Bayesian Nonparametric Reliability Analysis for a Railway System at Component Level

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Abstract—Railway system is a typical large-scale complex system with interconnected sub-systems which contain numerous components. System reliability is retained through appropriate maintenance measures and cost-effective asset management requires accurate estimation of reliability at the lowest level. However, real-life reliability data at component level of a railway system is not always available in practice, let alone complete. The component lifetime distributions from the manufacturers are often obscured and complicated by the actual usage and working environments. Reliability analysis thus calls for a suitable methodology to estimate a component lifetime under the conditions of a lack of failure data and unknown and/or mixture lifetime distributions. This paper proposes a nonparametric Bayesian approach with a Dirichlet Process Mixture Model (DPMM) to facilitate reliability analysis in a railway system. Simulation results will be given to illustrate the effectiveness of the proposed approach in lifetime estimation.

Keywords—Finite Mixture Model; Lifetime Estimation; Nonparametric Bayesian; Reliability Modeling

I. INTRODUCTION

Rail system requires high asset investment and yields low return over the long asset life cycle. It is a complex system with physically interconnected and functionally interdependent sub-systems and components, such as tracks, rolling stocks, power supply and signaling. The overall reliability is imperative to the quality of service provision and it is upheld through appropriate maintenance works. Maintenance scheduling is a delicate balancing act between cost and reliability. The desired level of reliability is the driver while the cost is the constraint. The system reliability inevitably relates to that of the sub-systems and components through the system configuration and function criticality.

In order to evaluate system reliability, it is essential to understand the reliability at the lowest levels. However, not every sub-system or component comes with adequate reliability data when its condition changes, usually deteriorates, due to usage, tear-and-wear, fatigue and working conditions. Failure data is not particularly well recorded, and in most cases, it is simply not available as rail systems tend to be over-maintained to eliminate failures at all. Failure behavior of the components is not necessarily constant or homogeneous. It may change over time because of possible maintenance regimes, service intensity, operation conditions, locations and climate, and vary over different components. These factors attribute to an unknown component lifetime distribution or a mixture of distributions, which complicates the estimation of component lifetime and thus fails to inform the necessary maintenance planning. To address the uncertainties on component lifetime estimation, nonparametric statistical approaches are conceived to be a useful tool to extract lifetime information from limited available data [1].

Reliability analysis is always related to statistical approaches as the commonly adopted lifetime models are usually expressed in probability density functions [1]. Applications in railway systems have not been very extensive but successful examples can be found from component to system levels [2–4]. In order to estimate the component lifetime at a particular time period with limited real-life data and uncertain lifetime distribution, a nonparametric Bayesian approach at sub-system or component level is proposed here. Bayesian models have been employed in various railway system reliability studies [5–7], particularly in response to the uncertainty in the condition deterioration of the system or component through its life-cycle.

With Bayesian models, statistical inference can be built up from little knowledge on the component failure data and distributions, and it evolves by incorporating additional data whenever it is made available. Bayesian methods are broadly classified into parametric and nonparametric approaches. The former has the advantage of simple representation, in the sense that model parameters are able to explain the behavior of the entire data. However, the resulting model strongly depends on stringent model assumptions and imposes certain structural restrictions. The latter is quite commonly adopted in practice when the model assumptions do not always hold or the available data does not contain sufficient information.

As the component lifetime distribution in railway may be a composition of a number of unknown distributions, a mixture distribution, instead of a typical one such as Weibull and Lognormal, is a more realistic model. A Bayesian nonparametric method, based on Dirichlet Process Mixture Model (DPMM) using Markov Chain Monte Carlo (MCMC) algorithm, is proposed here. DPMM allows an empirical mixture distribution to fit the available failure data. The number and characteristics of the mixtures may be unknown but they can be captured through gradual feeding of available data [8–11]. In addition, different kernel distributions of the model are possible and the comparison of the estimation capability will be discussed through simulation. The main objective of this study is to find out the effectiveness of nonparametric Bayesian methods in the estimation of the component reliability and the necessary conditions of the available data to achieve such effectiveness.

The remainder of this paper is structured as follows. In Section II, the nonparametric Bayesian methods and Dirichlet

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Big Data and Differential Privacy Nii O. Attoh-Okine,2017-05-12 A comprehensive introduction to the theory and practice of contemporary data science analysis for railway track engineering Featuring a practical introduction to state of the art data analysis for railway track engineering Big Data and Differential Privacy Analysis Strategies for Railway Track Engineering addresses common issues with the implementation of big data applications while exploring the limitations advantages and disadvantages of more conventional methods In addition the book provides a unifying approach to analyzing large volumes of data in railway track engineering using an array of proven methods and software technologies Dr Attoh Okine considers some of today s most notable applications and implementations and highlights when a particular method or algorithm is most appropriate Throughout the book presents numerous real world examples to illustrate the latest railway engineering big data applications of predictive analytics such as the Union Pacific Railroad s use of big data to reduce train derailments increase the velocity of shipments and reduce emissions In addition to providing an overview of the latest software tools used to analyze the large amount of data obtained by railways Big Data and Differential Privacy Analysis Strategies for Railway Track Engineering Features a unified framework for handling large volumes of data in railway track engineering using predictive analytics machine learning and data mining Explores issues of big data and differential privacy and discusses the various advantages and disadvantages of more conventional data analysis techniques Implements big data applications while addressing common issues in railway track maintenance Explores the advantages and pitfalls of data analysis software such as R and Spark as well as the ApacheTM Hadoop data collection database and its popular implementation MapReduce Big Data and Differential Privacy is a valuable resource for researchers and professionals in transportation science railway track engineering design engineering operations research and railway planning and management The book is also appropriate for graduate courses on data analysis and data mining transportation science operations research and infrastructure management NII ATTOH OKINE PhD PE is Professor in the Department of Civil and Environmental Engineering at the University of Delaware The author of over 70 journal articles his main areas of research include big data and data science computational intelligence graphical models and belief functions civil infrastructure systems image and signal processing resilience engineering and railway track analysis Dr Attoh Okine has edited five books in the areas of computational intelligence infrastructure systems and has served as an Associate Editor of various ASCE and IEEE journals Handbook of RAMS in Railway Systems Qamar Mahboob,Enrico Zio,2018-03-14 The Handbook of RAMS in Railway Systems Theory and Practice addresses the complexity in today s railway systems which use computers and electromechanical components to increase efficiency while ensuring a high level of safety RAM Reliability Availability Maintainability addresses the specifications and standards that manufacturers and operators have to meet Modeling implementation and assessment of RAM and safety requires the integration of railway engineering systems mathematical and

statistical methods standards compliance and financial economic factors This Handbook brings together a group of experts to present RAM and safety in a modern comprehensive manner **Bayesian Nonparametric Reliability Analysis Using Dirichlet Process Mixture Model** Nan Cheng,2011 **Journal of the American Statistical Association** ,2005 A scientific and educational journal not only for professional statisticians but also for economists business executives research directors government officials university professors and others who are seriously interested in the application of statistical methods to practical problems in the development of more useful methods and in the improvement of basic statistical data

Probabilistic Safety Assessment and Management Cornelia Spitzer,Ulrich Schmocker,Vinh N. Dang,2014-01-04 Probabilistic Safety Assessment and Management is a collection of papers presented at the PSAM 7 ESREL 04 Conference in June 2004 The joint Conference provided a forum for the presentation of the latest developments in methodology and application of probabilistic and reliability methods in various industries The aim of these applications is the optimisation of technological systems and processes from the perspective of a risk informed safety management while also taking economic and environmental aspects into account Bringing together leading experts from all over the world the papers reflect a wide variety of disciplines such as principles and theory of reliability and risk analysis systems modelling and simulation consequence assessment human and organisational factors structural reliability methods software reliability and safety insights and lessons from risk studies and management decision making Government Reports Annual Index ,1975 Sections 1 2 Keyword Index Section 3 Personal author index Section 4 Corporate author index Section 5 Contract grant number index NTIS order report number index 1 E Section 6 NTIS order report number index F Z *Bibliographic Guide to Technology* New York Public Library. Research Libraries,1978 **The British National Bibliography** Arthur James Wells,1979 Electrical & Electronics Abstracts ,1972 **Index to Theses with Abstracts Accepted for Higher Degrees by the Universities of Great Britain and Ireland and the Council for National Academic Awards** ,2006 Theses on any subject submitted by the academic libraries in the UK and Ireland Government Reports Announcements & Index ,1996-08 *AMSTAT News* American Statistical Association,2003 **Index to Scientific & Technical Proceedings** ,1979-07 Monthly with annual cumulation Published conference literature useful both as current awareness and retrospective tools that allow searching by authors of individual papers as well as by editors Includes proceedings in all formats i e books reports journal issues etc Complete bibliographical information for each conference proceedings appears in section titled Contents of proceedings with accompanying category permuterm subject sponsor author editor meeting location and corporate indexes Contains abbreviations used in organizational and geographical names The Theory and Applications of Reliability With Emphasis on Bayesian and Nonparametric Methods Chris Tsokos,2012-12-02 The Theory and Applications of Reliability With Emphasis on Bayesian and Nonparametric Methods Volume I covers the proceedings of the conference on The Theory and Applications of Reliability with Emphasis on Bayesian and Nonparametric Methods The

conference is organized so as to have technical presentations a clinical session and round table discussions This volume is a 29 chapter text that specifically deals with the theoretical aspects of reliability estimation Considerable chapters on the technical sessions are devoted to initial findings on the theory and applications of reliability estimation with special emphasis on Bayesian and nonparametric methods A Bayesian analysis implies the use of suitable prior information in association with Bayes theorem while the nonparametric approach analyzes the reliability components and systems under the assumption of a time to failure distribution with a wide defining property rather than a specific parametric class of probability distributions The clinical session chapters discuss the actual problems encountered in reliability estimation The remaining chapters deal with the status of the subject areas and the empirical Bayes developments These chapters also present various probabilistic and statistic methods for reliability estimation Theoreticians and reliability engineers will find this book invaluable

Theory Applications Of Reliability -emphasis On Bayesian Nonparametric M.- C.P. Tsokos, **Reliability and Risk** Nozer D. Singpurwalla,2006-09-11 We all like to know how reliable and how risky certain situations are and our increasing reliance on technology has led to the need for more precise assessments than ever before Such precision has resulted in efforts both to sharpen the notions of risk and reliability and to quantify them Quantification is required for normative decision making especially decisions pertaining to our safety and wellbeing Increasingly in recent years Bayesian methods have become key to such quantifications Reliability and Risk provides a comprehensive overview of the mathematical and statistical aspects of risk and reliability analysis from a Bayesian perspective This book sets out to change the way in which we think about reliability and survival analysis by casting them in the broader context of decision making This is achieved by Providing a broad coverage of the diverse aspects of reliability including multivariate failure models dynamic reliability event history analysis non parametric Bayes competing risks co operative and competing systems and signature analysis Covering the essentials of Bayesian statistics and exchangeability enabling readers who are unfamiliar with Bayesian inference to benefit from the book Introducing the notion of composite reliability or the collective reliability of a population of items Discussing the relationship between notions of reliability and survival analysis and econometrics and financial risk Reliability and Risk can most profitably be used by practitioners and research workers in reliability and survivability as a source of information reference and open problems It can also form the basis of a graduate level course in reliability and risk analysis for students in statistics biostatistics engineering industrial nuclear systems operations research and other mathematically oriented scientists wherein the instructor could supplement the material with examples and problems **Reliability, Safety, and Security of Railway Systems. Modelling, Analysis, Verification, and Certification** Alessandro Fantechi,Thierry Lecomte,Alexander Romanovsky,2017-10-20 This volume constitutes the proceedings of the Second International Conference on Reliability Safety and Security of Railway Systems RRSRail 2017 held in Pistoia Italy in November 2017 The 16 papers presented in this volume were carefully reviewed and selected from 34

submissions They are organized in topical sections named communication challenges in railway systems formal modeling and verification for safety light rail and urban transit and engineering techniques and standards The book also contains one keynote talk in full paper length **Bayesian Nonparametric Inference in Reliability Theory** Purushottam Laud,1977

A Bayesian Nonparametric Approach to Reliability Richard L. Dykstra,Purushottam Waman Laud,MISSOURI UNIV-COLUMBIA DEPT OF STATISTICS.,1979 It is suggested that problems in a reliability context may be handled by a Bayesian non parametric approach A stochastic process is defined whose sample paths may be assumed to be either increasing hazard rates or decreasing hazard rates by properly choosing the parameter functions of the process The posterior distribution of the hazard rates are derived for both exact and censored data Bayes estimates of hazard rates c d f s densities and means are found under squared error type loss functions Some simulation is done and estimates graphed to better understand the estimators Finally estimates of the c d f from some data in a paper by Kaplan and Meier are constructed Author **Bayesian Reliability** Michael S. Hamada,Alyson Wilson,C. Shane Reese,Harry Martz,2008-07-10 Bayesian Reliability presents modern methods and techniques for analyzing reliability data from a Bayesian perspective The adoption and application of Bayesian methods in virtually all branches of science and engineering have significantly increased over the past few decades This increase is largely due to advances in simulation based computational tools for implementing Bayesian methods The authors extensively use such tools throughout this book focusing on assessing the reliability of components and systems with particular attention to hierarchical models and models incorporating explanatory variables Such models include failure time regression models accelerated testing models and degradation models The authors pay special attention to Bayesian goodness of fit testing model validation reliability test design and assurance test planning Throughout the book the authors use Markov chain Monte Carlo MCMC algorithms for implementing Bayesian analyses algorithms that make the Bayesian approach to reliability computationally feasible and conceptually straightforward This book is primarily a reference collection of modern Bayesian methods in reliability for use by reliability practitioners There are more than 70 illustrative examples most of which utilize real world data This book can also be used as a textbook for a course in reliability and contains more than 160 exercises Noteworthy highlights of the book include Bayesian approaches for the following Goodness of fit and model selection methods Hierarchical models for reliability estimation Fault tree analysis methodology that supports data acquisition at all levels in the tree Bayesian networks in reliability analysis Analysis of failure count and failure time data collected from repairable systems and the assessment of various related performance criteria Analysis of nondestructive and destructive degradation data Optimal design of reliability experiments Hierarchical reliability assurance testing

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