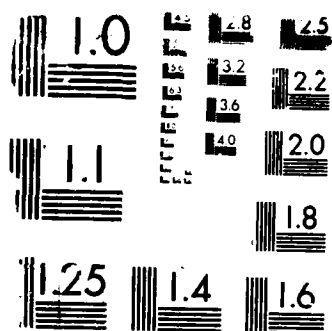


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RELIABILITY CENTER M HOLLANDER ET AL OCT 87
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A total of 33 research reports were issued, and 35 papers were published in scientific journals or are in press. Research topics included optimal assembly of systems, multistate system theory, testing whether new is better than used nonparameter survival function estimation measuring information in censored models, generalizations of total positively and multivariate probability inequalities.

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Final Report to Air Force Office
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October 1, 1984 - September 30, 1987

Statistical Aspects of
Reliability, Maintainability, and Availability

Reliability Center
Department of Statistics
Florida State University
Tallahassee, FL 32306-3033

Prof. Myles Hollander & Prof. Frank Proschan, Co-Principal Investigators

Prof. Hani Doss, Co-Investigator

October, 1987

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A. Summary.

Under Contract AFOSR Number F49620-85-C-0007, a total of 33 research reports were issued, and 35 papers were published in scientific journals or volumes, or are in press.

The research performed under the Contract developed theory, concepts, and methods in reliability, availability, and maintainability, applicable or potentially applicable to the programs of the U.S. Air Force in particular and to the Department of Defense in general. In addition, because of the general nature of the mathematical and statistical approach used, the results obtained are of value in a variety of other applied and theoretical areas of statistics and probability used by the U. S. Air Force.

A partial list of topics treated may give an idea of the broad scope of the research performed under the Contract:

1. Optimum assembly of systems resulting from optimal choice of components.
2. Multistate system theory, generalizing current function-fail 2 state theory.
3. Testing whether a new item is stochastically longer-lived than an item of specific age.
4. Nonparametric estimation of a discrete survival function when observations are censored, yielding a smoother, more credible estimate than the standard Kaplan-Meier method estimate.
5. Measuring a priori the effect of increased censorship on an estimate of a life distribution.
6. Measuring information in censored models.
7. Generalizations of total positivity, with applications in multivariate probability and statistics.



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Codes

8. Characterization of discrete IFR distributions based on coincidences among order statistics.
9. Extension of Schur functions and majorization to the continuous case, the multivariate vector case, and the continuous multivariate case.
10. Testing whether new is better than used of a specified age with randomly censored data.
11. Further multivariate probability inequalities using Schur functions and increasing in arrangement functions; in both cases the extension permits multivector arguments. The applications apply to many practical reliability and maintainability problems faced by the U.S. Air Force.
12. Simultaneous estimation of coherent system survival function and component survival functions when the system death prevents further monitoring of the components.
13. Development of maintenance models in which maintenance actions are subject to random error of either the measuring device or the inspector operating it.
14. Development of new Markov stochastic processes corresponding to notions of IFR, IFRA, and other life distribution classes arising in reliability and maintainability problems.
15. Development of confidence bands for the reliability function under a proportional hazards model.
16. Estimation of the quantiles of the distribution of the lifelength of a complex system from partial information on the components.
17. Investigation of the performance of bootstrap methodology to estimation of the reliability of systems composed of a large number of components.

Our academic year and summer programs of visitors to the Reliability Center were highly successful. We had twelve distinguished visiting researchers, well known for their work in reliability. Three of the twelve came for two summers and three others came for all three summers in the period. Research activity and interaction were quite high. In several cases, new bonds of interaction and joint research were formed. These bonds will yield future research.

B. Basic Research - Technical Reports and Published Papers

Technical Reports:

- El-Newehi, E., Proschan, F. and Sethuraman, J. (1984). Optimal Allocation of Components in Parallel-Series and Series-Parallel Systems. AFOSR 84-173.
- Barlow, R.E. and Proschan, F. (1985). Life Distribution Model and Incomplete Data. AFOSR 84-174.
- El-Newehi, E., Proschan, F. and Sethuraman, J. (1985). Optimum Allocation in Multistate Systems with Applications in Reliability. AFOSR 85-175; USARO D-80.
- Mimmack, G. and Proschan, F. (1985). Piecewise Geometric Estimation of a Survival Function. AFOSR 85-176.
- Hollander, M., Proschan, F. and Sconing, J. (1985). Information in Censored Models. AFOSR 85-177.
- Guess, F. and Proschan, F. (1985). Mean Residual Life: Theory and Applications. AFOSR 85-178.
- Joag-Dev, K. and Proschan, F. (1985). A Negative Result About Some Concepts of Negative Dependence. AFOSR 85-179.
- Hollander, M., Proschan, F. and Sconing, J. (1985). Measures of Dependence for Evaluating Information in Censored Models. AFOSR 85-180.
- Hollander, M., Proschan, F. and Sconing, J. (1985). Efficiency Loss with the Kaplan-Meier Estimator. AFOSR 85-181.
- Boland, P., Proschan, F. and Tong, Y.L. (1985). Moment and Geometric Probability Inequalities Arising from Arrangement Increasing Functions. AFOSR 85-182.
- Doss, H., Freitag, S. and Proschan, F. (1985). Assessing System Reliability Using Censoring Methodology. AFOSR 85-183.

- Chan, W., Proschan, F. and Park, D.H. (1985). Peakedness of Weighted Averages of Jointly Distributed Random Variables. AFOSR 85-184.
- Boland, P., Proschan, F. and Tong, Y. (1985). Fault Diversity in Software Reliability. AFOSR 85-185.
- Doss, H., Freitag, S. and Proschan, F. (1986). Estimating Jointly System and Component Reliabilities Using a Mutual Censorship Approach. AFOSR 86-186.
- Taksar, M. (1986). Stationary Markov Sets. AFOSR 86-187.
- Hollander, M. (1986). Easily-Stated But Hard Statistical Problems. AFOSR 86-188.
- Hollander, M. and Peña, E. (1986). Exact Significance Testing with Biased Coin Randomization. AFOSR 86-189.
- Herge, D., Proschan, F. and Sethuraman, J. (1986). Optimal Replacement Age in an Imperfect Inspection Model. AFOSR-86-190; USARO D-88.
- Proschan, F. and Joag-Dev, K. (1986). A Covariance Inequality for Coherent Structures. AFOSR 86-191.
- Hollander, M. and Peña, E. (1986). Tests Conditional on Imbalance with Biased Coin Designs. AFOSR 86-192.
- El-Newehi, E., Proschan, F. and Sethuraman, J. (1986). Optimal Assembly of Systems, Using Schur Functions Majorization. AFOSR 86-193; USARO D-93.
- Boland, P. and Proschan, F. (1986). Schur-Convexity of the Maximum Likelihood Function for the Multivariate Hypergeometric and Multinomial Distributions. AFOSR 86-194.
- Doss, H. and Freitag, S. (1986). Bahadur Representation of Quantiles of the Kaplan-Meier Estimator and the Asymptotic Independence of Estimates of Quantiles in the Competing Risks Problem. AFOSR 86-195.
- Hollander, M. and Peña, E. (1986). Confidence Bands Under Proportional Hazards. AFOSR 86-196.
- Taksar, M. and Sethi, S. (1986). A Note on Merton's Optimum Consumption and Portfolio Rules in a Continuous-Time Model. AFOSR 86-197.
- Boland, P. and Proschan, F. (1986). Multivariate Arrangement Increasing Functions with Applications in Probability and Statistics. AFOSR 86-198.
- Taksar, M. (1986). Free Boundary Control of Brownian Motion and a Related Optimal Stopping Problem. AFOSR 86-199.
- Sethi, S. and Taksar, M. (1986). Optimal Consumption and Investment Policies with Bankruptcy Modelled by a Diffusion with Delayed Reflection. AFOSR 86-200.
- Fitzsimmons, P. and Taksar, M. (1986). Construction of Stationary Sets Via Kuznetsov Measures. AFOSR 86-201.
- Sethi, S. and Taksar, M. (1986). Infinite Horizon Investment Consumption Model with a Nonterminal Bankruptcy. AFOSR 86-202.
- Taksar, M. and Grassmann, W. (1986). Probabilistic Approach to Computational Algorithms for Finding Stationary Distributions of Markov Chains. AFOSR 86-203.

Taksar, M. and Fitzsimmons, P. (1986). Stationary Regenerative Sets and Subordinators. AFOSR 86-204.

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Proschan, F. and Shaked, M. (1984). Random Averaging of Vector Elements *SIAM Journal of Applied Mathematics*, 44, 587-590.

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- Doss, H. (1985). Bayesian Nonparametric Estimation of the Median; Part I: Computation of the Estimates. *The Annals of Statistics*, **13**, 1432-1444.
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- Boland, P. and Proschan, F. (1986). An Integral Inequality with Applications to Order Statistics. *Reliability and Quality Control*, 107-116.
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- Doss, H. (1986). Comments on the paper by Diaconis and Freedman. *Annals of Statistics*, **14**, 45-47.
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Boland, P.J., and Proschan, F. (1987). Schur Convexity of the Maximum Likelihood Function for the Multivariate Hypergeometric on Multinomial Distributions. *Statistics and Probability Letters* 5, 317-322.

C. Visitors to Reliability Center During the Period

A number of researchers visited our Reliability Center. The visitors were:

1. Professor Alan Sampson, University of Pittsburgh
2. Professor Philip Boland, University of Dublin, Ireland
3. Professor Wai Chan, Ohio State University
4. Professor Emad El-Newehi, University of Illinois at Chicago
5. Professor Ramesh Korwar, University of Massachusetts
6. Professor Lincoln E. Moses, Stanford University
7. Professor Dong Ho Park, University of Nebraska
8. Professor C. N. Rao, Old Dominion University
9. Professor Frank Samaniego, University of California, Davis
10. Professor James Sconing, University of Iowa
11. Professor Y. L. Tong, Georgia Institute of Technology
12. Professor Douglas Wolfe, Ohio State University

Most of the visits occurred during the summers. The visits lasted from several days up to the entire summer. During this period the visitors interacted with F.S.U. researchers, participated in the weekly reliability seminars, and actively engaged in research projects of mutual interest.

D. Consulting for Air Force Laboratories

We continue to believe that working with Air Force laboratories on their actual problems is mutually beneficial, and additionally, helps increase AFOSR support and esteem from Air Force management and other government decision-makers:

- (1) The A.F. laboratories benefit directly from having expert statistical advice on their basic data analysis problems.
- (2) The researchers funded by the AFOSR grant or contract become aware of new reliability, availability, and maintainability problems occurring in actual practice. In helping to formulate and to solve these real problems, the researchers are stimulated to develop new mathematical and statistical concepts and methods.

Problems under study arising from consultation at Griffiss Air Force Base, Rome, New York, include research by Duane Meeter (of our Statistical Consulting Center) and Jim Clair (Clair is Meeter's Ph.D student) on hypothesis testing concerning the repair times of a system to determine if two specified percentile standards are met.

E. Special Activities of Co-Principal Investigators and Co-Investigator During the Period.

Myles Hollander was Buckingham Scholar-In Residence at the Department of Mathematics and Statistics, Miami University, Oxford, Ohio, during the last week of September, 1985. Hollander gave three public lectures and consulted with faculty and students. Hollander gave an invited talk at the 1986 Annual Statistical

Meeting in Chicago, August 1986, and an invited talk at the Symposium on Dependence in Probability and Statistics, Hidden Valley, PA., August, 1986. In October, 1985, Hollander began a three-year term as Associate Editor of the Journal of the American Statistical Association.

Frank Proschan was named Robert O. Lawton Distinguished Professor at Florida State University in June 1984, just prior to the start of this contract period. In 1986 a volume Reliability and Quality Control, edited by A. P. Bauer, North Holland Publishers, was dedicated to Frank Proschan. In 1987 the book Statistical Theory of Reliability and Life Testing, by R. Barlow and F. Proschan, was translated into Chinese and Arabic. His conference activity included the International Conference on Reliability and Quality Control, Columbus MO, 1984, the Air Force Workshop on Reliability, 1985, the Army Workshop on Reliability, 1985, and the Symposium on Dependence, 1987 (in the latter meeting he chaired a session and co-authors presented three papers, joint with F. Proschan).

Hani Doss spent the summers of 1985-87 at Stanford University. He gave a number of colloquia at departmental seminars. Doss gave invited talks at the NATO Advanced Study Institute on Software Reliability in Durham, England in August 1985, the Conference on Reliability and Quality at the University of Missouri - Columbia in June 1986, and at the IMS Central Regional Meeting at Purdue University in June 1986.

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