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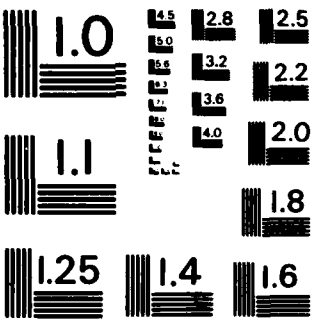

RESEARCH IN SOME APPLIED AND THE MODELLING ASPECTS OF RELIABILITY THEORY

Final Report

GWU/IRRA/TR-83/3

Nozer D. Singpurwalla

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The George Washington University

Washington, D.C. 20052

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Quantile estimation, Bayesian bioassay, Failure rate estimation, Accelerated life testing, Life testing, Sequential life testing, Time series analysis, Kalman filtering, Software reliability, Goodness of fit testing, Reliability growth, Simulating Gaussian processes.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this report a summary of the various topics of interest in reliability and life testing research are summarized. References to published literature are cited. The topics covered are described by the key words.

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FOREWORD

This is a final report which summarizes the research conducted under the referenced contract, on a large class of topics motivated by reliability and life testing problems. The topics covered include, in alphabetical order, accelerated life tests, Bayesian bioassay, failure rate estimation, goodness of fit testing, Kalman filtering, life testing, quantile estimation, reliability growth monitoring, software reliability, sequential life testing, simulation of Gaussian processes, and time series analysis of reliability data. Most of the work undertaken has appeared in print as journal articles, and this is referenced. The other work is currently under review for various professional journals.

FINAL REPORT

During the contract period several topical areas motivated by practical problems in reliability modelling and life testing were undertaken. Some of these problems were directly generated by Army laboratories, and were undertaken as a result of direct interaction with Army personnel. The others were generated in the interest of promoting research in reliability. The research can be categorized into the following topical areas, described under statements of the problems studied and summary of results.

A. Statements of Problems Studied and Summary of Results

Our involvement with the U.S. Army Research Office began with a practical problem from an Army laboratory, and this is described first.

1. Quantile Estimation and Bayesian Bioassay

The problem of estimating the strength of an armor plate by firing projectiles at it, was posed by the Ballistics Research Laboratory at Aberdeen Proving Ground. Dr. Richard Moore was the key person involved. The aim is to estimate the probability of response at various values of the striking velocity.

A Bayesian procedure for solving the above problem has been developed under the contract, and a paper describing the details of this

procedure published. Also, a report describing the computer programs used for undertaking the above has been written.

Current work involves strengthening the proposed approach to consider concave or convex response functions, and issues pertaining to the design of experiments for conducting the tests.

2. Accelerated Life Testing

Accelerated life testing is a problem of great importance and interest to various parts of the Army. Here one attempts to make inference about the life behavior of an item, under environmental conditions which are difficult to create for laboratory tests.

Accomplishments include a Bayesian procedure for inference from accelerated tests which demands little of the user, a model for step-stress testing, and a nonparametric approach involving estimation and test of hypothesis under accelerated testing. All results are published.

3. Estimation of the Failure Rate

The failure rate is one of the most important parameters used in reliability theory. Estimation of the failure rate under minimal assumptions of its general form is an important problem.

Accomplishments incolve kernel estimates of the failure rate using jackknifing procedures, Bayesian methods for estimating the failure rate, and a survey of the various methods of estimating the failure rate. All results are published.

4. Goodness of Fit Testing for the Weibull Distribution

The problem of developing a Kolmogorov-Smirnov type of goodness of fit test for the Weibull distribution was motivated by the research on accelerated testing.

Accomplishments include the development of such a test, and a publication of the results.

5. A Bayesian View of Kalman Filtering

Kalman filtering, successfully used by engineers and other scientists, has a tremendous potential for solving several problems in reliability. Examples of these are: accelerated life testing, reliability growth monitoring, software reliability analysis, and quality control.

An expository paper which explains the connection between Bayesian inference and multivariate analysis which leads to the Kalman filter has been published.

6. Software Reliability Modelling and Analysis

Modelling the reliability of computer software is a problem of great interest to many parts of the Army. Several models describing the stochastic failure of computer software have appeared in the literature.

Accomplishments include developing some additional models for describing software failure, a unification of several models by adopting a Bayesian point of view, and the analysis of some software failure data generated by AMSAA at Aberdeen Proving Ground using Fourier analysis. The AMSAA point of contact is Dr. Larry Crow; he is also co-author of

some of the work. Much of the work here is currently under review for publication.

7. Sequential Life Testing Procedures

Sequential procedures are a key part of acceptance procedures used by the Army; they are codified as Military Standard 781C. A key assumption underlying a use of these standards is exponentiality of the life lengths. In practice, this assumption is either deliberately or otherwise overlooked. The goal now is to investigate the robustness of these procedures.

Accomplishments include a technical report (under review for publication) which points out the circumstances under which either the government (consumer) or the producer gets penalized when the specified procedures are misused.

8. Simulating the Extremes of Gaussian Processes

The need to simulate extremes of Gaussian processes arose in connection with the goodness of fit tests for the Weibull distribution, which in turn arose out of the work on accelerated testing. Some unusual properties were observed in the context of conducting such simulations, and these are reported in a published paper.

9. Time Series Analysis of Failure and Logistics Data

It is felt that much of the real life data on the failure of components and systems, and other data on the logistics of large systems which arise in a practical real life environment, can be meaningfully

analyzed using the methods of time series analysis.

Significant accomplishments include a published paper describing how "intervention analysis" and "cross spectral analysis" can be successfully used to analyze data on the logistics performance variables of a fleet of aircraft.

B. List of Publications and Technical Reports Published

A total of 27 papers and technical memoranda and reports have been written under the aegis of the referenced contract. Of these, 19 have appeared in the open literature, and four are currently under review. The remaining are for the record only. These papers and reports are cited below under the appropriate topic headings.

1. Quantile Estimation and Bayesian Bioassay

[1] Mazzuchi, T. A. and N. D. Singpurwalla (1982). "The U.S. Army (BRL's) kinetic energy penetrator problem: Estimating the probability of response for a given stimulus," *Proceedings of the 27th Conference on the Design of Experiments in Army Research Development and Testing*, ARO Report 82-2, pp. 27-58.

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[3] Soyer, R. (1983). "The design of a quantal response experiment: An empirical approach," Technical Report Serial GWU/IRRA/TR-83/2, IRRA, GWU.

2. Accelerated Life Testing

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of Reliability, Vol. R-29, No. 2, June, pp. 98-102.

[5] Sethuraman, J. and N. D. Singpurwalla (1982). "Testing of hypotheses for distributions in accelerated life tests," *Journal of the American Statistical Association*, Vol. 77, No. 377, March, pp. 204-208.

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3. Estimation of the Failure Rate

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[11] Singpurwalla, N. D. and M.-Y. Wong (1983). "Fourier integral estimate of the failure rate function and its mean square error properties," in *Survival Analysis* (J. Crowley and R. A. Johnson, eds.), Vol. 2, Lecture Notes-Monograph Series (S. S. Gupta, Series Editor), Institute of Mathematical Statistics.

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[13] Mazzuchi, T. A. and N. D. Singpurwalla (1982). "Some Bayesian approaches for estimating the failure rate," Technical Report Serial GWU/IRRA/TR-82/5, IRRA, GWU; and in *Electronic Systems Effectiveness and Life Cycle Costing* (J. K. Swirzynski, ed.), NATO ASI Series, pp. 75-92, Springer-Verlag, 1983.

4. Goodness of Fit Testing for the Weibull Distribution

[14] Chandra, M., N. D. Singpurwalla, and M. A. Stephens (1981). "Kolmogorov statistics for tests of fit for the extreme-value and Weibull distributions," *Journal of the American Statistical Association*, Vol. 76, No. 375 (Theory and Methods Section), September, pp. 729-731.

5. A Bayesian View of Kalman Filtering

[15] Meinhold, R. J. and N. D. Singpurwalla (1983). "Understanding the Kalman filter," *The American Statistician*, Vol. 37, No. 2, May, pp. 123-127.

6. Software Reliability Modelling and Analysis

[16] Meinhold, R. J. and N. D. Singpurwalla (1983). "Bayesian analysis of a commonly used model for describing software failures," *The Statistician*, Vol. 32, pp. 168-173.

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7. Life Testing, Including Sequential Tests

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8. Simulating Extreme of Gaussian Processes

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9. Time Series Analysis of Failure and Logistics Data

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C. Participating Scientific Personnel

1. Nozer D. Singpurwalla, Principal Investigator.
2. Thomas A. Mazzuchi, earned D.Sc. with partial support from the project.
3. Beverley Littlewood, Visiting Associate Professor of Engineering.
4. Refik Soyer, currently working on D.Sc. with partial support from the project.
5. Mohamed Habibullah, previous graduate student.
6. Richard J. Meinhold, currently working on Ph.D. with a small amount of support from the project.
7. Ariela Sofer, assisted Professor Littlewood.
8. Hossein Arsham, earned D.Sc. with a small amount of support from the project.

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