

# Bayesian Nonparametric Reliability Analysis for a Railway System at Component Level

Payam Mokhtarian<sup>1\*</sup>, Mohammad-Reza Namzi-Rad<sup>2</sup>, Tin Kin Ho<sup>2</sup>, and Thomas Suesse<sup>2</sup>

<sup>1</sup>National Institute for Applied Statistics Research Australia, University of Wollongong, NSW 2522, AUSTRALIA

<sup>2</sup>Smart Infrastructure Facility, University of Wollongong, NSW 2522, AUSTRALIA

**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 Modelling

## 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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**AN Whitehead**



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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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