Preface

One of the most common problems in the practice of engineering reliability is that of selecting a particular system design among the several options available for achieving some particular performance goal. Often, the goal is a long-lived system. In the case of repairable systems, the goal might be identifying a system design that has as little downtime as possible. The best performance per unit cost is another worthy potential goal. The purpose of this monograph is to provide some guidance on how problems of this type might be formulated and solved. Our approach relies on the relatively new notion of "system signatures." We will introduce the concept here in the context of the well established theory of coherent systems and will seek to provide convincing evidence that the recommended approach to the problems mentioned above is efficacious.

I must admit that I stumbled on the notion of system signatures quite by accident. While visiting the University of Washington in 1982-3, on sabbatical leave from the University of California, Davis, I was, among other things, working on a number of research problems in Reliability Theory. One problem involved trying to understand more deeply the concept of "closure" under the formation of coherent systems. My being in Seattle, where much of the seminal work in this area had been done in the 60s by Birnbaum, Esary, Marshall, Proschan and Saunders, may have subconsciously driven me toward this topic. What was well known at the time was that a (coherent) system in components with increasing failure rates (IFR) is not "closed," that is, is not necessarily IFR, but that the larger class of systems in components with the IFRA (increasing failure rate average) property is closed, that is, these systems are themselves IFRA.

The question that interested me at the time was more or less halfway between these two results – what could one say about the class of systems that did enjoy the IFR closure property? The literature contained a partial answer: k-out-of-n systems in i.i.d. IFR components were known to be IFR.

Expanding upon this result seemed to require a new tool. My immediate goal was to find ways of identifying a direct connection between the failure rate of a system and the common failure rate of its components. The representation theorem in Samaniego [61] expressing the system's failure rate as a multiple of the component failure rate turned out to be the tool that permitted the complete characterization of systems that will be IFR when their components are i.i.d. IFR. That representation had the form $r_T(t) = h(\mathbf{s}, F)r(t)$, where $\mathbf{s}$ is the signature of the system, a vector essentially capturing the influence of the system design on the system's failure rate, and F and r are the underlying distribution and failure rate of the components. So the birth of the signature idea dates back nearly 25 years. In the preceding paragraph, I referred to this notion as "relatively new." In the grand scheme of things, 25 years goes by in a flash, so from that point of view, one could say that signatures are relatively new. My intent, however, was to acknowledge that the notion was not recognized as broadly useful until its properties were carefully studied in their own right. In Kochar, Mukerjee and Samaniego [51], some new preservation theorems were proven, and the comparison of system lifetimes via the properties of their signatures was shown to be feasible and fruitful. These results revealed the potential power and breadth of the concept. Both of the themes referred to above will be presented in detail in Chapter 4 of the present work.

This monograph consists of six substantive chapters on signatures and their applications, together with an opening chapter introducing the topic and a closing chapter summarizing the state of research on signatures and sharing some of my thoughts on future theoretical developments and potential applications of interest. Most of the existing theory on structural reliability is based on Birnbaum, Esary and Saunders' [9] seminal work on multicomponent, two-state systems. As in Birnbaum, et al. [9], our emphasis here will be on binary systems (which are either in a functioning (1) or failed (0) state). My work with the notion of signatures began with the publication of Samaniego [61], a paper entitled "On the Closure of the IFR Class under the Formation of Coherent Systems." In that paper, the signature vector was defined for a coherent system with components having i.i.d. lifetimes with common distribution F. In brief, the signature of such a system in n components is an n-dimensional probability vector $\mathbf{s}$ that is the distribution of the index of the ordered component failure time that corresponds to system failure.

Especially in the last decade, the broad applicability of system signatures has become apparent, and their utility in the comparison of coherent systems and communication networks has been more firmly established. Most recently, we have found that the tool can facilitate the reformulation of heretofore analytically intractable discrete optimization problems in the area of Reliability Economics, providing a mechanism which can make the analytical treatment of these problems feasible. My purpose here is to present a useful overview of work to date on the properties and applications of system signatures with a view toward opening up new potential applications. Some new results will be combined with work available in the literature. The present work is intended to be both comprehensive and unifying. If I succeed in accomplishing these goals, I am convinced that both the scope and depth of application of system signatures in reliability will be substantially enhanced in future work.

I wish to thank my students and coworkers who have participated in many of my studies in this general problem area. These include, in alphabetical order, Debasisis Bhattacharya, Henry Block, Philip Boland, Michael Dugas, Subhash Kochar, Myles Hollander, Michael McAssey, Hari Mukerjee, Moshe Shaked and Eric Vestrup. Many of the ideas presented in this monograph came to life in the course of my conversations with these collaborators, and I express to each of them my deep appreciation for the many stimulating discussions we have had and for each of their contributions to the theory and application of the signature idea. I hope that this attempt to present a coherent and unified version of our collective results does justice to both the work and to these key contributors.

I express my special appreciation to Dr. Robert Launer and to Dr. Harry Chang of the Army Research Office for their sustained support of this project. The present work combines new results developed under ARO support with a reworking and new presentation of years of work on signature-related ideas. My recent research in this area, as well as my work on the present project, was supported by ARO grants ARO19-02-1-0377 and WN11NF05-1-0118. It is also a pleasure to acknowledge other agencies that have supported this work over the years, including the Air Force Office of Scientific Research, The Ford Foundation, The National Security Agency and The National Science Foundation. This monograph was written during a sabbatical leave funded by the University of California, Davis, and I gratefully acknowledge that support as being a critical element in the completion of this project. I would like to thank Brad Efron for inviting me to spend a portion of that leave in the Statistics Department at Stanford University. This provided me with a stimulating yet quiet place to hide out while getting this project off the ground. Finally, I thank the students in my graduate reliability course in Winter Quarter, 2007, for reading the penultimate draft of this monograph and suggesting many improvements. My thanks to Ying Chen, Tammy Greasby, Yolanda Hagar, Jung Won Hyun, Michelle Norris, Clayton Schupp, and Li Zhu.

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