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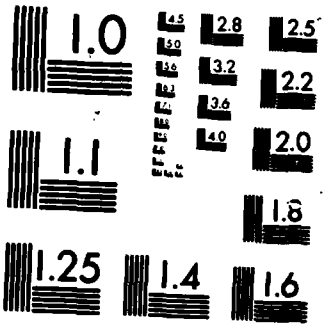

RESEARCH IN SOME METHODOLOGICAL AND MODELLING ASPECTS OF RELIABILITY THEORY

Final Report

GWU/IRRA/TR-85/18

Nozer D. Singpurwalla

17 December 1985

U.S. Army Research Office

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Quantile estimation, Bayesian life table, Failure Rate estimation, Kalman Filtering, Reliability growth, Software Reliability, Nonhomogeneous Poisson process, Time Series Analysis, Random Coefficient Autoregressive Model, Adaptive Kalman filter.

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 presented. 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 topics motivated by reliability and life testing problems. The topics covered include, in alphabetical order, failure rate estimation, quantile and response probability estimation, reliability assessment in systems of dependent components, reliability growth monitoring, and software reliability. Most of the work undertaken has appeared or will appear in print as journal articles. The other work is currently under review for various professional journals.

FINAL REPORT

During the contract period several topic areas motivated by practical problems in reliability modelling and life testing were undertaken. Some of these problems were directly generated by U.S. Army personnel and/or Army laboratories. The other problems were generated in the interest of promoting research in reliability. The research can be categorized into the following topic areas, described under statements of the problems studied and summary of results.

A. Statements of Problems Studied and Summary of Results

One of the efforts supported by this contract involves extension of the research conducted for the Ballistics Research Laboratory at Aberdeen Proving Ground, and this is described first.

1. Quantile and Response Probability Estimation

The initial problem was the estimation of armor plate strength via projectile penetration test information. Such a problem is a specific example of quantile and response probability estimation. Previous results have been extended by incorporating the assumption of a nondecreasing and concave response function. A general Bayesian framework has been presented for the analysis of such problems and the numerical implementation of the suggested approach has been investigated. The paper describing the above details is currently under review for publication.

2. Failure Rate Estimation

In reliability theory, the notion of monotone failure rate plays a central role. Estimation of the failure rate under monotonic assumptions

has received little attention from a Bayesian viewpoint.

A Bayesian Life table procedure which incorporates monotonicity assumption has been developed. One of the key benefits of the life table approach to failure rate estimation is that the subjective prior information can be easily elicited and incorporated in a straightforward and intuitive manner. A paper which describes the above results has been published.

3. Reliability Monitoring

The following problem was posed by Dr. Willard of the Office of the Deputy Undersecretary of the Army. The reliability of an arsenal which is comprised of identical units is an unknown parameter which presumably could change over time. The testing required to monitor the reliability of the arsenal is destructive and depletes the arsenal inventory. Thus, it is highly desirable to find an optimal number of items to be tested each year for effective reliability monitoring.

An approach which consists of a combination of both Bayesian and non-Bayesian features has been developed for monitoring the growth or decay in reliability of a weapon system arsenal. A paper describing the details of this approach will appear as a publication. Also, a technical report describing an algorithm and a computer code which were developed for the implementation of the above procedure has been written.

Current work involves using a Kalman filter model to monitor the reliability of the arsenal. This would also provide a tool for predicting the future arsenal reliability.

4. Reliability Assessment in Systems of Dependent Components

Assessing the reliability of series and parallel systems in terms of the reliability of their components is an important practical problem. In assessing the reliability of a system of components it is usual to

assume that the components function independently. Often this is inappropriate due to the common environment acting on all system components. Sharing a common environment induces correlation (dependence) on the components. A simple model which incorporates such dependencies has been developed. Several properties and extensions of the model have been considered. The results are presented in a paper which has been accepted for publication.

5. Software Reliability Modelling

Assessment of the reliability of software and modelling software reliability growth (decay) are key issues during the development stage of the software. Contributions in this area includes the development of a Bayesian approach to inference for nonhomogeneous Poisson processes and the implementation of the approach for assessing software reliability growth. A paper describing the details of the approach is published.

Further contributions to the software reliability literature have been made by viewing the reliability growth process as a time series. A random coefficient autoregressive model has been introduced for monitoring software reliability growth (decay) and a Bayesian inference procedure has been developed for the model. All the results are published..

Current work involves the use of adaptive Kalman filter models for software reliability monitoring and the development of inference procedures for these models.

B. List of Publications and Technical Reports Published

A total of 8 papers and technical memoranda and reports have been written under the referenced contract. Of these, 3 have appeared in the open literature, 3 have been accepted for publication, and one is currently under review. The remaining one is for the record only. These papers and reports are cited below under the appropriate topic headings.

1. Quantile and Response Probability Estimation

[1] Shaked, M. and N.D. Singpurwalla (1984). "A Bayesian Approach to Quantile and Response Probability Estimation with Applications in Reliability". Under Review.

2. Failure Rate Estimation

[2] Mazzuchi, T.A. and N.D. Singpurwalla (1985). "A Bayesian Approach to Inference for Monotone Failure Rates", *Statistics and Probability Letters, Vol. 3, No. 3,* pp. 135-142.

3. Reliability Monitoring

[3] Launer, R. and N.D. Singpurwalla (1984). "Monitoring the Reliability of Pershing II Missiles -- A Critique of the Current Methodology and a Suggested Combined Bayesian - Sample Theoretic Approach", Technical Paper Serial GWU/IRRA/TR-84/4, Institute for Reliability and Risk Analysis, The George Washington University.

[4] Launer, R. and N.D. Singpurwalla (1985). "Monitoring the Reliability of an Arsenal Using a Combined Bayesian and Sample Theoretic Approach", *Reliability and Quality Control* (A.P. Basu, ed.) North-Holland. To Appear.

4. Reliability Assessment in Systems of Dependent Components

[5] Lindley, D.V. and N.D. Singpurwalla (1986). "Multivariate Distributions for the Reliability of a System of Components Sharing a Common Environment", *Journal of Applied Probability*. To Appear, June 1986.

5. Software Reliability Modelling

[6] Kyparisis, J. and N.D. Singpurwalla (1984). "Bayesian Inference for the Weibull Process with Applications to Assessing Software Reliability Growth and Predicting Software Failures", *Proceedings of the 16th Computer Science and Statistics Symposium on the Interface* (L. Billard, ed.), pp. 57-64.

[7] Singpurwalla, N.D. (1985). "Software Reliability", *Encyclopedia of Statistical Sciences, Vol. 6.* In Press.

[8] Horigome, M., N.D. Singpurwalla, and R. Soyer, (1984). "A Bayes empirical Bayes approach for (software) reliability growth", *Proceedings of the 16th Computer Science and Statistics Sympoisum on the Interface* (L. Billard, ed.), pp. 47-56.

C. Participating Scientific Personnel

1. Nozer D. Singpurwalla, Principal Investigator

2. Dennis V. Lindley, Visiting Professor of Statistics.

3. Michio Horigome, Visiting Associate Professor of Engineering.

4. Jerzy Kyparisis, earned D.Sc. with partial support from the project.

5. Refik Soyer, earned D.Sc. with partial support from the project.

6. Sikander Daryanani, Research Assistant.

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