment, Bayesian analysis, Markov chain.

Session Number	**5 (Invited)**
Session Title	**Planning Accelerated Tests**
Time and Day	**10:00–11:30, Thursday**
Place	**Room 303, Russell House**
Session Organizer	**William Meeker**, Iowa State University
Session Chair	**William Meeker**, Iowa State University

Bayesian Optimum Planning for Accelerated Life Tests

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Abstract: We present a Bayesian method for optimum accelerated life test planning with one accelerating variable, when the acceleration model is linear in the parameters, based on censored data from a log-location-scale distribution. We develop a Bayes criterion based on the estimation precision of a distribution quantile at a specified use condition and use this criterion to find the optimum test plans. A large-sample normal approximation provides an easy-to-interpret yet useful simplification to this planning problem. We present a numerical example using the Weibull distribution with Type I censoring to illustrate the method and to examine the effects of the prior distribution, censoring, and sample size. The general equivalence theorem is used to verify that the numerically optimized test plans are globally optimum. The resulting optimum plans are also evaluated by using simulation.

Key Words: c-optimality; Censored data; Equivalence theorem; Log-location-scale family; Optimal design; Preposterior; Reliability.

Accelerated Life Test Plans Robust to Misspecification of Stress-Life Relationship under the Lognormal or Weibull Distributions

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Abstract: This presentation discusses the asymptotic distribution of maximum likelihood estimators of model parameters in accelerated life tests (ALTs) when form of the stress-life relationship is misspecified. Results are presented for the lognormal and Weibull distributions, two most commonly used distributions in ALT. The results are used to obtain optimal test plans based on asymptotic bias and asymptotic mean-squared error. These approaches provide some control over estimation bias and variance when the

relationship is misspecified.

Key Words: Asymptotic bias; Asymptotic mean square error; Maximum likelihood estimation

Test Planning for Accelerated Destructive Degradation Tests

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Abstract: Accelerated Destructive Degradation Tests (ADDT) are used to assess long term strength of materials. Samples of units are tested at increased levels of stress. Units are removed from the experiment over time to be destructively evaluated. Then a nonlinear regression model for strength is fit to the data and used to estimate a time to first-crossing (failure) distribution.

This talk describes methods for ADDT planning. We show how to use large sample approximations to obtain optimum test plans to provide insight for obtaining more useful compromise plans. Simulation to allows fine-tuning of the plans and visualization of how the design affects statistical uncertainty. The methods are illustrated with an accelerated destructive degradation test for an adhesive bond.

Key Words: None provided.

Session Number	**06 (Invited)**
Session Title	**Frailty Models in Survival Analysis**
Time and Day	**10:00–11:30, Thursday**
Place	**Room 305, Russell House**
Session Organizer	**David Oakes**, University of Rochester
Session Chair	**David Oakes**, University of Rochester

Non-parametric estimation for baseline hazard function and covariate effects with time-dependent covariates

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Abstract: Often in many biomedical and epidemiologic studies, estimating hazard function is of interest. The Breslow's estimator (1974) is commonly used for estimating the integrated baseline hazard but this

estimator requires the functional form of covariate effects to be correctly specified. It is generally difficult to identify the true functional form of covariate effects from data, particularly in the presence of time-dependent covariates. In this paper, a tree-type model is proposed which enables simultaneously estimating both baseline hazard function and the effects of time-dependent covariates. The proposed method approximates the baseline hazard and covariate effects with step-functions. The jump points in time and in covariate space are searched via an algorithm based on the improvement of a full log-likelihood function. Since the determination of these jump points is totally data driven, the proposed method in principle takes a non-parametric approach. In contrast to most other estimating methods, the proposed method estimates the hazard function rather than integrated hazard. The method is applied to a study evaluating the effect of anti-depression treatment in preventing the development of clinical depression.

Key Words: Baseline hazard; Time-dependent covariate; Survival data; Tree-structured method.

Robust Inference for Proportional Hazards Univariate Frailty Regression Models

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Abstract: We consider a class of semiparametric regression models which are one parameter extensions of the Cox (1972) model for right-censored univariate failure times. These models assume that the hazard given the covariates and a random frailty unique to each individual have the proportional hazards form multiplied by the frailty. The frailty is assumed to have mean one within a known one-parameter family of distributions. Inference is based on a nonparametric likelihood. The behavior of the likelihood maximizer is studied under general conditions where the fitted model may be misspecified. The estimator is shown to be uniformly consistent for the pseudo-value maximizing the asymptotic limit of the likelihood. Appropriately standardized, the estimator converges weakly to a Gaussian process. When the model is correctly specified, the procedure is semiparametric efficient, achieving the semiparametric information bound. It is also proved that the bootstrap gives valid inferences for all parameters, including the cumulative hazard, even under misspecification. We demonstrate analytically the importance of the robust inference in several examples. In a randomized clinical trial, a valid test of the treatment effect is possible when other prognostic factors and the frailty distribution are both misspecified. Under certain conditions on the covariates, the ratios of the regression parameters are still identifiable. The practical utility of the procedure is illustrated on a non-Hodgkin's lymphoma dataset.

Key Words: None provided.

Combining Stratified and Unstratified Log-Rank Tests for Matched Pairs Survival Data

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Abstract: We consider the problem of testing for a treatment effect in matched pairs survival data, with one member of each pair receiving active treatment, the other member receiving the control treatment. The stratified log-rank test, which is commonly used in this situation, reduces to a simple counting of the "preferences" (treatment, control, or indeterminate) established by each pair. The unstratified log-rank test is optimal under the proportional hazards model when the two members of a pair are independent, but loses this optimality property under models allowing dependence. Moreover the variance estimate for the log-rank statistic requires adjustment due to the within-pair dependence (Jung, 1999). While

the stratified log-rank test and the unstratified log-rank tests are optimal (under proportional hazards models) in the cases of extreme dependence and independence respectively, in intermediate cases, a linear combination of the two statistics may be locally more powerful than either individual statistic. Under Hougaard's positive stable frailty model, which allows proportional hazards both marginally and conditionally, we derive the optimal linear combination and show how this may be estimated from the data. We show that for moderate dependence this combined test statistic is noticeably more powerful than either individual statistic. We examine the robustness of the procedure to the choice of frailty distribution and briefly consider extensions from pairs to blocks of arbitrary size.

Key Words: None provided.

Session Number	**07 (Invited)**
Session Title	**New Ideas in Reliability and Survival Analysis**
Time and Day	**1:30–3:00, Thursday**
Place	**Room 203, Russell House**
Session Organizer	**Terje Aven**, Stavanger University, Norway **Uwe Jensen**, University of Ulm, Germany
Session Chair	**Uwe Jensen**, University of Ulm, Germany

Covariate Order Tests for Covariate Effect

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Abstract: A new approach for constructing tests for association between a random right censored life time variable and covariates is presented. The basic idea is for each covariate to first arrange the observations in increasing order of the covariate and then base the test on a certain point process defined by the observation times. Tests constructed by this approach are robust against outliers in the covariate values or misspecification of the covariate scale since they only use the ordering of the covariate. Of particular interest is a test based on the Anderson-Darling statistic. This test has good power properties both against monotonic and nonmonotonic dependencies between the covariate and the life time variable.

Key Words: Censored data, tests for association, rank based tests, nonmonotonic covariate effects, point processes, permutation tests.

How to use expert judgement in regularity analyses to obtain good predictions

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Abstract: The purpose of regularity analyses is to assess future deliveries of production and transportation systems, such as offshore oil and gas installations. When conducting such analyses, models are developed reflecting the performance of various equipment, for example compressors and pumps. The

performance covers both uptimes and downtimes. To assess the equipment performance there is a need for relevant knowledge, including observed data and expert judgement.

In this paper we address the need for expert judgement in such settings when having different amount of hard data available. More specifically we discuss how expert judgement can be used to establish procedures for determining suitable uptime and downtime distributions. Recommendations are provided for how to balance hard data and expert judgement. Our starting point is a Bayesian perspective, but adjusted procedures are sought to make the analyses operational in the practical setting and improve predictions.

Key Words: Regularity, availability, expert judgment, Bayesian analysis

Aalen's Additive Risk Model Applied to Software Reliability

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Abstract: Most models used in Software Reliability are parametric and do not accommodate covariates. To address this problem we consider the benefit of applying the well-known nonparametric model suggested by Aalen to this area. This model is based on a counting process with intensity $\lambda(t) = Y(t)\alpha(t)$, where $Y(t)$ is a matrix of covariates and $\alpha(t)$ is an unknown deterministic vector-valued process. A dataset from open-source software is used to illustrate the idea.

Key Words: Software Reliability, Multivariate Counting Processes, Nonparametric Inference, Martingale Methods

Session Number	**08 (Invited)**
Session Title	**Modelling with Frailties**
Time and Day	**1:30–3:00, Thursday**
Place	**Room 205, Russell House**
Session Organizer	**Nader Ebrahimi**, Nothern Illinois University
Session Chair	**Nader Ebrahimi**, Northern Illinois University

The role of frailty models in genetics

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Abstract: Usually the genetic dependence between family members is evaluated statistically by means of normal distribution random effects models. Such models are, however, not sensible, when the response studied is a time variable, for example, a lifetime or a time until development of a specific disease. There are two major reasons for this: censored data in the multivariate normal require numerical integration, and the normal distribution does not fit well to lifetimes (specifically its does not allow the same flexibility as the non- or semiparametric approaches usually desired in survival analysis). Furthermore, truncation is difficult to handle in a normal model. Frailty models are random effects model designed to handle censored survival data, based on modeling dependence by a common unobserved factor on the hazard function.

I will discuss to which extent, they can serve the same purpose as standard random effects for normally distributed responses. This involves basic questions like what is the genotype and what is the

phenotype, and more complicated questions like how to split the variance into variance components. Both shared frailty models and correlated frailty models are considered. The talk will be illustrated with results on the survival of like-sex Danish twins born 1870-1930, for which both were alive by age 6. They were followed up to 1995. Frailty models are well suited to evaluate dependence in lifetimes, but a precise evaluation of genetic variance components is not possible due to the lack of a sensible scale, on which the various contributions act additively.

Key Words: None provided.

Fitting the Frailty Distribution Using Empirical Bayes

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Abstract: For multivariate survival data, modeling via the common frailty distribution typically requires choice of a parametric form for the distribution of the random frailty terms. This distribution is often chosen for computational or interpretive ease, but can in selective cases affect estimation of regression parameters. We present an alternative methodology using the approach of Walker and Mallick (1997), which eliminates the need to specify a specific form of the frailty distribution. We discuss the computational and practical implications of this model. In addition, we demonstrate how this approach may be used to assess the fit of a parametric frailty distribution.

Key Words: None provided.

Inference in Frailty Measurement Error Models for Clustered Survival Data

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Abstract: We propose a new class of models, frailty measurement error models (FMeMs), for clustered survival data when covariates are measured with error. We explore FMeMs from three directions: bias analysis, structural modeling and functional modeling. We study the asymptotic bias when measurement error is ignored and when the underlying distribution of the unobserved error-prone covariates is misspecified. Structural modeling and functional modeling is developed to make statistical inferenence in FMeMs. Under structural modeling, we assume a distribution for the unobserved error-prone covariates and calculate nonparametric maximum likelihood estimates (NMLEs) using an EM algorithm. Under functional modeling, we make no distributional assumption on the unobserved error-prone covariates and use the SIMEX method for parameter estimation. The NMLEs and SIMEX estimates are compared in terms of efficiency and robustness. The proposed methods are applied to the west Kenya parasitemia data and their performance is evaluated through simulations. This is a joint work with Yi Li at Harvard School of Public Health.

Key Words: None provided.

Session Number	**09 (Invited)**
Session Title	**Semiparametric and Longitudinal Models**
Time and Day	**1:30–3:00, Thursday**
Place	**Room 303, Russell House**
Session Organizer	Organizers
Session Chair	**Andrew Lawson**, University of South Carolina

Semiparametric estimation in an accelerated failure model with time-dependent covariates

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Abstract: Semiparametric estimation is studied in a simple model for the load-sharing and simultaneous-failure mechanisms of multiple-component systems. The model, which specifies componentwise clock speeds under various loading states as parameters but leaves the componentwise hazards completely general, has precursors in work of Cinlar (1977, 1984) and was first proposed in a preprint of the author (Slud 1996). In this paper, consistency and semiparametric efficiency of estimators within the model are proved. The estimation methodology is illustrated on simulated data.

Key Words: Accelerated failure model, dynamic reliability, modified profile likelihood, time-dependent covariates, semiparametric estimation.

A new model for joint analysis of an event process and associated longitudinal outcome

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Abstract: It is increasingly common for biomedical studies to monitor multiple outcomes of mixed data types over a specified study period. We consider modeling the joint outcomes of a recurrent event process and an associated longitudinal biomarker. A situation in which such outcomes might be monitored is one where the event that recurs is heart attack and the associated longitudinal biomarker is cholesterol level, blood pressure, or a measure of left ventricular hypertrophy. For data resulting from studies of this type, the number of events observed over the study period is informative about the event process, as is the end-of-study censoring time. Building on the work of Lin et al. (2002, J. Amer. Statist. Assoc. 97:55-65) and Peña et al (2001, J. Amer. Statist. Assoc. 96:1299-1315), we propose a latent class model in which the event process and longitudinal outcome are conditionally independent given the latent class. Thus, the latent class captures the dependence between the event process and longitudinal biomarker. Additionally, by incorporating an "aging" function in the event process model, we accommodate the effects of interventions performed after each event occurrence or the weakening effect on the subject of accumulating event occurrences. In this talk, we discuss characteristics of the joint model and display its behavior under varying simulation scenarios.

Key Words: longitudinal model, event process, repeated events, survival model, latent class

Estimating Load-Sharing Properties in a Dynamic Reliability System

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Abstract: An estimator for the load share parameters in an equal load-share model is derived based on observing k-component parallel systems of identical components. In a load share model, after the first of k components fails, failure rates for the remaining components change due to a transfer of a system load. On the basis of observations on n independent and identical systems, a nonparametric estimator of the component baseline cumulative hazard function is presented, and its asymptotic limit process is established to be a Gaussian process. Potential applications can be found in diverse areas, including materials testing, software reliability and power plant safety assessment.

Key Words: Dependent systems; Nelson-Aalen estimator; proportional hazards model.

Session Number	**10 (Invited)**
Session Title	**The Relationship between Reliability and Quality**
Time and Day	**1:30–3:00, Thursday**
Place	**Room 305, Russell House**
Session Organizer	**Sallie Keller-McNulty** and **Donna Baker**, Los Alamos National Laboratory
Session Chair	**Jerome Morzinski**, Los Alamos National Laboratory

Process Quality and Reliability !!!!WITHDRAWN!!!!

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Abstract: Product reliability is related directly or indirectly to the processes used during manufacturing. Customers expect product reliability for form, fit, and function over product lifetime; they also anticipate those products to exceed usual lifetime expectations. Optimum product reliability and process quality tie to organizational design, development, and production capabilities.

This presentation will describe three areas that characterize process quality and reliability: customers, organizational competencies, and optimum processes. Tools such as comparative-evaluation quantify customer requirements while conjoint analyses are used to integrate requirements, competencies, and processes. Other discussion will address the connection of optimum process (unnecessary delay), process wear-out, and product reliability.

Key Words: None provided.

Six Sigma and Reliability - Is There any Connection?

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Abstract: In the past ten years Six Sigma has become almost a passion in many of the leading companies in the United States. Literally hundreds of thousands of people have received what for many is viewed as a crash course in statistics. Far fewer have received training in Design for Six Sigma (DFSS), and even fewer have received any training in advanced statistical methods in becoming Master Black Belts.

Does training in reliability fit in any of this training? If so, where? What problems are these Green Belts, Black Belts and Master Black Belts actually trying to solve? How far can we go in providing them with the needed tools of reliability analysis, prediction and modeling? How will they use these tools?

Key Words: Six Sigma, Reliability Prediction, Reliability Estimation, Black Belt, Master Black Belt, Design, Problem Solving.

Reliability: The Other Dimension of Quality

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Abstract: Quality technology has been recognized as important to manufacturing industry. Today's customers, however have higher expectations for both quality and reliability. It has been said that "reliability is quality over time." Although good quality is necessary for high reliability, it is not sufficient.

In this talk I will describe some of the key ideas behind achieving quality over time with focus on current trends and implications for the future. I will contrast traditional reliability demonstration with today's need for reliability assurance. I will describe the role of emerging engineering and statistical technologies and how they can be used to better achieve high reliability within stringent cost constraints. I will illustrate some of the ideas by describing a current project at the National Institute of Standards and Technology on the problem of service life prediction and service life improvement of organic paints and coatings.

Key Words: None provided.

Session Number	**11 (Plenary)**
Session Title	**State of Degradation and Failure Prediction Models**
Time and Day	**3:00–3:45, Thursday**
Place	**Russell House Ballroom**
Session Organizer	Organizers
Session Chair	**Jeffrey A. Robinson**, General Motors Research & Development Center, MI

Degradation Models and Failure Prediction

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Abstract: Failures in units or systems can often be related to, and in some cases are defined by, measures of physical degradation or deterioration. If degradation processes can be observed and modeled, they can be used to predict or prevent failure. This talk will review models for degradation and failure; the predictability of failure and the predictive capabilities of degradation processes will be considered. Implications for failure prevention, reliability improvement, and maintenance planning will be discussed.

Key Words: degradation; failure time; hazard process; prediction; reliability; stochastic process

Session Number	**12 (Contributed)**
Session Title	**Goodness-of-Fit Procedures**
Time and Day	**4:00–5:30, Thursday**
Place	**Room 203, Russell House**
Session Organizer	Contributed Talks
Session Chair	**Jason Owen**, University of Richmond

Repairable Systems and Hazard-Based Goodness-of-Fit Tests

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Abstract: In engineering and operations research where studies involving repairable systems are prevalent, an important issue that often arises is the development of optimal maintenance policies. In order to devise any maintenance scheme, an essential aspect that has to be addressed is the underlying distribution of failure times. In this talk, we will explore a class of goodness-of-fit tests for the distribution of the initial failure times of a repairable system. In particular, we will focus on the family of hazard-based smooth goodness-of-fit tests that was introduced by Peña (1998ab) and extended to the recurrent event setting by Agustin and Peña (2000, 2001). An important aspect of this class of tests that will be addressed in this talk is the determination of an appropriate smoothing parameter. The results of a Monte Carlo simulation study as well as an application to a real data set will be presented to illustrate the potential of these tests as powerful directional and omnibus tests.

Key Words: Counting process; Directional Test; Omnibus Test; Score test

Goodness of Fit Test Based on Order Statistics

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Abstract: Let $X_{(1)} < X_{(2)} < \ldots < X_{(n)}$ and $Y_{(1)} < Y_{(2)} < \ldots < Y_{(n)}$ be order statistics of two independent samples from continuous distribution. Denote $S_n = \sum_{r=1}^{n} I\{Y_{(r)} \in (X_{(r-1)}, X_{(r+1)})\}, (X_{(0)} = -\infty, X_{(n+1)} = \infty)$, where $I\{A\}$ is indicator of the set A. Note that S_n is number of order statistics of second sample, hitting to the interval formed by previous numbered and next numbered order statistics of first sample. In this study, we present a new goodness of fit test procedure based on distribution of S_n. Furthermore, we investigate the properties and limit behavior of S_n.

Key Words: Order statistics, spacings, goodness of fit tests.

Tests for Trend under Extended Null Hypotheses

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Abstract: Generally we say there are no trend in the pattern of recurrent events if the sequence of interarrival times is a stationary sequence. Tests for trend in recurrent events are usually based on a stochastic model for the occurence of events, the most popular being the Poisson process. Within this model class the null hypothesis of no trend equals a homogenous Poisson process. But in many situations the Poisson assumption may be a far too restrictive model for a system without trend.

Poisson based trend tests are not generally robust against other non-trend alternatives, like renewal processes or processes incorporating serial dependence. However in this paper we propose several ways by which the Poisson based tests can be generalized to a more general null hypothesis. In particular we explore three strategies: transformation of interarraival times, theoretical modification of test statistics and the use of resampling methods.

Key Words: Recurrent events, trend tests, Poisson process, renewal process, stationary sequence, robust tests, resampling.

Goodness of Fit of a Joint Model for Event Time and Nonignorable Missing Longitudinal Quality of Life Data - A Study

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Abstract: In many survival studies one is interested in two variables of interest, the duration time to some terminal event and a time dependent covariate. In these studies, subject often drop out of the study before the occurrence of the event of interest and the problem of interest is modeling the

relationship between the time to dropout and the internal covariate. Jean-Francois Dupuy and Mounir Mesbah (2001) proposed a model that described this relationship when the value of the covariate at the dropout time is unobserved. This model combined a first-order Markov model for the longitudinally measured covariate with a time-dependent Cox model for the dropout process.

Here, we propose a test statistic to test the above-mentioned model. The test statistic is based on the method of weights as proposed by Lin (1991). The asymptotic properties and the distribution of the test statistic is studied, with some results presented as conjectures.

Key Words: None provided.

Session Number	**13 (Contributed)**
Session Title	**Inference Issues in Survival and Reliability Methods**
Time and Day	**4:00–5:30, Thursday**
Place	**Room 205, Russell House**
Session Organizer	Contributed Talks
Session Chair	**Arzu Onar**, University of Miami

Information Sufficiency under Presence of Length-Biased Sampling Plan

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Abstract: In the presence of length-biasedness a lifetime measure of interest may be estimated in two ways: (i) modeling the data correctly using a length-biased distribution and using the resulting estimators in the original model as an adjustment, or (ii) modeling the data correctly using a length-biased distribution, and obtaining the original lifetime of interest via a transformation, if exists. We examine the sufficency in information context under transformations.

Key Words: None provided.

Statistical Inference for Competing Risks Model via Empirical Likelihood

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Abstract: Competing risks model received more attention recently. This model arises from situations in reliabilty life testing. Numerous nonparametric tests and their applications have been studied. Based on the empirical likelihood we derive a simultaneous confidence band for the ratio of two cause-specific hazard functions in the competing risk model without censoring, i.e. random censorship model. We develop a test for the equality of the two cause-specific hazard rates. Following the same line we derive a simultaneous confidence band for the ratio of cumulative cause-specific hazards functions and develop a goodness-of-fit test for the proportional hazards assumptions. A Monte Carlo method for the construction of confidence band is obtained. Moreover, our approach can be extended to adjust for covariate effects. The approach is illustrated with a real data example.

Key Words: cause-specific, competing risk, covariate effect, goodness-of-fit test, proportional hazards assumption, right censoring

On the Reliance of the Logrank Test for Assessing Equality of Survival Curves

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Abstract: Hypothesis tests of the equality of survival curves is typically accomplished using one of the available methods designed for this purpose but, without doubt, the logrank test is the one most commonly used (almost 90% of the time in The New England Journal of Medicine during a three year period (1999-2001)). This observation is surprising and probably reflects a general lack of appreciation for the fact that different alternative hypotheses may be appropriate in different clinical settings and that some investigators may not be aware that the proportional hazards assumption should be checked. There is no general test that fits all comparisons, therefore the testing should be performed according to the alternative hypothesis of interest and the relationship of the hazards. Consequently, I suggested guidelines that may be helpful in determining the alternative hypothesis when testing the equality of survival distributions.

Key Words: hazard function, nonparametric tests, Lehmann and Non-Lehmann alternatives, guidelines

Empirical Likelihood for Cox Regression Model

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Abstract: In this paper we investigate the empirical likelihood method for Cox regression model when the failure times are subject to random censoring. An empirical likelihood ratio for the vector of regression coefficients is defined and it is shown that its limiting distribution is a chi-square distributions with p degrees of freedom. Some simulation studies are presented to compare the empirical likelihood method with the normal approximation method.

Key Words: Empirical likelihood; Cox model; Normal approximation

Session Number	**14 (Invited)**
Session Title	**Weibull and Related Distributions**
Time and Day	**4:00-5:30, Thursday**
Place	**Room 303, Russell House**
Session Organizer	**Min Xie**, National University of Singapore, Singapore
Session Chair	**Chin Diew Lai**, Massey University, New Zealand

On discrete Weibull distributions

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Abstract: In some situations, system lifetime is expressed by a discrete random variable. This is the case, for example, when an equipment operates in cycles or on demands, and the number of cycles or demands prior to failure is observed. This is also the case when reliability data are grouped or truncated. Then, the usual reliability concepts for continuous lifetimes have to be defined again to be adapted to discrete time. In particular, discrete analogous of usual distributions for continuous lifetimes, such as the exponential or Weibull distributions, have to be defined. It is well known that the geometric distribution is the discrete counterpart of the exponential distribution, but it is not so easy for Weibull. In the literature, several models have been defined as discrete Weibull distributions : Nakagawa-Osaki (1975), Stein-Dattero (1984), Padgett-Spurrier (1985). More recent discrete ageing models do not refer to Weibull : Gupta-Gupta-Tripathi (1997), Klar (1999), Roy-Gupta (1999). It appears that many of them can be understood as distributions based on a Plya urn scheme. This paper proposes a survey on probability models for ageing in discrete time, in view of determining what should be "the" discrete Weibull distribution. Several models are analyzed and compared. The importance of inverse Plya distributions is stressed. Some considerations on the statistical analysis of these models are given: parameter estimation and goodness-of-fit testing.

Key Words: Discrete Reliability, Ageing, Weibull Distribution, Plya Urn

Confidence intervals and joint confidence regions for the parameters of the Weibull distribution

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Abstract: This paper discusses confidence intervals and joint confidence regions for the parameters of the Weibull distribution. While there are some approaches in literature for obtaining confidence intervals for the parameters of the Weibull distribution based on BLUEs, BLIEs or MLEs of the parameters, this paper focuses on recent advances of this areas.

Key Words: Weibull distribution, confidence interval, joint confidence region

Properties of some extended Weibull models with bathtub shaped failure rate function

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Abstract: Recently, several models with bathtub shaped failure rate function are proposed. In this talk, we review the models and discuss some of their properties.

Key Words: None provided.

Session Number	**15 (Invited)**
Session Title	**Ideas in Survival Analysis and Reliability**
Time and Day	**4:00–5:30, Thursday**
Place	**Room 305, Russell House**
Session Organizer	**Luis Escobar**, Louisiana State University
Session Chair	**Luis Escobar**, Louisiana State University

Resampling methods in relative risk models

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Abstract: Suppose failure times arise from a Cox model with a relative risk function that is twice differentiable. We consider resampling procedures to estimate the regression parameters. The three methods proposed are based upon different features of the score function arising from the partial likelihood analysis. The Estimating Function or EF method makes use of an uncorrelated decomposition of the score function, and is a direct generalization of the EF bootstrap of Hu and Kalbfleisch (2000). The other two resampling methods are introduced in the context of a partial likelihood filtration which is convenient for asymptotic results. The risk set or RS method resamples individuals from the observed risk sets in the study. The Weighted Permutation or WP method is a generalization of a permutation approach and constructs a resampled history for individuals under study. Each of these methods is invariant under reparameterization and yields accurate confidence intervals for diverse relative risk functions. The EF and RS methods easily handle time-dependent covariates and independent right censoring, and often outperform asymptotic results for moderate sample sizes. When applicable, the WP method demonstrates improvement in accuracy over other methods, but WP can only handle defined covariates.

Key Words: None provided.

First Hitting Time Models for Survival Data

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Abstract: Engineering and medical applications offer many examples of hitting time failures in which items deteriorate and fail when their deterioration first reaches a failure threshold. The items may be engineering components, human subjects, business firms or social organizations. These first hitting time models assume deterioration follows a stochastic process (a *degradation process*) that is usually latent or unobservable. The degradation process can be tracked by one or more observable stochastic processes (*marker processes*) that covary with degradation. The models are estimated using a combination of marker and censored survival data. The estimation also takes account of effects of fixed covariates on process parameters and the failure threshold. This talk discusses extensions to this model that expand its scope for practical application. The extensions include (1) longitudinal data, (2) markers as directing

processes for degradation, (3) modeling monotonic degradation and (4) drawing nonparametric inferences from fitted parametric models. These extensions should help first hitting time models find greater acceptance by practitioners and provide an alternative to proportional hazard and other conventional models.

Key Words: Censoring, degradation, failure, first passage time, marker, reliability, stochastic processes, survival data

A Class of Degradation Based Models for Reliability Analysis

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Abstract: Recent advances in sensing and measurement technologies are making it feasible to collect extensive amounts of data on degradation and other performance measures associated with components, systems, and manufacturing processes. Degradation data are a very rich source of reliability information and offer many advantages over the analysis of time-to-failure data. In this talk, we propose a class of models for degradation data and describe their application for reliability inference. Here, time-to-failure is defined as the level crossing (first-passage time) of a specified degradation threshold. The models we consider are based on non-homogeneous Gaussian processes obtained through appropriate transformations of the Wiener process. These models can accommodate a variety of degradation rates and shapes. They also lead naturally to a wide class of time-to-failure distributions. The inverse Gaussian distribution plays a central role, similar to the exponential distribution with hazard rates. These degradation models lead to analytical forms for the time-to-failure distributions, so we can combine degradation and time-to-failure data for inference and trade-off the relative information from different data sources for various purposes such as accelerated tests and reliability improvement studies. This is joint work with Xiao Wang.

Key Words: None provided.

Session Number	**16 (Contributed)**
Session Title	**Algorithms and Computer-Intensive Methods**
Time and Day	**8:00–9:30, Friday**
Place	**Room 203, Russell House**
Session Organizer	Contributed Talks
Session Chair	**Webster West**, University of South Carolina

Characterization and Computation of the NPMLE with Univariate Censored Data

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Abstract: In this paper, we study the characterization and computation of the Nonparametric Maximum Likelihood Estimator (NPMLE) with several types of univariate censored data: univariate interval censored data: case 2, univariate "mixed case" interval censored data, univariate doubly censored data, and univariate panel count data. All these estimation problems will be characterized as a Nonlinear Complementary Problem (NLCP). The primal-dual infeasible-interior point algorithm combined with a preliminary parameter reduction algorithm is proposed to compute the NPMLE, followed by applications to real problems and Monte-Carlo simulations.

Key Words: doubly censored data, infeasible-interior-point algorithm, interval censored data, nonhomogeneous Poisson process, maximum likelihood, NPMLE, panel count data.

Block Bootstrap Estimation of the Distribution of Cumulative Outdoor Degradation

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Abstract: An interesting prediction problem involving degradation of materials exposed to outdoor environments (weathering) is the estimation of the distribution of future cumulative degradation using small- to moderate-size degradation data sets. This distribution, which arises as a result of the uncertainty/variability in the weather, can be expressed mathematically as the distribution of the sum of a periodic dependent time series, and is approximately normal by the Central Limit Theorem. The estimation of this distribution is thus equivalent to estimating the mean and the variance of the distribution. We propose a block-bootstrap-based approach to estimate the distribution, and a novel technique to estimate the variance of the distribution. An example involving the degradation of a solar reflector material is provided. We also present the results of a simulation study, which will show that in particular the proposed variance estimator is superior to the sample variance in estimating the variance of the distribution.

Key Words: periodic dependent time series, normal distribution, Central Limit Theorem

An EM Estimation of Distribution Functions with Accelerated Life Test Data
!!!!WITHDRAWN!!!!

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Abstract: Suppose that when a unit operates in a certain condition, its lifetime has distribution G, and when the unit operates in another condition, its lifetime has a different distribution, say F. Moreover, suppose the unit is operated for a certain period of time in the first condition and is then transferred to the second condition. Thus we observe a censored lifetime in the first condition and a failure time of a "used" unit in the second condition. This produces accelerated lifetime data. We propose an EM algorithm approach for obtaining a self-consistent estimator of F using observations from both conditions. Both parametric and nonparametric approaches each with complete and censored data are considered. We also establish the maximum likelihood estimator of F when the unit is repairable. Application and simulation studies are presented to illustrate the methods derived.

Key Words: Censored data, EM algorithm, minimum repair, MLE, product limit estimator, self-consistent estimator

Parameter Estimation from Censored Samples using the Expectation-Maximization Algorithm

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Abstract: This paper deals with parameter estimation when the data are randomly right censored. The maximum likelihood estimates from censored samples are obtained by using the expectation-maximization (EM) and Monte Carlo EM (MCEM) algorithms. We introduce the concept of the EM and MCEM algorithms and develop parameter estimation methods for a variety of distributions such as normal, Laplace and Rayleigh distributions. These proposed methods are illustrated with three examples.

Time permitting, we present a quantile implementation of the expectation-maximization (QEM) algorithm. This method shows a faster convergence and greater stability than the MCEM algorithm. The performance of the proposed method is numerically illustrated through examples and simulation results.

Key Words: EM algorithm, Maximum likelihood, Censored data, Missing data.

Session Number	**17 (Contributed)**
Session Title	**Models and Analysis of Failure-Time Data**
Time and Day	**8:00–9:30, Friday**
Place	**Room 205, Russell House**
Session Organizer	Contributed Talks
Session Chair	**Ma. Zenia Agustin**, Southern Illinois University, Edwardsville

Predicting Survival Based upon Attained Age in Patients with Cystic Fibrosis

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Abstract: The goal of this study is to predict survival in cystic fibrosis patients, based on attained age, gender, and clinical findings. The data set comprises all 35,510 patients in the U.S. Cystic Fibrosis Patient Registry from 1982 to 2001. Patients were followed until death or censored at loss to follow up. Patient and disease characteristics include sex, P. aeruginosa, FEV1, body weight percentile, and CF-related diabetes. The generalized gamma model was used to predict survival. Parametric and Kaplan-Meier survival curves show good agreement for each of the covariates, separately and for combinations of covariates for patients aged 15 to 30 suggesting that the model fits well for up to 10 years beyond attained age. The complete generalized gamma model with all covariates can be used to estimate median survival for individual patients. This is a first step towards developing a tool that can be used in CF clinics.

Key Words: Generalized Gamma Model, Survival Analysis, Median Lifetime

A Power Analysis for Tests Using Paired Lifetime Data

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Abstract: Recent research in the theory of lifetime distributions for paired-data experiments has given rise to a new bivariate lifetime model that is essentially based on (conditionally independent) marginal Weibull distributions. Using this new model, two pivotal quantities are proposed for testing the equality of the marginal lifetimes. The distribution of each testing statistic is derived, and it is shown that either procedure offers an exact parametric test. In this presentation, the important consequences of this research will be reviewed, and a thorough scrutiny of the two tests will be addressed. Some interesting and surprising features in the analysis of the power functions will be discussed in detail.

Key Words: Asymptotic relative efficiency, Bivariate data, Logistic distribution, Monte Carlo Simulation, Pivotal quantity, Weibull distribution.

Optimal Progressive Censoring Plans for The Weibull Distribution

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Abstract: In this paper we compute the expected Fisher information and the asymptotic variance-covariance matrix of the ML estimates based on progressively Type-II censored sample from Weibull distribution by direct calculation as well as the missing information principle. These values are then used to determine the optimal progressive censoring plans. Three optimality criteria are considered and some selected optimal progressive censoring plans are presented according to these optimality criteria. We also discuss the construction of progressively censored reliability sampling plans for the Weibull distribution. Illustrative examples are provided with discussion.

Key Words: Acceptance sampling plan; Lifetime data; Maximum Likelihood estimators; Missing Information; Progressive Type-II censoring.

A Burr Type X Chain-of-Links Model

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Abstract: A model for application to carbon fibrous composites is proposed based on the Burr type X distribution first proposed by Burr (1942) with an included parameter to account for fiber length. The model is further generalized similar to the generalization of the Weibull proposed by Padgett et al. (1995). Maximum likelihood estimation is briefly discussed, and the model is applied to the single-filament data of Bader and Priest (1982).

Key Words: Burr Type X; Carbon Fibrous Composites; Clam Effect; End Effect

Session Number	**18 (Contributed)**
Session Title	**Stochastic Process-Based Models**
Time and Day	**8:00–9:30, Friday**
Place	**Room 303, Russell House**
Session Organizer	Contributed Talks
Session Chair	**Inmaculada Aban**, University of Nevada, Reno

Bayesian Approach in Warranty Cost Analysis: Non-zero Repair Time

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Abstract: In this study the main focus is on the modeling of the warranty claims and evaluating the warranty expenses. The cost of each warranty claim is affected by the non-zero length of the repair time. The operative times and repair times are assumed to be conditionally independent or the latter is assumed to be a function of the former. Conditional alternating renewal processes are employed to model the operating and repair times. New results for alternating renewal process over a finite horizon are derived. They are needed to evaluate the warranty costs over a warranty period under non-renewing free replacement policy and over the life cycle of the product. Also, the case of renewing warranty coverage is considered and the expected warranty costs under pro-rata policy of reimbursement over a warranty period and over the life cycle of the product are studied. A Bayesian approach is used to obtain estimates of the model parameters. Examples are provided to illustrate the ideas.

Key Words: Warranty, warranty period, life cycle, alternating renewal process, prior distribution, posterior distribution

Statistical Inference of a Modulated Gamma Process

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Abstract: Failure data pertaining to a repairable system is commonly modeled by a nonhomogeneous Poisson process (NHPP). A modulated gamma process evolves as a generalization to a NHPP, where the observed failure epochs correspond to every successive kth event of the underlying Poisson process, k being an unknown parameter to be estimated from the data. We focus on a special class of modulated gamma process, called modulated power law process (MPLP) that assumes the Weibull form of the intensity function. The traditional power law process is a popular stochastic formulation of certain empirical relationships between the time to failure and the cumulative number of failures, often observed in industrial experiments. The MPLP retains this underlying physical basis and provides a more flexible modeling environment potentially leading to a better fit to the failure data at hand. The Maximum likelihood estimators (MLE's) of the model parameters are not in closed form and possess the curious property of being asymptotically normal with a singular variance-covariance matrix. Consequently, the derivation of the large-sample results requires non-standard modifications of the usual arguments. We also propose a set of simple closed-form estimators that are asymptotically equivalent to the MLE's. Performance of the estimators in small samples are compared and contrasted by means of extensive numerical simulation.

Key Words: Asymptotics; Maximum Likelihood; Modulated Power Law Process; Nonhomogeneous Poisson Process; Repairable Systems.

A Dynamic Model for a System of Softwares Following the Littlewood Software Reliability Model

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Abstract: This paper considers a system of softwares where each software failure rate follows the model by Littlewood (1980). At any time t, each software failure depends on the residual number of bugs remaining with each bug producing failures at varying rates. Tasks are assigned to the system where the task completion times are independent of the software failure times. The system is observed over a fixed testing period and the system reliability upon test termination is examined. An estimator of the system reliability is presented based on the maximum likelihood estimators of the unknown parameters. Using the machinery of counting processes and martingales, the asymptotic properties of the resulting system reliability estimator are obtained. In addition, the finite-sample properties of the system reliability estimator are examined via a simulation study.

Key Words: Counting processes, martingales

Estimating the Convolution of Distributions Under the Koziol-Green Model of Random Censorship

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Abstract: An estimator is proposed for the convolution of distribution functions under the Koziol-Green model of random censorship in which the survival distribution of the censoring times is some power of the survival distribution of the lifetimes. Our estimator uses the maximum likelihood estimator for the survival function instead of the product limit estimator of Kaplan and Meier (1958) that is used in Lagakos and Reid (1981). The asymptotic distribution of the new estimator for the convolution of distribution functions is established using influence function (or influence curve) method.

Key Words: convolution, influence function, Koziol-Green model, random censorship, maximum likelihood estimator, product limit estimator

Session Number	**19 (Contributed)**
Session Title	**Recent Developments in Failure-Time Modelling**
Time and Day	**8:00–9:30, Friday**
Place	**Room 305, Russell House**
Session Organizer	Contributed Talks
Session Chair	**Torben Martinussen**, Denmark

Attributable fractions for survival data

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Abstract: The attributable fraction (AF) is the proportion of cases (failures) that could have been prevented by removal of an exposure. The concept has been developed in the context of cross-sectional studies, case-control studies and cohort studies with a fixed length of follow-up. This paper presents and discusses some possible definitions of AF when the observations are right-censored. It also addresses the relationships between the various measures and discusses when they will differ. Estimators of the various measures are developed and compared on real and simulated data. In particular the measures' performance under the proportional hazards model is discussed.

Key Words: Attributable fraction, right-censored data, proportional hazards model

The Aalen Additive Hazard Model with Case-Cohort and Nested Case-Control Data

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Abstract: In the Aalen additive model the hazard function is of the form $\lambda_i(t) = \beta_0(t) + \beta_1(t)Z_{i1} + \ldots + \beta_p(t)Z_{ip}$ for regression functions $\beta_j(t)$ and covariates Z_{ij}. In this paper estimators are developed for integrated regression functions with data from case-cohort and nested case-control studies. The estimators are based on weighting techniques with weights given as the inverse of inclusion probabilities. Variance estimators are developed. Performance of the estimators and their variance estimators are studied by means of simulation and by application to real data.

Key Words: Case-control studies, survival data, additive hazard regression, variance estimation, inclusion probabilities, weighting

Statistical Analysis of Current Status Data with informative Observation Times

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Abstract: This paper considers regression analysis of failure time when only current status data are available. By current status data, we mean that each study subject is observed only once and the survival time is known only to be less or greater than the observation time. Such data often occur in, for example,

cross-sectional studies, demographical investigations and tumorgenecity experiments. Furthermore, it is assumed that observation times may be related to the underlying survival time. Inference procedures are proposed for estimating regresson parameters under the additive hazards regression model. Simulation studies are conducted and the proposed methodology is applied to an illustrative example.

Key Words: Additive hazards model; Current status data; Informative censoring; Regression analysis

A bivariate frailty model with cure fraction

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Abstract: We suggest a bivariate cure-mixture model motivated by the paper of Chatterjee and Shih (2001, Biometrics 57, 779 - 786), but with a simpler estimation procedure and using the correlated gamma-frailty model instead of the shared gamma-frailty model. The approach allows to deal with bivariate left truncated and right censored lifetime data and accounts for heterogeneity as well as for a insusceptible (cure) fraction in the study population. We perform a simulation study to evaluate the properties of the estimates in the proposed model and apply it to breast cancer incidence data of 5857 Swedish female monozygotic and dizygotic twin pairs from the old cohort of the Swedish Twin Registry. The model is used to estimate the size of the susceptible fraction and the correlation between the frailties of the twin partners. Possible extensions, advantages and limitations of the proposed method are discussed.

Key Words: competing risks, survival analysis, breast cancer, frailty models, cure models

Session Number	**20 (Plenary)**
Session Title	**State of Modelling and Inference for Repairable Systems**
Time and Day	**9:30–10:15, Friday**
Place	**Russell House Ballroom**
Session Organizer	Organizers
Session Chair	**Edsel A. Peña**, University of South Carolina

Nonparametric Inference for Repair Models

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Abstract: Many systems are maintained by administering some type of repair after each failure. Repair models describe the stochastic behavior of such systems. The statistical analysis of these models is complicated due to the dependencies induced by the nature of the repair process and the specification of the period of observation. We survey results which pertain to nonparametric inference concerning the distribution of the time to first failure of the system. Contributions in this area include those of Whitaker and Samaniego(1989), Hollander, Presnell and Sethuraman(1992), Dorado, Hollander and Sethuraman(1997), Agustin and Pena (1999,2001), and Sethuraman and Hollander(2002).

Joint work with Jayaram Sethuraman.

Key Words: Repair Models, Minimal Repair, Imperfect Repair, Product-Limit Estimators, Bayes Estimators

Session Number	**21 (Invited)**
Session Title	**Bayesian Methods in Reliability**
Time and Day	**10:30–12:00, Friday**
Place	**Room 203, Russell House**
Session Organizer	**Terje Aven**, Stavanger University College, Norway **Uwe Jensen**, University of Ulm, Germany
Session Chair	**Terje Aven**, Stavanger University College, Norway

On nonparametric counting process models for software reliability

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Abstract: There exists a variety of parametric models to describe software failure processes. One branch, for example, has been focussed on nonhomogeneous Poisson processes with a given mean value function the parameters of which are estimated via the maximum likelihood principle. A lot of variations and alternatives of these models have been created up to now. But only a few nonparametric models have been considered so far. It seems that models of this latter kind can offer more flexibility in some cases, for instance, in incorporating stochastic covariates. In the framework of martingales there exists a well developed theory of nonparametric inference of counting processes basing on ideas of O. Aalen and others. It will be shown how this theory can be utilized in the field of software reliability.

Key Words: Software reliability, counting processes, nonparametric inference, additive-multiplicative regression model

Heterogeneity modeling for recurrent events

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Abstract: We consider the case when several sequences of recurrent events are observed simultaneously, for example failures of machines of the same type. Models for such situations may need to include individual effects, for example caused by the installation of machines in different environments. These differences are often realized in the form of observed covariates. However, there may be individual variation between systems which is not explained by the available covariates. This is called unobserved heterogeneity (or "frailty" in the biostatistics literature), and is commonly modeled as a random effect. In this talk we first review some approaches to heterogeneity. Then we go on to study a certain class of models, the trend-renewal process. The emphasis will be on model choice, where we have to choose between a model without heterogeneity versus one which includes heterogeneity. The problem will be considered as a case of Bayesian model choice.

Key Words: Recurrent event; heterogeneity; trend-renewal process; Bayesian hypothesis testing; Model choice

On how to approach uncertainty in reliability and availability analyses, using the Bayesian paradigm

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Abstract: In many reliability and availability analyses problems we study "similar units", for example the performance of items of the same type, and systems being repaired to a state as good as new. The traditional Bayesian approach for analysing such units is to introduce a probability model and obtain independence by conditioning on the values of the parameters of the model. Then a prior distribution on the parameters is specified and through Bayes formula the posterior distribution and the predictive distribution of the observables are derived. In practice, however, this procedure is often rather tedious and difficult to carry out, and other approaches are sought.

In this paper we look at some of these approaches, still within the Bayesian paradigm where probability is used as a subjective measure of uncertainty. These approaches put the focus on the predictive distribution such that we do not need to specify a prior distribution. We discuss when such approaches can be justified and how strong the background information needs to be. Examples are included to illustrate the approaches.

Key Words: Availability, Bayesian paradigm, Predictive distribution, Probability models, Independence

Session Number	**22 (Invited)**
Session Title	**Recent Advances in Survival Analysis**
Time and Day	**10:30–12:00, Friday**
Place	**Room 205, Russell House**
Session Organizer	**Jane-Ling Wang**, University of California, Davis
Session Chair	**Jane-Ling Wang**, University of California, Davis

On some statistical inference problems involving the bivariate mean residual function

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Abstract: A brief literature survey on the estimation of the univariate and bivariate mean residual life function is presented. With this survey as a background, some new statistical inference problems involving the bivariate mean residual lifetime function are considered. Some asymptotic theory of the procedures is developed, and simulation work indicates that the new procedures have good risk properties.

Key Words: None provided.

Recurrent Event Processes With Shape And Size Parameters

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Abstract: The intensity function of a recurrent event process is known as the occurrence probability conditional on the event history. In contrast with the conditional interpretation of the intensity function, the rate function of recurrent events is defined as the occurrence probability function unconditional on the event history. In this paper, the shape and size parameters of the rate function are introduced and the rate function is characterized by these two parameters. These two parameters are used to define the rate-independence between a random variable, X, and the recurrent event process, $N(\cdot)$. An association measure between X and $N(\cdot)$ is defined via shape- and size-based coefficients. Shape- and size-based test statistics are developed and the rate-independence is tested by the combined use of the test statistics. The variable X could be either (case 1) the censoring time at which the observation of $N(\cdot)$ is terminated, or (case 2) a covariable which is possibly correlated with $N(\cdot)$. Tests under case 1 are used to test the independent censoring assumption which has a critical role for validating many methodologies in the analysis of recurrent even data. Tests under case 2 can be used to examine the presence of correlation between potential risk factors and the recurrent event process.

Joint work with Yijian Huang, Fred Hutchinson Cancer Research Center.

Key Words: None provided.

Empirical likelihood based survival function estimation for current status data

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Abstract: Empirical likelihood is a powerful technique for obtaining confidence regions based on non-parametric likelihood ratios. The empirical likelihood theorem of Owen (1990) established a chi-squared limit law for the likelihood ratio statistic when parameter estimates converge at the standard root-n rate. This talk discusses an extension of Owen's result to settings where the optimal rate of convergence is slower than root n, and in which there is plug-in for nuisance parameters. Survival function estimation for current status data (which involves cube-root asymptotics) is examined in detail.

Key Words: None provided.

Session Number	**23 (Invited)**
Session Title	**Regression Models and Recurrent Events**
Time and Day	**10:30–12:00, Friday**
Place	**Room 303, Russell House**
Session Organizer	Organizers
Session Chair	**Ying Qing Chen**, University of California, Berkeley

Robust tests for trials with recurrent events occuring over multiple treatment periods

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Abstract: Robust methods for the analysis of recurrent events have been developed based on Poisson estimating equations (Andersen and Gill, 1982; Lawless and Nadeau, 1995). We describe alternative robust methods of analysis based on binomial or multinomial models, motivated by suitably conditioning within the class of mixed Poisson models. Such methods can be used when trials are designed with baseline periods of observation, or when patients' undergo different kinds of therapies in successive treatment periods. Here the relative efficiency of the robust conditional analyses versus a marginal analysis is examined and related tests are illustreated by application.

Key Words: baseline data, conditioning, recurrent events, robust tests

Linear Regression With Censored Data

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Abstract: In survival analysis, proportional hazards models are commonly used in a distribution-free way for regression where the response variable has been right-censored. However, often a simple linear model may be more appropriate for the data. We present the linear regression method of Buckley and James as an interesting distribution-free alternative. It is a method providing consistent parameter estimates, and, through simulation, has been successfully appraised in the literature in comparison to other regression methods. The model is fitted iteratively, and censored points in the scatterplot are moved to estimated positions as if they had been observed without censoring. In this talk we will concentrate on scatterplot effects, model fitting and diagnostics.

Key Words: Censored regression, Buckley-James Method, regression diagnostics

Variable Selection Methods in Nonparametric Accelerated Lifetime Regression Models

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Abstract: We discuss various variable selection methods for Nonparametric Accelerated Lifetime Regression Models. A few stepwise methods that are free of high dimensional smoothing will be introduced. Empirical studies show that these methods are competitive with a classical stepwise method. Asymptotic properties will be examined and a few real applications will be given.

Key Words: Design variables; Nonparametric test; Smoothing

Session Number	**24 (Invited)**
Session Title	**New Ideas in Reliability with Applications**
Time and Day	**10:30–12:00, Friday**
Place	**Room 305, Russell House**
Session Organizer	**Robert Launer**, Army Research Office
Session Chair	**Robert Launer**, Army Research Office

Stress-Strength Testing: Some Classical and Some New Formulations and Results

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Abstract: If Y is a random variable representing the breaking strength of a given material and X is a random variable measuring the stress placed on that material, then the probability that the material will survive the stress to which it is subjected is simply $p = P(X < Y)$. In most applications involving stress-strength testing, the variables X and Y are modeled as independent. The probability P arises in a broad array of applications, and has been studied extensively. Some of the highlights of the literature in this area will be reviewed, including Birnbaum's (1956) nonparametric confidence bounds for P and subsequent improvements, parametric inference regarding P pioneered by Mazumdar (1970) and Church and Harris (1970), work on general parametric families based on large sample theory (see Johnson (1988)) and Enis and Geisser's (1971) Bayesian treatment of the estimation of P. After surveying these classical results, our focus will shift from estimating P to the problem of estimating the stress and strength distributions themselves from available data. Two particular formulations of stress-strength testing will be discussed. Arcones, Kvam and Samaniego (2002) defined the notion of stochastic precedence as follows: X stochastically precedes Y, i.e $X <_{sp} Y$, if $P(X < Y) > 1/2$. In most industrial and military applications, test items can, more often than not, withstand the stress to which they will be subjected, that is, the assumption that $X <_{sp} Y$ is applicable. This leads to a constrained nonparametric estimation problem whose solution will be described. The second formulation to be discussed involves the analysis of autopsy data, for example, data on welded rebar from a collapsed bridge. Estimation of the distributions of stress and strength is shown to be feasible and efficacious in selected parametric settings.

Key Words: None provided.

Bayes Methods in Repair Models

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Abstract: When data on failures on an item are available as i.i.d. observations, there are many classical methods to estimate F, the failure distribution function. The talk will show how to do this if, necessitated by budget cuts for instance, the data comes from an item which has been successively repaired using a deterministic or random scheme. We model the lifetimes after each failure as depending on F and previous failure times and other covariates observed till the time of the last failure. Such models have been proposed before in Brown and Proschan (1983), Block, Borges and Savits (1987), Kijima (1989),

and Last and Szekli (1998), and frequentist methods of inference have been proposed in Whittaker and Samaniego (1989), Hollander, Presnell and Sethuraman (1992), Dorado, Hollander and Sethuraman (1997). In this talk we will describe new Bayesian methods of inference for F that overcome some limitations of frequentist methods.

Key Words: Repair Models, Minimal Repair, Bayesian Methods, Dirichlet Processes.

When Does Indefinite Testing Assure Infinite Trustworthiness?

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Abstract: In 1920 Jeffreys became interested in the general philosophic question of weather one can ever prove a physical law based on empirical evidence alone. Jeffreys' problem is germane to reliability and life testing in general, and software testing in particular. Using the latter as a motivating scenario we arrive upon the conclusion that what matters after testing very much depends on what you believed before testing, no matter how much testing you do. Thus from a logical point of view, beliefs play a strong role in life testing.

Key Words: None provided.

Session Number	**25 (Invited)**
Session Title	**Bayesian Inference in Reliability and Survival Analysis**
Time and Day	**2:00–3:30, Friday**
Place	**Room 203, Russell House**
Session Organizer	Organizers
Session Chair	**Deb Sinha**, Medical University of South Carolina

Bayesian Inference about the Ratio of Percentiles

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Abstract: Engineers sometimes compare the strength of two different materials by considering the ratio of their 5-th percentiles or other lower percentiles. Here, we take a Bayesian approach to making inferences about the ratio of percentiles. We first look briefly at procedures for making inferences about the ratio of percentiles from normal populations.

In the nonparametric setting, we select a Dirichlet process prior for the single sample problem. We begin by showing how to obtain a sample of several different percentiles from the posterior distribution. An example of approximation to the joint posterior distribution of two percentiles is given. We also investigate the large sample behavior of the posterior quantile process for a single population.

To compare two different populations, we select separate Dirichlet process prior distributions for each of the populations. We then describe how to generate an observation from the posterior distribution of the ratio of percentiles. By repeated sampling, we build an approximation to the posterior distribution of the ratio of percentiles. An example is given.

Key Words: Dirichlet process, posterior distribution, quantiles

Bayesian Nonparametric Estimation in a Series System or a Competing-Risks Model

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Abstract: This paper presents a Bayesian nonparametric approach to the estimation of a system and its components' survival functions arising from observing the failure of a series system or a competing-risks model. A Dirichlet multivariate process is used as a prior for the vector of the components' random subsurvival function to derive the Bayes estimator of the survival function when the cause of failure belongs to a certain risk subset. The weak convergence and the strong consistency of the estimator are established. The special case when the system has only two components corresponds to well studied randomly censored model.

Key Words: None provided.

Monte Carlo Methods for Bayesian Analysis of Survival Data Using Mixtures of Dirichlet Process Priors

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Abstract: Consider the model in which the data consist of possibly censored lifetimes, and one puts a mixture of Dirichlet process priors on the common survival distribution. The exact computation of the posterior distribution of the survival function is in general impossible to obtain. We develop and compare the performance of several simulation techniques, based on Markov chain Monte Carlo and sequential importance sampling, for approximating this posterior distribution. One scheme, whose derivation is based on sequential importance sampling, gives an exactly iid sample from the posterior for the case of right censored data. We also describe usage of a battery of programs we have developed that implement our methods. Our software may be conveniently used from within S-PLUS or R.

Key Words: Censored data; mixtures of Dirichlet processes; sequential importance sampling; Markov chain Monte Carlo.

Session Number	**26 (Invited)**
Session Title	**Competing Risks**
Time and Day	**2:00–3:30, Friday**
Place	**Room 205, Russell House**
Session Organizer	**John Klein**, Medical College of Wisconsin
Session Chair	**Thomas Scheike**, University of Copenhagen, Denmark

Cumulative Incidence Regression

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Abstract: With explanatory covariates, the standard analysis for competing risks data involves modeling the cause-specific hazard functions via a proportional hazards assumption. Unfortunately, the cause-specific hazard function does not have a direct interpretation in terms of survival probabilities for the particular failure type. In recent years, many clinicians have begun using the cumulative incidence function – the marginal failure probabilities for a particular cause – which is intuitively appealing and more easily explained to the non-statistician. The cumulative incidence is especially relevant in decision analyses in which the survival probabilities are needed to determine treatment utility. Previously, researchers have considered methods for combining estimates of the cause-specific hazard functions under the proportional hazards formulation. However, these methods do not allow the analyst to assess the net effect of a covariate on the cumulative incidence function. In this talk, we discuss an alternative semiparametric modelling strategy in which the cumulative incidence is modelled directly, as one ordinarily models the survival function. Estimation and inference procedures are developed for the finite-dimensional covariate effect parameter under a variety of censoring scenarios. A uniformly consistent estimator for the predicted cumulative incidence for an individual with certain covariates is given and confidence intervals and bands can be obtained analytically or with an easy to implement simulation technique. To contrast the different modelling frameworks, data from a breast cancer clinical trial is analyzed using both approaches.

Key Words: None provided.

Regression analysis of competing risks data using pseudo-observations

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Abstract: In event history analysis regression analysis typically involves the modelling of each transition intensity separately. A major example is the competing risks model where models may be specified via the cause specific hazards. The probability a subject will be in a given state at some time, e.g. the cumulative incidence function in the competing risks model, is a complex nonlinear function of the intensity regression coefficients. We present a technique which models the state probabilities directly. This method is based on the pseudo-values from a jackknife statistic constructed from simple summary statistic estimates of the state probabilities. These pseudo-values are then used in a generalized estimating equation to obtain estimates of the model parameters. We present some theoretical results for this technique and illustrate how it works using bothreal medical examples and Monte Carlo results.

This is a joint work with John Klein of the Medical University of Wisconsin.

Key Words: None provided.

Extensions and applications of the Cox-Aalen survival model

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Abstract: Cox's regression model is the standard regression tool for survival analysis in most applications. Often, however, the model only provides a rough summary of the effect of some covariates. Therefore, if the aim is to give a detailed description of covariate effects and to consequently calculate predicted probabilities, more flexible models are needed. In this talk we consider a flexible extension of Cox's regression model that aimed at extending the Cox model only for those covariates where additional flexibility are needed. One important advantage of the suggested approach is that even though covariates are allowed a nonparametric effect the hassle and difficulty of finding smoothing parameters are not needed. We show how the extended model also leads to simple formulae for predicted probabilities and their standard errors, for example the predicted cumulative incidence function in the competing risk framework.

Key Words: Cox regression, Aalen model, competing risk, cumulative incidence.

Session Number	**27 (Invited)**
Session Title	**Models in Reliability and Survival Analysis**
Time and Day	**2:00–3:30, Friday**
Place	**Room 303, Russell House**
Session Organizer	**Martin Crowder**, Imperial College, United Kingdom
Session Chair	**Paul Kvam**, Georgia Tech University

Modelling Converging Hazards

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Abstract: The proportional hazards model continues to be the first-choice approach for the analysis of survival data, in biostatistical applications at least. So much so that authors often feel that explicit reasons need to be given when this model is not selected. Yet in practice there are good reasons why converging hazards should be more often seen than proportional. Indeed Keiding (1987) describes how Tetens in 1786, in one of the very first publications on survival, took it as axiomatic that hazards for subgroups will converge over time.

This talk reviews models which allow converging hazards but include the proportional hazards model as a nested special case, which can then be tested as a null hypothesis. Requirements are that the baseline hazard is left unspecified, that estimation is based on the order of events rather than their exact times, and that the model is sufficiently flexible to describe a variety of converging patterns. A special case of the generalised proportional hazards family of Bagdonavicius and Nikulin (1999) is shown to have these properties and also allows covariates to have mixed effects, some converging and some proportional. Although the model is specified in its own right, it can be derived as a non-standard frailty mixture of proportional hazards, and this leads naturally to an EM estimation procedure with

the frailties treated as missing data. Testing for this type of departure from proportional hazards is discussed and an illustration using survival of terminally ill hospice patients is provided.

Key Words: None provided.

A flexible additive multiplicative hazard model

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Abstract: We present a new additive-multiplicative hazard model which consists of two components. The first component contains additive covariate effects through an additive Aalen model while the second component contains multiplicative covariate effects through a Cox regression model. The Aalen model allows for time-varying covariate effects, while the Cox model allows only a common time-dependence through the baseline. Approximate maximum likelihood estimators are derived by solving the simultaneous score equations for the nonparametric and parametric components of the model. The suggested estimators are provided with large sample properties and are shown to be efficient. The efficient estimators depend, however, on some estimated weights. We therefore also consider unweighted estimators and describe their large sample properties. Some examples are provided to illustrate the model and suggested method.

Key Words: Aalen's additive model, Cox regression, counting processes, hazard model, proportional excess hazard model

Proportional Rates/Means Models for Clustered Recurrent Event Data

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Abstract: In biomedical studies, the event of interest is often recurrent and within-subject events cannot usually be assumed independent. In addition, individuals within a cluster might not be independent; for example, in multi-center or familial studies, subjects from the same center or family might be correlated. We propose methods of estimating parameters in a proportional rates/means model for clustered recurrent event data. The model is semi-parametric, with a common baseline rate function across clusters. Dependence structures for patients-within-cluster and events-within-patient are both unspecified. Estimating equations are derived for the regression parameter, and a non-parametric estimator of the baseline mean function is proposed. The asymptotic distributions of the model parameters are derived, while finite-sample properties are assessed through a simulation study. The proposed methods are applied to data based on patients receiving dialysis.

Key Words: clustered failure time data; empirical processes; proportional rates model; recurrent events; semi-parametric model.

Session Number	**28 (Invited)**
Session Title	**Statistical Modelling in Reliability**
Time and Day	**2:00–3:30, Friday**
Place	**Room 305, Russell House**
Session Organizer	**Frank Samaniego**, University of California, Davis
Session Chair	**Frank Samaniego**, University of California, Davis

The Gompertz degradation model, functional equations and resu1ting distributions in one and two dimensions

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Abstract: Gompertz (1825) derived the distribution that carries his name by using a model for degradation of a man's power to resist destruction. This model can be represented as a differential equation, the solutions of which include the Gompertz distributions and the exponential distributions. Another class of solutions, improper distributions called negative Gompertz distributions, can be used with Gompertz distributions to generate a family of distributions with bathtub hazard rates Modifications of the Gompertz differential equation lead to the two extensions of Makeham (1860, 1890); another modification leads to the Weibull distributions.

The Gompertz and Gompertz-Makeham distributions have also been derived using functional equations, the first to do this was De Morgan (1860).

In this paper, two dimensional versions of the differential and functional equations are used to derive bivariate distributions.

Key Words: None provided.

The Physical Basis of Statistical Models in Reliability

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Abstract: This talk takes an approach to modeling component lifetimes that parallels the approach taken in control theory to modeling electro-mechanical systems, namely: Delineate the state- or phase space manifold; endow it with the existing physical structure; and then derive the physical invariants as meaningful quantities. In this way, we can define some of the existing concepts in reliability, including the survival distribution and a maintenance policy, but others, such as the hazard gradient, appear as physically meaningless. I will show which reliability-theory concepts parallel the electro-mechanical ones, including energy, momentum, voltage, current, etc. Finally, I will show how this approach can be useful in deriving probability distributions from physical assumptions rather than statistical ones.

Key Words: None provided.

Comparing Reliability Experiments with the Convolution Order

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Abstract: In this talk I will describe some results involving comparison of experiments in system reliability theory when the component lifetimes are independent and identically distributed random variables that have a common two-parameter exponential distribution with a unknown location parameter. For this purpose, a stochastic order, called the convolution order, is defined, and some basic properties of it are studied. Attention is then focused on the family of distribution functions which are mixtures of distributions of partial sums of independent exponential random variables, and some results, which identify several conditions under which members of this family are ordered in the convolution stochastic order, are derived. The results are applied to order lifetimes of coherent systems, and as a consequence, information inequalities among various lifetimes of coherent systems are obtained. In particular, situations where high reliability decreases statistical information, are pointed out. This is joint work with Alfonso Suarez-Llorens.

Key Words: Convolution order, stochastic orders, Coxian distributions, poles and zeroes of rational functions, information comparisons, coherent systems, signatures, order statistics, dispersive order.

Session Number	**29 (Plenary)**
Session Title	**Multivariate Failure Times**
Time and Day	**3:30–4:15, Friday**
Place	**Russell House Ballroom**
Session Organizer	Organizers
Session Chair	**James R. Hebert**, University of South Carolina

Aspects of the Analysis of Multivariate Failure Time Data

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Abstract: Multivariate failure time data arise in various forms, including recurrent event data when individuals are followed to observe the sequence of occurrences of a certain type of event, and correlated failure times when individuals in groups or clusters have correlated failure times. A critical review of statistical models and data analysis methods in these settings will be presented. This review suggests a valuable role for partially marginalized intensity models for the analysis of recurrent event data, and points to the usefulness of marginal hazard rate models and nonparametric estimates of pairwise dependencies for the analysis of correlated failure times. Areas in need of further methodology development are indicated. This represents joint work with Jack Kalbfleisch of the University of Michigan.

Key Words: Correlated failure times; independent censoring; marginal models; survivor function estimation; recurrent events.

Session Number	**30 (Invited)**
Session Title	**Models Based on Poisson-Type Processes**
Time and Day	**4:30–6:00, Friday**
Place	**Room 203, Russell House**
Session Organizer	Organizers
Session Chair	**Marcus Agustin**, Southern Illinois University, Edwardsville

On Stochastic Approximation Methods in Reliability

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Abstract: Depending on the state of the stand-by equipment, can be distinguished loaded, non-loaded and partially loaded relief. In the case of loaded relief, the stand-by unit is in the same state as the operating unit and for this reason has the same intensity of breakdowns. In the partially loaded case, the stand-by device is loaded, but not so fully as the main equipment and for this reason has a different breakdown intensity. A stand-by unit that is not loaded does not, naturally, suffer breakdown. The spare wheel of an automobile is a typical example of non-loaded relief. Quite naturally, loaded and non-loaded relief are special cases of partially loaded relief.

On the other hand, the stochastic-approximation procedures require very little prior knowledge of the process and achieve reasonably good results. And for this reason such methods work satisfactorily in various applications. Many and very important results are obtained in particular by Solovyev, Gnedenko, Venter and Gastwirth.

In this paper we refer to some aspects regarding to the problem of the increase of the effectiveness of stand-by systems as a way in which the stochastic-approximation techniques can be applied in practice.

Key Words: stochastic differential equations, stand-by systems stochastic approximation processes, control processes.

On Some Problems Relating to Model Selection for the Power Law Process

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Abstract: In this paper a review of some results relatng to the power law process is considered. Power law process models for non-homogeneous Poisson process with change points are considered. We develop procedures for estimating the model parameters and the system intensity of failures under the assumption of change point. Predictive distributions are derived for future system failure times and the number of system failures in a future interval.

Key Words: None provided.

Estimating and Simulating NonHomogeneous Poisson Processes

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Abstract: Nonparametric techniques for estimating the cumulative intensity function of a nonhomogeneous Poisson process from one or more realizations on an interval $(0, S]$ are developed and illustrated. The cases considered here are estimating the cumulative intensity function from:

- exact event event times from k realizations on (0, S],

- exact event event times from k overlapping realizations on $(0, S]$,
- counts of events on intervals on $(0, S]$.

The first two cases do not require any arbitrary parameters from the modeler. In all three cases, the estimated cumulative intensity function can be used to generate a point process for simulation by inversion.

Key Words: Discrete-Event Simulation, Nonparametric Estimation, Point processes, Repairable Systems.

Session Number	**31 (Invited)**
Session Title	**Residual Life Functions**
Time and Day	**4:30–6:00, Friday**
Place	**Room 205, Russell House**
Session Organizer	Organizers
Session Chair	**Kerrie Nelson**, University of South Carolina

Analysis of proportional mean residual life model in presence of censoring

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Abstract: As a function of time t, mean residual life is defined as remaining life expectancy of a subject given its survival to t. It plays an important role in some research areas to characterise stochastic behavior of survival over time. Similar to the Cox proportional hazard model, the proportional mean residual life model were proposed in statistical literature to study the association between the mean residual life and individual subject's explanatory covariates. In this article, we will study this model and develop appropriate inference procedures in presence of censroing. Numerical studies including simulation and real data analysis are presented as well.

Key Words: None.

A characterization of the multivariate normal distribution by using the hazard gradient

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Abstract: We give a general result to characterize a multivariate distribution from a relationship between the left truncated mean function $m(x) = E(X|X > x)$ and the hazard gradient function $h(x)$. This result allows us to obtain new characterizations of multivariate distributions. In particular, we show that, for the multivariate normal distribution $N(\mu, V)$, the simple relationship $m(x) = \mu + Vh(x)$, actually characterizes the multivariate normal distribution.

Key Words: Hazard gradient function, Failure rate, Mean residual life, Left truncated mean function, Multivariate Normal.

Information in Lifetime and Residual Lifetime Distributions

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Abstract: Comparison of probability distributions is pivotal to statistical methodologies. In many problems such as hypothesis testing, model selection, classification, and minimum discrepancy estimation methods the comparison is explicit. In some problems like the maximum likelihood estimation the comparison between distributions is shown to be implicit. Information functions quantify discrepancies between probability distributions in the logarithmic scale. For lifetime distributional analysis, consideration of the current age requires using the appropriate subset of the space, which provides suitable information measures for the problem at hand. We discuss various information functions for lifetime and residual lifetime distributions, outline their properties, and present some examples.

Key Words: Component entropy, conditional dependency, dynamic information

Session Number	**32 (Invited)**
Session Title	**Quality of Life and Accelerated Testing**
Time and Day	**4:30–6:00, Friday**
Place	**Room 303, Russell House**
Session Organizer	Organizers
Session Chair	**John Spurrier**, University of South Carolina.

Quality of Life — Adjusted Survival Analysis: Parametrics and Beyond

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Abstract: The MRL (mean remaining life) function fails to capture totally the impact of the important Q0L (quality of life) factor which is quite often a basic ingredient in survival analysis of pateints with terminal as well as chronic diseases, such as cancer, dementia, diabetes, and heart transplant, among others. To incorporate the QWoL impact, various methods have been advocated. In a parametric setup, a QoL based utility function has been introduced in a Markov model formulation, although it may be less robust than nonpatrametric and semiparametric approaches. These later developments are highlighted here.

Key Words: None provided.

A General Bayes Exponential Inference Model for Accelerated Life Testing

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Abstract: This article develops a general Bayes inference model for accelerated life testing assuming failure times at each stress level are exponentially distributed. Using the approach, Bayes point estimates as well as probability statements for use-stress life parameters may be inferred from the following testing scenarios: regular life testing, fixed-stress testing, step-stress testing, profile-stress testing, and also mixtures thereof. The inference procedure uses the well known Markov Chain Monte Carlo (MCMC) methods to derive posterior quantities and accommodates both the interval data sampling strategy and type I censored sampling strategy for the collection of ALT test data.

Key Words: Dirichlet Distribution, Markov Chain Monte Carlo Method .

A Bibliography of Accelerated Test Plans

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Abstract: This paper provides a current bibliography of accelerated test plans, which will aid practitioners in selecting plans and will stimulate researchers to develop needed plans. Performance of existing plans has been evaluated using analytic theory or simulation. Such plans deal with factors including

- life distributions (exponential, Weibull, lognormal, etc.),
- different life-stress or degradation-stress relationships,
- types of data censoring (right and interval),
- types of stress loading (constant. step, ramp, cyclical, stochastic, field use),
- specimen size and geometry,
- optimization criteria (minimum variance or determinant, cost, etc.)
- constraints on the test region or test order of specimens,
- allocation of specimens to test stress levels.

Many plans need to be developed, especially for degradation models. The author welcomes additions to the bibliography and will email a current copy on request.

Key Words: accelerated test plans, overstress testing, statistical models

Session Number	**33 (Invited)**
Session Title	**Survival Analysis: Some Current Research in Biostatistics**
Time and Day	**4:30–6:00, Friday**
Place	**Room 305, Russell House**
Session Organizer	**Robert Strawderman**, Cornell University
Session Chair	**Robert Strawderman**, Cornell University

Marginal Estimation in Multistage Models Using Current Status Data

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Abstract: In a multistage model, individuals are observed over time in various stages (states). In addition to internal covariates such as the past stage occupation and transition times, the future transitions of an individual may be influenced by additional observable external covariates. Estimation of marginal quantities such as the stage occupation probabilities, marginal hazards and stage waiting time distribution functions are of interest for answering questions such as: what is the probability that a randomly selected person is in stage at time , and; what is the rate (hazard) at which persons in stage move to stage , and so on. In the case of complete data, such quantities are easily estimated by their empirical versions. Current status data represent the status (i.e., stage occupied) of individuals inspected at a single inspection time per individual. We will illustrate how to construct estimates of the above marginal quantities under current status data without making any structural assumptions (such as Markov or semi-Markov) about the multistage process.

Key Words: stage occupation probabilities, hazard, nonparametric estimation, current status data, stage waiting time

Estimation of Optimal Treatment Strategies for Survival Outcomes

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Abstract: A physician must dynamically choose a treatment strategy for his HIV positive patients in the sense that he must, at monthly visits, choose the drugs and dosages to prescribe based on the each patient's past clinical, laboratory, and treatment history. Suppose one's goal is to maximize quality-adjusted survival I will describe two statistical methods for estimation of the optimal treatment strategy from either observational or randomized trial data. These methods provides an alternative approach to that proposed by Susan Murphy in her recent seminal paper on this topic. It combines much of the machinery for causal inference from longitudinal data developed by myself and colleagues over the past 15 years.

Key Words: Causal, Longitudinal Data, Sequential Decisions

Semiparametric Bivariate Location-Shift Regression Model for Estimation of the Joint Effect of Treatment on Time to Disease Progression and Death !!!!WITHDRAWN!!!!

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Abstract: In this paper, we consider estimation of the joint effect of a randomized treatment on time to disease progression and death, after adjusting for baseline prognostic factors. We assume that death is observed on all subjects and that time of disease progression is subject to dependent censoring by death. We posit a semi-parametric bivariate location shift regression model with unspecified error distribution and show how to construct locally efficent estimators of the regression parameters. The causal interpretation of the parameters depends on non-identifiable assumptions. We discuss two assumptions: the first applies to situations where it is reasonable to view disease progression as well defined after death and the second applies to situations where such a view is unreasonable. We conduct a simulation study and analyze data from a randomized trial for the treatment of brain cancer.

Key Words: Causal Inference; Informative Censoring

Session Number	**34 (Banquet and Plenary)**
Session Title	**'Surviving Contemporary Times'**
Time and Day	**8:30–9:15PM, Friday**
Place	**Russell House Ballroom**
Session Organizer	Organizers
Session Chair	**Thomas Mazzuchi**, George Washington University

Surviving Financial Risk

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Abstract: The asset pricing formula for a fixed income instrument, like a bond, bears an isomorphic relationship to a key formula in reliability and survival analysis. In this talk we point out this relationship and interpret it. We will then argue that the isomorphism enables one to infuse ideas and notions from reliability and survival analysis into mathematical finance. Our hope is that the said connection, which we feel has not been recognized before, will add a new dimension to finance.

Key Words: None provided.

Session Number	**35 (Invited)**
Session Title	**Bayesian Modelling in Survival Analysis and Reliability**
Time and Day	**8:00–9:30, Saturday**
Place	**Room 203, Russell House**
Session Organizer	Organizers
Session Chair	**Alyson Wilson**, Los Alamos National Laboratory

Some Issues in Bayesian Modeling of Health Surveillance Data

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Abstract: Health surveillance is now of growing and immediate interest particularly after the events of 9/11/01. In particular there is a need to develop a range of methods that can flexibly detect a wide range of possible changes in health status within communities. Because of the large scale and wide focus of this activity, there is a need to develop methods that can be useful in detecting specific changes, but also broad enough to be able to detect different effects in a range of diseases. For example monitoring of 10 respiratory diseases over time within 18 age x gender groups w ould mean monitoring 180 time series. Data mining techniques are one set of methods that have been successfully employed for this purpose. However these techniques are often not specifically designed for the surveillance task, and there is great need for the development of a statistical modeling framework for surveillance. In this talk I will outline some of the important issues to be addressed in Bayesian Models for surveillance with particular reference to the relatively novel area of the monitoring of the spatial distribution of disease.

Key Words: Bayesian; spatial; surveillance; health; data mining

Models and Bayesian analysis of recurrent events data with dependent termination

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Abstract: We consider models and Bayesian methods for recurrent events data when the termination time for each subject may depend on the point process of the recurrent events via a *frailty* variable. This article develops a class of fully specified stochastic models which allow negative association between the risk of termination and the rate of recurrent events. We derive several properties of our model and other existing models to provide a comparison of our model with competing models. We also explore the relationship of our model with existing models for medical costs data. We develop efficient Markov chain Monte Carlo algorithms for sampling from the posterior distribution of the parameters when the data from each subject is recorded via scheduled clinic visits and is subject to right censoring. We demonstrate the usefulness of our new models and methodologies through the reanalysis of a dataset from a clinical trial.

Key Words: Frailty; Gibbs sampling; Panel Counts; Semiparametric Bayes.

Uncertainty in Counts and Operating Time in Estimating Poisson Occurrence Rates

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Abstract: When quantifying a plant-specific Poisson event occurrence rate l in reliability or probabilistic risk analysis studies, it is sometimes the case that either the reported plant-specific number of events x or

the operating time t (or both) are uncertain. We present a full hierarchical Bayesian MCMC method that can be used to obtain the required average posterior distribution of l which reflects the corresponding uncertainty in x and/or t. The method is easy to implement using existing WinBUGS software that is freely available from the Web. A real-data example from the commercial nuclear power industry is used to illustrate the method, and the corresponding WinBUGS code is provided and discussed.

Key Words: Poisson; Data Uncertainties; Hierarchical Bayes; MCMC

Session Number	**36 (Invited)**
Session Title	**Adaptive Designs with Delayed Responses**
Time and Day	**8:00–9:30, Saturday**
Place	**Room 205, Russell House**
Session Organizer	**Nancy Flournoy**, University of Missouri, Columbia
Session Chair	**William Rosenberger**, University of Maryland at Baltimore County

The accelerated biased coin up-and-down-design in phase I trials

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Abstract: The Biased Coin up-and-down Design (BCD) is used to allocate doses in phase I clinical trials. The BCD requires that the treatment response or the toxicity evaluation is observed quickly. In trials with a long treatment evaluation, the BCD will lead to long trial duration because a new patient cannot be enrolled until the preceding patient has completed the evaluation period. We propose a simple method to modify the BCD that will reduce the trial duration without significantly affecting the estimate of the target dose. The idea is to allocate a dose to each patient as he arrives based on the toxicity information of the last completed subject. This allows multiple patients to be concurrently under evaluation. A simulation study shows that this modification does not adversely affect the precision of the recommended dose, as estimated by isotonic regression, but it does significantly reduce the total time to complete the study.

Key Words: Toxicity, biased coin up-and-down design, isotonic regression, dose finding.

Optimality, Variability, Power: A Template for Evaluating Response-Adaptive Randomization Procedures

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Abstract: We provide a theoretical template for the comparison of response-adaptive randomization procedures for clinical trials. Using a Taylor expansion of the noncentrality parameter of the usual chi-square test for binary response, we show explicitly the relationship among the target allocation

proportion, the bias of the randomization procedure from that target, and the variability induced by the randomization procedure. We also generalize this relationship for more than two treatments under various multvariate alternatives. This formulation allows us to directly evaluate and compare different response-adaptive randomization procedures. For two treatments, we compare four response-adaptive randomization procedures and three target allocations based on multiple objective optimality criteria. We conclude that Ivanova's Drop-the-Loser Rule and Eisele's Doubly Adaptive Biased Coin Design are clearly superior to sequential maximum likelihood estimation or the randomization play-the-winner rule in terms of decreased variability, but the latter is preferable because it can target any desired allocation.

Key Words: None supplied.

Handling Delayed Response in Response-Adaptive Randomization Procedures Using Urn Models

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Abstract: For response-adaptive randomiization procedures using a generalized Friedman's urn design, we derive the limiting distribution of the urn composition and allocation proportions under staggered entry and delayed response. The stochastic delay mechanism is assumed to depend on both the treatment assigned and the patient's response. We show that maximum likelihood estimators from a clinical trial using the randomized play-the-winner rule under delayed response have the usual asymptotic properties.

Key Words: None supplied.

Session Number	**37 (Invited)**
Session Title	**Models and Inference for Reliability Systems**
Time and Day	**8:00–9:30, Saturday**
Place	**Room 303, Russell House**
Session Organizer	Organizers
Session Chair	**Olcay Akman**, Coastal Carolina University

Probabilistic and Statistical Analysis of S-Order Old Age Life Distributions

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Abstract: It is well known that old age can be taken to be the equilibrium life defined as the weak limit $\tilde{X}$ of the remaining life at time t, X_t which has survival function $\bar{F}_t(x) = \bar{F}(x+t)/\bar{F}(t), x, t \geq 0, \bar{F}(t) > 0$. Thus, the s-order old age can be defined as the weak limit $\tilde{X}^{(s)}$ of $\tilde{X}_t^{(s-t)}$ as $t \to \infty$. In this investigation we obtain basic probabilistic properties of $\tilde{X}^{(s)}$ such as the distribution function, the density, the moment generating function, and relate them to the original life X. We show that if $\tilde{X}^{(s)}$ is harmonic new is better than used in expectation and if $E(X^s) < \infty$, then the moment generating function of $\tilde{X}^{(s)}$ exists and is finite. Assuming that $\tilde{X}^{(s)}$ belongs to one of several well-known classes of ageing, we obtain moments inequalities relating the moments of X. These inequalities are used for testing $\tilde{X}^{(s)}$ is exponential against that it falls in one of several known ageing classes based on data from the original life X.

Key Words: Equilibrium life; old age; s-order; moments inequalities; ageing life distributions; hypothesis testing

Stochastic Comparisons of Parallel Systems

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Abstract: Let $X_1, \ldots, X_n$ be independent random variables with X_i having hazard rate $\lambda_i h(t)$, $i = 1, \ldots, n$. Let $Y_1, \ldots, Y_n$ be a random sample of size n from a distribution with common hazard rate $\tilde{\lambda} h(t)$, where $\tilde{\lambda} = (\prod_{i=1}^n \lambda_i)^{1/n}$, the geometric mean of the λ_i's. Let $X_{n:n} = \max\{X_1, \ldots, X_n\}$. It is shown that $X_{n:n}$ is greater than $Y_{n:n}$ according to hazard rate ordering and if the baseline distribution is DFR, then $X_{n:n}$ is greater than $Y_{n:n}$ according to dispersive ordering These results are extensions of those proved in Khaledi and Kochar (Appl. Prob. **37** (2000), 1123- 1128) and lead to a lower bound for the variance of $X_{n:n}$ and an upper bound on the hazard rate function of $X_{n:n}$ in terms of $\tilde{\lambda}$. The new bounds are sharper than those obtained by Dykstra, Kochar and Rojo [J. Stat. Plann. Inf. **65** (1997) 203-211], which are in terms of the arithmetic mean of the λ_i's. Furthermore, let $X_1^*, \ldots, X_n^*$ be another set of independent random variables with X_i^* having hazard rate $\lambda_i^* h(t)$, $i = 1 \ldots, n$. It is proved that if $(\log \lambda_1, \cdots, \log \lambda_n)$ weakly majorizes $(\log \lambda_1^*, \cdots, \log \lambda_n^*)$, then $X_{n:n}$ is stochastically greater than $X_{n:n}^*$.

Key Words: None

A Survival Model of Medical Treatments: Life (Function) after Death

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Abstract: Survival times and medical treatments are not separable or are they? If $S(t)$ is the survival function of drug treated patients and $C(t)$ is the survival function of the control group (treated with placebo), then define the Medical treatment function $M(t)$ as the convolution ratio of S and C, i.e. $S(t) = M(t) * C(t)$, where * denotes the convolution. In this sense our life expectancy T can be viewed as the 'composition' of e.g. 20% medical treatment (M) and 80% nature (N), i.e. $T = M + N$, where M and N are independent and the sum of four iid copies of M has the same distribution as N. If $S(t)$

is infinitely divisible, there is no problem in splitting T into M and N. Here we show that every convex survival function is infinitely divisible in the class of functions with bounded variation. A simple model for the 'Medical treatment density' $m_a(x)$ is the a-th power of the uniform distribution $(0 < a < 1)$. This 'density' $m_a(x)$ does not exist in the traditional sense because it takes both positive and negative values. We show that

$$m_a(x) = \sum_{n=0}^{\lfloor x \rfloor} (-1)^n \binom{a}{n} (x-n)^{a-1}/\Gamma(a)$$

which has singularities at integer points. The fictitious survival function of $m_a(x)$ tends to 0 but not monotonically as if there were life after death. This kind of "fictitious survival functions" can help to understand the effect of "nurture" vs "nature". If 'death' is e.g. cancer, then we know there is life after 'death', so the situation is not completely mystical. Vector observations, one of them binary, the other one is survival time, can also be modelled by our signed densities.

Key Words: None.

Session Number	**38 (Invited)**
Session Title	**Semiparametric Modelling in Survival Analysis**
Time and Day	**8:00–9:30, Saturday**
Place	**Room 305, Russell House**
Session Organizer	**Ian McKeague**, Florida State University
Session Chair	**Ian McKeague**, Florida State University

Semiparametric Time-Varying Coefficients Regression Model for Longitudinal Data

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Abstract: In this paper, we propose a semiparametric method for the joint modeling of longitudinal responses and measurement times. The semiparametric time-varying coefficients regression model postulates that the influences of some covariates vary nonparametrically with time while the effects of the remaining covariates follow certain parametric functions of time. The measurement times of responses are modeled by Cox's proportional model for conditional mean rate. We developed weighted least squares type estimators for the unknown parameters of the parametric regression functions as well as estimators for the nonparametric regression functions. We also used the kernel method of neighborhood smoothing for the response and the covariate processes if necessary instead of single-neighborhood smoothing as did by Lin and Ying (2001) to improve efficiency. Uniform confidence bands for the cumulative functions of regression coefficients are derived. The proposed model allows for additional flexibility to explore how covariate effects change over time and provides a base to test whether simpler models with scientific relevance hold. A hypothesis testing procedure is proposed to test whether some covariate effects follow certain parametric forms. Testing for constant covariate effects is a special case of this general approach. A data-driven bandwidth selection procedure is proposed. Simulation studies demonstrate that the proposed estimation methods are accurate and that the testing procedures are valid and powerful. An application to a data set from a AIDS clinical trial study is provided.

Key Words: None provided.

Double robust estimation of causal parameters with censored longitudinal data

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Abstract: We propose a general estimating function methodology for estimating a causal effect of a treatment regime on an outcome (such as survival) in longitudinal studies in which the treatment regime is assumed to be sequentially randomized given the observed past. The method relies on the counterfactual framework to define causal models (e.g. marginal structural models) and thereby the causal parameters of interest. Under the sequential randomization assumption the likelihood of the observed data structure factors into the conditional distribution of the treatment regime, given all the treatment specific counterfactuals, and the distribution of the treatment regime specific counterfactual data, which has been named the G-computation formula (Robins). The proposed double robust estimator is based on a maximum likelihood estimator of the treatment mechanism and a maximum likelihood estimator of the G-computation formula. The double robust estimator is consistent and asymptotically linear (under regularity conditions) if either 1) the model for the G-computation formula is correct or 2) the model for the treatment mechanism is correct and an experimental treatment assignment assumption holds. We illustrate the performance of the general method with a simulation study and apply it to a data analysis.

Key Words: None provided.

Tests for Comparing Mark-specific Hazards and Cumulative Incidence Functions Between Two Groups, with Application to HIV Vaccine Trials

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Abstract: An important problem to address from data collected in a preventive HIV vaccine efficacy trial is whether the efficacy of the vaccine to prevent HIV infection depends on the genotypic or phenotypic variation of the exposing HIV. This problem can be approached by studying the "distances" of the HIV viruses that infect trial participants to the HIV strain that is contained in the vaccine. Because thousands of nucleotides in each HIV genome are sequenced, it is often most natural to treat the viral distance as a continuous random variable (e.g., a Hamming distance). In this case, the distance of an infecting virus is a continuous mark that accompanies each failure (infection) time, and the problem can be addressed by testing if the ratio of the mark-specific hazard functions for the vaccine and placebo groups is independent of the mark. Procedures for testing this null hypothesis against ordered and two-sided alternatives are described. The test statistics are based on a bivariate test process equal to a weighted average of vaccine versus placebo group contrasts of nonparametric Nelson–Aalen-type estimates of mark-specific cumulative hazard functions. Since the limiting covariance structure of the test process is complicated, asymptotically correct critical values are obtained through a simple Gaussian multipliers simulation technique. Results of numerical studies of the procedures are presented. In addition, the procedures are applied to HIV genetic sequence data collected in a prospective cohort study of female sex workers in Senegal, where the "vaccine" group consists of sex workers who were previously infected with HIV type 2 (a natural, live vaccine), and the placebo group consists of sex workers who were not previously infected with HIV type 2., This is joint work with Ian McKeague and Yanqing Sun.

Key Words: None provided.

Session Number	**39 (Invited)**
Session Title	**Aspects of Reliability and Risk Modelling**
Time and Day	**9:45–11:15, Saturday**
Place	**Room 203, Russell House**
Session Organizer	Organizers
Session Chair	**Lori Thombs**, University of South Carolina

On discrete time minimal repair processes

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Abstract: Recently Pellerey, Shaked and Zinn (2000) introduce a discrete-time analog of the minimal repair process. They study conditions under which the epoch times and the interepoch intervals of these discrete-time processes have logconcave discrete probability densities. In this paper we study conditions under which the epoch times and interepoch intervals of two of these processes, can be stochastically compared in various senses.

Key Words: None supplied.

X-Testing using Binary Data with Applications to Reliability Demonstration Plans

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Abstract: Reliability demonstration plans are frequently used in industry to formally verify that the reliability of a product exceeds a certain specified value with a certain degree of confidence. When the value of the reliability to be demonstrated is close to one, traditional reliability demonstration plans are problematic since they require extremely large sample sizes and have low power. One solution to this problem is to induce failure in the testing process by testing products under conditions in which they are more likely to fail. Under these conditions, it is sufficient to demonstrate a lower value of reliability which is then mapped back to the required reliability under standard conditions. Methods of inducing failure can include testing products for a longer period of time, testing at higher stress conditions, or testing weaker products through biased sampling. We give a general framework to describe this type of extreme testing, or "X-testing". Specially, we consider the effect of X-testing on sample size and power of reliability demonstration plans biased on binary data. This depends on the X-transform which is defined as the mapping of the reliability under standard conditions to those of the X-test. We study properties of various X-transforms with respect to zero failure plans, fixed sample size plans and fixed power plans and derive conditions under which X-transforms lead to inadmissible or universally efficient X-tests.

This work is joint with Vijay Nair.

Key Words: None provided.

Multivariate extremes, max-stable processes and the analysis of financial risk

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Abstract: Multivariate extreme value theory was developed to model the joint distributions of extremes from several dependent variables, such as multiple components of a reliability system or different types of extreme environmental events. When the available data consist of whole time series of the different variables of interest, the natural extension of multivariate extreme value theory leads to a class of stochastic processes known as max-stable processes. In this talk we shall review a specific class of multivariate max-stable processes known as M4 processes (short for *M*ultivariate *M*axima of *M*oving *M*axima). Estimation of these processes is quite tricky because of degeneracies that preclude the routine use of maximum likelihood estimation. Instead, we propose some alternative methods of estimation. As an application of these methods, we discuss the problem of evaluating Value at Risk in financial time series. Value at Risk involves calculating probabilities of extreme changes in the price of a stock or a portfolio. Over the past several years, numerous authors have proposed extreme value techniques for evaluating Value at Risk, but so far there is very little work in the multivariate context. We propose a method of evaluating Value at Risk that takes into account time-series dependencies as well as dependencies among the different series. Examples are given using price series data from Pfizer, General Electric and Citibank.

Key Words: Extreme value theory; financial risk; multivariate extremes; max-stable processes.

Session Number	**40 (Invited)**
Session Title	**Reliability Classes of Distributions**
Time and Day	**9:45–11:15, Saturday**
Place	**Room 205, Russell House**
Session Organizer	**Thomas Savits**, University of Pittsburgh
Session Chair	**Thomas Savits**, University of Pittsburgh

Mixtures of IFR Weibull Distributions

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Abstract: Populations of a specific component in an industrial setting are heterogeneous and consist of a small number of different sub-populations. This is often called a mixture and it arises naturally in a number of situations. For example, an industrial population often consist of at least two groups: defective items with short lifetimes and standard items with long lifetimes. It is a well-known result that

distributions with decreasing failure rate are closed under mixture. However, little is known about the monotonicity of the mixture failure rate when the various sub-populations all have an increasing failure rate or some have decreasing failure rates and the remaining have increasing failure rates. The main objective of this paper is to study the shape as well as the behavior of the mixture failure rate from two Weibull sub-populations with strictly increasing failure rate.

Key Words: Mixture; Weibull Distributions; Increasing Failure Rate (IFR).

Bathtub Shaped Failure Rate Function And Lower Bounds For Some Optimization Problems

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Abstract: Assuming that the failure rate function of products exhibits bathtub shape, much work has been done on upper bound for various optimization problems. For instance, it has been found that the optimal burn-in times associated with maximizing the mean residual life, the conditional survival probability, and minimizing different cost functions has the first change point of the bathtub shaped failure rate function as an upper bound. This greatly facilitates the numerical search of the optimal burn-in times. It will further facilitates the numerical search of the optimal policies if lower bound is also available. This paper studies this problem and gives sufficient conditions under which lower bound of the optimal burn-in times, optimal replacement and warranty policies, and optimal inspection policy associated with many problems can be obtained.

Key Words: None provided.

On Shapes and Mixtures

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Abstract: Recently there has been much interest in quantifying the shape of the distribution and failure rate function for various classes of distributions, and in particular, for mixtures of such. In this talk, we present a survey of known results. We also present a new result connecting the shape of the distribution and its failure rate function.

Key Words: Failure rate function, shape, mixtures.

Session Number	**41 (Invited)**
Session Title	**Survival Analysis and Demography**
Time and Day	**9:45–11:15, Saturday**
Place	**Room 303, Russell House**
Session Organizer	**Niels Keiding**, University of Copenhagen, Denmark
Session Chair	**Niels Keiding**, University of Copenhagen, Denmark

The Accelerated Gap Times Model

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Abstract: In this talk we introduce a new intensity model for recurrent event data in which covariates serve to "accelerate" the times in between successive event occurrences. A class of estimating functions for the regression parameters is motivated from the semiparametric efficient score function, and neatly extends the results of Tsiatis (1990) to the case of recurrent event data. Some useful insight into the accelerated failure time model is obtained as a by product of these results. Asymptotics, efficiency considerations, and variance estimation are discussed.

Key Words: None provided.

Survival Models in Aging Studies of Biological Systems

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Abstract: Aging of individual organisms is accompanied by the decline in their survival chances. Such a decline cannot be measured directly. Indirect measurements require models relating parameters of individuals physiological and biological decline to their life spans. In this paper we discuss several models used in the analyses of several data sets collected in demographic or experimental aging studies. First we consider the model, which relates decline in individual stress resistance with respective life span, and discuss the results of its application to demographic time series mortality data on developed countries. Then we outline the class of models used in the analyses of data from stress experiments with laboratory animals, as well as models, which relate reproduction and life span. Then we consider survival models used in genetic studies of human longevity. Finally we discuss models used in the analyses of data from longitudinal studies of aging and longevity.

Key Words: Semiparametric models, stress, mortality decline, heritability, hormesis

Age-period-cohort models in demography

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Abstract: Age-period-cohort models are well-established in epidemiology and - from different perspectives - in sociology, while it seems that there has been less activity around this tool in recent demographic research. The basic unidentifiability of the linear trend (period vs. cohort+age) is usefully handled by sensitivity analysis, as demonstrated by a study of the mortality of Danish women, where a clear non-linear cohort effect generates hypotheses about the causes behind the recent stagnant growth in life expectancy of Danish women compared to similar countries.

This is joint work with Rune Jacobsen and Elsebeth Lynge.

Key Words: None provided.

Session Number	**42 (Invited)**
Session Title	**Recurrent Events and Survival Analysis**
Time and Day	**9:45–11:15, Saturday**
Place	**Room 305, Russell House**
Session Organizer	**Mei-Cheng Wang**, Johns Hopkins University
Session Chair	**Mei-Cheng Wang**, Johns Hopkins University

Frequency of recurrent events at failure time: Modeling and inference

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Abstract: Recurrent events arise in many longitudinal medical studies where time to a terminal event or failure is the primary endpoint. With incomplete follow-up data, the analysis of recurrent events is a challenge owing to their association with the failure. One specific quantity of interest, yet rarely addressed in the statistical literature, is the recurrence frequency at the failure time; examples include hospitalization frequency which is often used as a rough measure of lifetime medical cost. In this talk, we show that a marginal model (e.g., the log-linear model) of the recurrence frequency, albeit desirable, is typically not identifiable. For this reason, we advocate to model the recurrent events and the failure time jointly, with an approach proposed to constructing joint models from given marginal ones. Two conceptually simple and nested regression models are suggested, aiming respectively at the recurrence frequency as being a mark of the failure and at the process of recurrent events. We formulate monotone estimating functions, and propose novel interval-estimation procedures to accommodate nonsmooth estimating functions. The resulting estimators are consistent and asymptotically normal. Simulation studies exhibit that these proposals are easy to implement and reliable for practical use. Illustration is provided with application to an AIDS clinical trial. Finally, we generalize our proposals to marked recurrent events, and devise a global inference procedure for recurrent events of multiple types.

Joint work with Mei-Cheng Wang, Bloomberg School of Public Health, Johns Hopkins Univ.

Key Words: None provided.

Proportional hazards regression model with unknown link function

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Abstract: In survival analysis, the relationship between a survival time and covariates is conveniently modeled with the proportional hazards regression model. This model usually assumes that covariates have log-linear effects on the hazard function. We consider the proportional hazards regression model

with an unspecified nonparametric link function and unspecified baseline hazard function. A two-stage iterative algorithm is proposed to estimate the covariate effects and the unknown link function, whence the baseline hazard function. The procedure is then illustrated to show the effect of misspecifying the link function. Extensions to longitudinally observed covariates will also be discussed.

Joint work with Wei Wang, School of Public Health, Harvard University.

Key Words: None provided.

Inference for a General Class of Models for Recurrent Events

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Abstract: Peña and Hollander (2003, to appear) presented a general class of models for recurrent events that takes into account the effects of possibly time-dependent covariates, the weakening or strenghtening effects of accumulating event occurrences, the impact of interventions that are performed after each event occurrence, and which also incorporates the presence of unobservable frailties that could be inducing associations among the inter-event times for each unit. Formally, if $N(s)$ is the counting process counting the number of event occurrences upto calendar time s for a unit with a predictable covariate vector $\mathbf{X}(s)$ and at-risk indicator $Y(s)$, the model specifies that

$$\Pr\{dN(s) = 1 | Z, \{(N(u), Y(u), X(u), \mathcal{E}(u)), u < s\}\} = Y(s) Z \lambda_0[\mathcal{E}(s)] \rho[N(s-); \alpha] \exp\{\beta' \mathbf{X}(s)\} ds$$

where $\lambda_0(\cdot)$ is an unknown baseline hazard function; Z is an unobserved frailty, usually assumed to be gamma distributed with same shape and scale parameter; $\rho(\cdot; \alpha)$ is a nonnegative function on the set of nonnegative integers; and $\mathcal{E}(s)$ is a predictable process encoding the effect of interventions. In this talk, progress on research dealing with inference for this model, specifically methods for estimating β and $\lambda_0(\cdot)$, will be presented. Since the accruing data for each unit will be restricted by the finite, possibly random, observation period, the impact of the consequent informative censoring mechanism and informativeness of the number of observed events will be pointed out.

Key Words: Recurrent events, multiplicative intensity models, frailties, sum-quota accrual scheme.

Session Number	**43 (Plenary)**
Session Title	**Aspects of Mixtures in Failure-Time Modelling**
Time and Day	**11:30–12:15, Saturday**
Place	**Russell House Ballroom**
Session Organizer	Organizers
Session Chair	**James Lynch**, University of South Carolina

On the Failure Rates of Mixtures

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Abstract: Mixtures of distributions of lifetimes occur in many settings. In engineering applications it is often the case that populations are heterogeneous, often with a small number of subpopulations. In survival analysis, selection effects can often occur. The concept of a failure rate in these settings becomes a complicated topic, especially when one attempts to interpret the shape as a function of time. Even if the failure rates of the subpopulations of the mixture have simple geometric or parametric forms, the shape of the mixture is often not transparent.

Recent results, developed by the author (with Joe, Li, Mi, Savits and Wondmagegnehu) in a series of papers, are presented. These results focus on general results concerning the asymptotic limit and eventual monotonicity of a mixture and also of the overall behavior for mixtures of specific parametric families. There has also been some recent work on mixtures of Weibull and gamma distributions by other authors and this also will be discussed.

Connections between unimodality of densities and their mixtures and changes in monotonicity of the failure rates have recently been studied and these results will also be presented.

An overall picture of the various things which influence the behavior of the failure rate of a mixture will be given.

Key Words: None provided.

Poster Session I Presenters

May 22, 2003 (Thursday)
Russell House Room 302
Period: 12:00–6:00
(Set-Up Time: Thursday Morning)

Simultaneous Group Sequential Analysis of Rank-Based and Weighted Kaplan-Meier Tests for Paired Censored Survival Data

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Abstract: This research develops strategies for sequentially monitoring differences in survivorship between two groups using a new class of non-parametric tests based on functionals of standardized paired weighted log-rank ($PWLR$) and standardized paired weighted Kaplan-Meier ($PWKM$) tests. By monitoring $EMAX$, the most extreme of standardized $PWLR$ and $PWKM$, one may combine the advantages offered by rank-based and non rank-based paired testing paradigms.

Simulations indicate that when monitoring treatment differences using $EMAX$, the type I error is properly maintained and the testing procedure is nearly as powerful as the more advantageous of the two tests, in proportional hazards (PH) as well as non-PH situations. Hence, $EMAX$ is more robust at preserving power than individually monitored $PWLR$ and $PWKM$, while maintaining a reasonably simple approach to design and analysis of results.

An example of how to design a group sequential trial using the proposed methodology is given.

Key Words: Clinical Trials; Group Sequential Monitoring; Nonparametric; Survival Analysis; Paired Weighted Kaplan-Meier; Paired Weighted Log-Rank.

Nonparametric Accelerated Degradation Models in Life-Testing

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Abstract: In analyzing the reliability of a product, the quantity of interest is usually the time-to-failure. However, many products may degrade before failure, and it is possible to record the actual degradation on units as a function of time. The time-to-failure will be defined as the time when a unit reaches a particular level of degradation. We would like to use degradation data in assessing product performance. It may be advantageous to use such data in designing systems with high reliability that may have very few failures. In this paper we will focus on accelerated degradation models in life testing. In accelerated degradation life testing experiments, a certain number of units are subjected to a stress that is higher than normal. For each unit we measure the degradation at specified points of time, and the experiment is conducted under different values of the stress. We propose a new model for acceleration degradation data called a proportional wearout model. For the proportional wearout model we develop a nonparametric procedure to obtain estimates of the mean degradation curves at the various stress levels, and we estimate the acceleration factor for each stress level. From that we obtain a point estimate and a bootstrap confidence interval of the time-to-failure for the mean degradation curve under the usual use condition. Also we obtain an estimate of the distribution of time-to-failure for individual units under the usual use condition. The procedure is applied to a set of sliding metal wear data. We present a

method to test the goodness of fit of the proportional wearout model and we evaluate the bias, mean square error and coverage percentages of the nonparametric procedure.

Key Words: Accelerated degradation life test, local linear regression smoother, nonparametric regression, stochastic process

Quality of Life in Epilepsy Patients after Resective Surgery by Seizure Outcome

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Abstract: Five domains of quality of life were measured on patients once before and three times after resective surgery. We try to model these data on several covariates, including seizure outcome after surgery. Seizure outcome is classified into four groups,depending on how well the patient performed after surgery. We found that this was the only significant predictor of quality of life from our list of candidate covariates.

Key Words: None provided.

The generalized hazardgram: An alternative nonparametric estimator for the hazard function

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Abstract: We introduce a non-parametric estimator of the hazard function called generalized hazardgram defined as the generalization of histogram type estimators for density function proposed by Delicado and del Ro (1999). These new estimators are expressed as a linear combination of density functions that are piecewise polynomials, where the coefficients are optimally chosen to minimize a weighted version of the integrated square error. The asymptotic behavior of these estimators is established. We proposed a bandwidth choice method based in their asymptotic properties and assuming a weibull model. We extend this estimator to right censored case and we carry out a simulation in order to perform its statistical properties. Finally an example of a real data, using the R functions implemented in the "ghe package", is analyzed. References: Delicado, P. and del Ro, M. (1999) A Generalization of Histogram Type Estimators. Economics Working Paper 422, UPF. (submitted at the *Journal of Nonparametric Statistics*.)

Key Words: non-parametric hazard estimator, generalized histogram, convolution

Inference from Accelerated Degradation and Failure Data Based on Gaussian Process Models

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Abstract: An important problem in reliability and survival analysis is that of modeling degradation together with any observed failures in a life test. Here, based on a continuous cumulative damage approach with a Gaussian process describing degradation, a general accelerated test model is presented in which both failure times and degradation measures can be used for inference about system lifetime. The specific model when the drift of the Gaussian process depends on the acceleration variable through the power law is discussed in detail. Illustrative examples using simulated data as well as temperature-accelerated degradation data observed in carbon-film resistors are presented.

Key Words: Inverse Gaussian distribution; accelerated life test; degradation process; Fisher information; power law; censoring.

A General Counting Process Model for Recurrent Event Data

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Abstract: A general class of models for recurrent event data given by Peña and Hollander (2002) is considered. The class of models includes many of the models found throughout the literature. These include the imperfect repair model of Brown and Proschan (1983), the general Cox proportional hazards model, and the general repair model of Dorado, Hollander, and Sethuraman (1997). The model is based on using a flexible multiplicative intensity process. It allows for the inclusion of the effect of repeated failures by perturbing the baseline intensity process with an "effective age" process. The effect of interventions due to multiple failures is included by use of a function included multiplicatively in the intensity process. The influence of outside factors through the use of a link function with covariates is included. The inclusion of a frailty component is allowed for modeling unobservable random effects. The model is considered under a fully parametric specification where a frailty is assumed not to exist. Estimators are obtained by the development of a partial likelihood function using the results of Jacod (1975). The asymptotics and consistency for the estimators are found by transforming the model from calendar time into a gap time formulation. The estimators are found to follow asymptotically a Gaussian process with a certain quadratic variation process under certain regularity conditions. The performances of the estimators are also accessed through computer simulation.

Key Words: Counting Processes, Martingales, Product Integration, Hazard

Poster Session II Presenters

May 23, 2003 (Friday)
Russell House Room 302
Period: 12:00–6:00
(Set-Up Time: Friday Morning)

Comparison of Failure Probabilities in the Presence of Competing Risks

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Abstract: We consider methods for comparing probabilities of a specific event between several groups in the presence of competing risks. Attention will be focused on various hypothesis testing methods to

directly compare cumulative incidence functions. Along with the unadjusted methods, we will discuss hypothesis testing techniques based on regression models for the cumulative incidence functions that allow us to make comparisons between several groups after accounting for some other factors that affect event rates. Some modifications of the earlier proposed tests as well as new hypothesis testing methods will be discussed. We present simulation results to estimate type I error rates and power under different scenarios. Recommendations regarding which hypothesis tests are most appropriate and perform best in the competing risks setting will be provided. A study of the outcomes of bone marrow transplanation is used as an illustration.

Key Words: Competing risks, cumulative incidence function, K-sample tests

Bivariate Mean Residual Life Function

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Abstract: In survival analysis the additional lifetime an object survives past a time t is called the residual life function of the object. Mathematically speaking if the lifetime of the object is described by a random variable T then the random variable $R = [T - t|T > t]$ is called the residual life random variable. The quantity $e(t) = E(R)$ is called the mean residual lifetime function or the life expectancy at age t. The objective of our work is to extend the concept of mean residual function to the multivariate case. A new estimator of the mean residual function is proposed and its asymptotic properties are studied.

Key Words: Mean residual function, Asymptotic properties.

Tensile reliability of an inhomogeneous bundle of fibers, using the Maximum Entropy Principle

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Abstract: The Maximum Entropy formalism developed by E. T. Jaynes is applied to the breaking strain of a bundle of fibers of various cross-sectional areas. When the bundle is subjected to a tensile load, and it is assumed that Hooke's law applies up to the breaking strain of the fibers, it is proved that the survival strain distribution for a fiber in the bundle is restricted to a certain class consisting of generalizations of the log-logistic distribution. Since Jaynes' formalism is a generalization of statistical thermodynamics, parallels are drawn between concepts in thermodynamics and in the theory of the inhomogeneous bundle of fibers. In particular, heat transfer corresponds to damage to the bundle in the form of broken fiber, and the negative reciprocal of the parameter corresponding to thermodynamic temperature is the resistance of the bundle to damage. For log-logistic fibers, the bundle hazard function and reliability are illustrated.

Key Words: max entropy, breaking strain, log-logistic distribution, thermodynamics, bundle of fibers, tensile load, temper

Modeling the agreement of discrete bivariate survival times using kappa index

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Abstract: Estimation of the agreement between discreet bivariate survival times is examined when the same event time is measured by two methods. In previous works, the relationships between two inter-raters are usually reflected by the odds ratio, which measures the association between events. However, the primary interest in study may lie in the agreement rather than the association of two measurements. In this paper, we choose kappa index, the frequently used agreement parameter for categorical data, to assess the agreement between the two survival time measures at each grid point. We model the marginal distributions and kappa-index in terms of covariates. An estimating equation is used for modeling the marginal distributions and a pseudo-likelihood procedure is used to estimate the kappa agreement index and covariate effects relating to the kappa index. The performance of the estimation procedure is examined through simulations. The proposed method can be extended to multivariate discrete distributions.

Key Words: agreement, discrete bivariate survival times, kappa

Examining the Reliability of the DAC Statistic in Detecting Spatial Clusters and its Relationship with the Survivorship Function

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Abstract: The DAC statistic represents the difference between the empirical cumulative distribution of cases and that of population at particular points. We examined its usefulness when used in conjunction with kriging to predict spatial clusters based on each datum's coordinates, and the effects of changing the orientation of axes using the empirical survivorship function based on random samples taken from all live births occurring in Spartanburg County between 1989-1990. The results indicated a variation of the location of the DAC statistic with random rotations within each sample after conversion to original coordinates. Moreover, the location of the maximum DAC statistic is not unique, and its geometrical locus varies with changes of the orientation of axes. At this time the DAC statistic is not the measure of choice when using empirical spatial distributions, but we speculate that its gradients will help predicting spatial clusters. Our results indicate the necessity of further developments.

Key Words: clusters, ECDF, spatial statistics

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