AD-A136 579 INTERIM SCIENTIFIC REPORT: AFOSR-81-0122(U) CALIFORNIA 1/1
UNIV BERKELEY OPERATIONS RESEARCH CENTER R E BARLOW
05 MAY 83 AFOSR-TR-83-1244 AFOSR-81-0122

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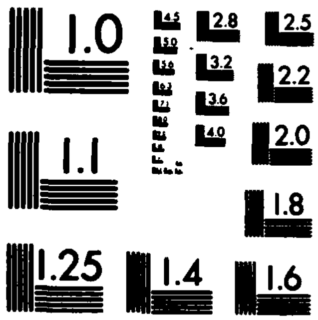

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A136579

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 83 - 1244
6a. NAME OF PERFORMING ORGANIZATION: University of California; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Air Force Office of Scientific Research
6c. ADDRESS (City, State and ZIP Code): Operations Research Center, Berkeley, CA 94720	7b. ADDRESS (City, State and ZIP Code): Directorate of Mathematical & Information Sciences, Bolling AFB DC 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR; 8b. OFFICE SYMBOL (If applicable): NM	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-81-0122
8c. ADDRESS (City, State and ZIP Code): Bolling AFB DC 20332	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2304	A5	

11. TITLE (Include Security Classification): "INTERIM SCIENTIFIC REPORT: AFOSR-81-0122"

12. PERSONAL AUTHOR(S): Richard E. Barlow

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Interim	FROM 1/6/82 TO 31/5/83	May 5, 83	15

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

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

Three researchers and one visitor were supported by this grant during this period. Most of the research was in various aspects of reliability, including network reliability, a generalized model of continuous reliability growth, a software reliability model combining the results of several independent inspectors, and a model in which the failure rates for components depend on the working set. Other investigations included Bayesian methods for combining expert opinion, enriched prior distributions for the multinormal distribution, and a new approach to using simulation to estimate first-passage time distributions for Markov chains. Eleven research papers and one Ph.D. dissertation were produced during this period. This report summarizes research results and lists publications generated during this period.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
Dr. Robert T. Smythe	(202) 767- 5028	NM

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AFOSR-TR- 83-1244

INTERIM SCIENTIFIC REPORT: AFOSR-81-0122

R. E. Barlow

A paper entitled "A Survey of Network Reliability" has been completed and revised after refereeing. It will be published in the Journal of Operations Research. A talk based on this paper was given at the Conference on Stochastic Failure Models, Replacement and Maintenance Policies, held June 24-26 in Charlotte, North Carolina. An abstract of the paper is attached.

A Ph.D. thesis completed in June 1983 by Paul Wakim, "A Bayesian Method for Model Discrimination Using the Kalman Filter," was partially supported by this grant. The thesis abstract is attached.

Currently, we are working on Bayesian methods for combining expert opinion. This is based in part on utility theory and is motivated in part by the problem of assessing seismic risk.

Professor Dennis V. Lindely was a research visitor at Berkeley during Winter Quarter 1983, and produced the attached list of reports credited to this grant.

W. S. Jewell

1. Reliability Growth

A generalized model of continuous reliability growth has been under development since 1979, in which the failure rate is assumed to be the sum of two effects:

a) the influence of the failure "history" since the start of testing;

b) the influence of the local "age" of the item on test.

This quite general model incorporates other previously studied learning-curve models, for example, those systems in which improvements are made only "as produced," and those made "as operated" (e.g., through retrofitting). Both models require the solution of similar non-linear equations to find the maximum-likelihood estimators of the growth parameters.

The revised version of ORC 79-11 was finally published in April 1983, with the addition of extensive numerical trials using an exponential growth function, constant age hazard, and known initial failure rate. These trials indicate the difficulty of using classical estimators of ultimate performance, as the maximum likelihood estimator is unstable for small testing intervals with a small number of systems on test, and is even inconsistent for a large number of such systems. The basic difficulty is, simply, that there is not enough information in the failure epoch "early returns" data to accurately extrapolate to ultimate failure rates. Thus, Bayesian procedures will have to be used for any practical implementation of reliability growth estimation, as they alone will give consistent results with the data from any testing protocol.

This paper has been accepted, in reduced form, for publication in a special issue of Operations Research.

2. Enriched Prior Distributions for the Multinormal Distribution

In a 1974 paper (ORC 74-14, "Exact Multidimensional Credibility"), the author showed how natural conjugate priors for the multi-dimensional exponential family likelihoods could be enriched in certain cases through linear transformations of independent marginal priors. In particular, it was shown how the usual Normal-Wishart prior for the multinormal distribution with unknown mean vector and precision matrix could have the number of hyperparameters increased; the "thinness" of the traditional prior is well-known. However, there was an error in one of the sufficient statistics for covariance prediction in the original paper, and the results were not widely published.

In ORC 82-14 ("Enriched Multinormal Priors Revisited," September 1982), these results are re-explained, with corrected formulae, and with detailed explanations of the importance and interpretation of the results in modelling multinormal problems. This paper will appear in 1983 in a special issue of the *Journal of Econometrics*.

3. Efficient Computation of Compound Distributions

An important computational issue in risk theory is the development of efficient methods to find the distribution of sums of random variables, as in the compound law:

$$\tilde{y} = \tilde{w}_1 + \tilde{w}_2 + \dots + \tilde{w}_{\tilde{n}}$$

where the random "severities" $(\tilde{w}_i)$ are assumed to be independent and identically distributed, independent of the random "frequency" $\tilde{n}$. In 1981 H. Panjer gave an interesting exact, recursive procedure for calculating the discrete density of y, when the (w_i) are positive and discrete, and n is either Binomial, Poisson, or Negative Binomial.

In a series of papers (ORC 81-20), the author and B. Sundt explored extensions of the Panjer approach, and applied it to the problem of estimating the total severity of a heterogeneous portfolio,

$$\tilde{y} = \tilde{x}_1 + \tilde{x}_2 + \dots + \tilde{x}_N ,$$

where the $(\tilde{x}_i)$ are independent, non-identically distributed positive discrete random variables, and N is large, and fixed.

In another ORC report, "Approximating the Distribution of Dynamic Risk Portfolio" (to appear), Jewell has extended the model to one in which the heterogeneous portfolio may itself be composed of homogeneous compound laws; this models the situation in which the composition of the portfolio may change dynamically over time. These results have been accepted for publication in the ASTIN Bulletin.

4. Other Research in Progress

Additional work currently near completion is in two areas:

a) the development of "credibility" (linearized Bayesian) estimators for predicting second moments as linear functions of first and second sample moments (joint with R. Schnieper);

b) the extension of a software reliability model, suggested by S. Ross, in which one estimates the number of errors that are still undetected through a Bayesian extrapolation of the numbers of errors which are found, independently and jointly, by several independent inspectors.

The first paper will be presented at an ASTIN Colloquium in Lindau, Germany in September 1983, while the second paper will be presented a few weeks earlier at the Second International Meeting on Bayesian Statistics in Valencia, Spain.

5. Honors and Awards

At a meeting of the Association of Swiss Actuaries in Chur, Switzerland in September 1982, Professor Jewell was named a Corresponding Member of that association. There are currently only some 25 non-Swiss Corresponding Members, including three Americans.

At a meeting of the Casualty Actuarial Society (U.S.A.) in San Francisco in November 1982, Dr. Jewell received the 1980 Halmstad Prize for the paper which "best demonstrates a significant contribution to actuarial research." That paper, "Models in Insurance: Paradigms, Puzzles, and Communications" (ORC 80-10), was presented in Switzerland in 1980 at the 21st International Congress of Actuaries.

6. Meetings

In addition to the meetings described above, Professor Jewell visited the Science and Research Division of SAC Headquarters (SAC/NR), Offutt AFB, in April 1983, at the invitation of F. J. O'Meara and D. Thompson. A variety of mutually interesting problems in the modelling of reliability were discussed.

S. M. Ross

In ORC 83-1, Ross and Schechner present a new approach to using simulation to estimate first passage time distributions. Specifically, they consider a discrete time Markov process $\{X_n, n = 0, 1, \ldots\}$ such that whenever the present state is x the next state is chosen according to the distribution P_x. Let $X_0 = 0$ be fixed and consider for a given set of states A the number of transitions N until the Markov process enters the set A. They were then interested in estimating the distribution and the mean of N by use of simulation.

Assuming that the process $\{X_n\}$ is such that N is finite with probability 1, this model can be simulated by the standard Monte Carlo method of letting $X_0 = 0$ and then generating a random variable from the distribution P_0 to determine X_1. If $X_1 = x$, we then generate a random variable from the distribution P_x and set it equal to X_2, and so on. We stop the run when we obtain a state in A. The process is then repeated for a second run, and so on until a total of r (a fixed predetermined number) simulation runs are obtained. If we let $N^{(i)}$, $i = 1, \ldots, r$ denote the number of steps until A is reached in the i^{th} run, then the usual way to estimate $P(N = k)$, $k \geq 1$ and $E[N]$ is as follows:

$$P(N = k) \text{ is estimated by } \#\{i : N^{(i)} = k\}/r$$

$$E[N] \text{ is estimated by } \sum_{i=1}^{r} N^{(i)}/r \, .$$

In ORC 83-1, new estimators for these quantities which are based on the "observed hazards" also known as the "predictable projection," were proposed. That is, consider a given simulation run terminating at N and define

$$\lambda_n = P_{X_{n-1}}(A) \quad \text{if } N \geq n$$

where X_{n-1} is the $(n - 1)^{th}$ state and $P_x(A)$ is the probability that the next state visited from x is in A. They use the process $\{\lambda_n\}$ to estimate the various quantities of interest, such as $E[N]$, the distribution of N, and the distribution of the final state X_N. They also consider the continuous time analog and as a consequence obtain a new formula for estimating convolution is obtained.

In ORC 82-11 (and a revised version), Ross considers an n component system such that each component is initially on and stays on for a random time at which it fails. The problem of interest is to characterize the distribution of the time until the system fails. Whereas this problem is usually considered under the assumption that the component lives are independent, the model in ORC 82-11 supposes a Markovian model in which the failure rate of a given component at any time is allowed to depend on the set of working components at that time. Specifically, it supposes that if at some time W, $W \subset \{1, 2, \ldots, n\}$, represents the set of working components then for $i \in W$ the instantaneous failure rate for component i is $\lambda_i(W)$.

Specific conditions that imply that system life is IFR and IFRA are presented. A method for easily simulating the process is also presented. Finally the model is generalized to allow for the repair of failed components and conditions implying that the process is, in steady state, time reversible are presented.

In ORC 82-6, Ross and Schechner consider some reliability applications of the variability ordering where if X_1 and X_2 are random variables having respective distributions F_1 and F_2, then we say that $X_1 \underset{v}{\leq} X_2$ (read X_1 is less variable than X_2) if

$$\int_{-\infty}^{\infty} f(x)dF_1(x) \leq \int_{-\infty}^{\infty} f(x)dF_2(x)$$

for all increasing convex functions f .

Applications to a variety of shock and survival models are presented.

The following Operations Research Center Reports were credited to the Air Force Office of Scientific Research under Grant AFOSR-81-0122:

Barlow, R. E. and J. Hsiung, "Expected Information from a Life Test Experiment," ORC 82-5, May 1982.

Ross, S. M. and Z. Schechner, "Some Reliability Applications of the Variability Ordering," ORC 82-6, May 1982.

Shachter, R. D., "An Incentive Approach to Eliciting Probabilities," ORC 82-9, July 1982.

Ross, S. M., "A Model in Which Component Failure Rates Depend on the Working Set," ORC 82-11, September 1982.

Wood, R. K., "Polygon-to-Chain Reductions and Extensions for Reliability Evaluation of Undirected Networks," ORC 82-12, October 1982.

Ramalhoto, M. F., "Identifiability and Estimation in Random Translations of Marked Point Processes," ORC 82-13, October 1982.

Jewell, W. S., "Enriched Multinormal Priors Revisited," ORC 82-14, November 1982.

Ross, S. M. and Z. Schechner, "Using Simulation to Estimate First Passage Distributions," ORC 83-1, January 1983.

Derman, C., G. J. Lieberman, and S. M. Ross, "On the Use of Replacements to Extend System Life," ORC 83-3, June 1983.

A SURVEY OF NETWORK RELIABILITY

R. E. Barlow

We present a brief survey of the current state of the art in network reliability. We survey only exact methods; Monte Carlo methods are not surveyed. There are many papers in this field, some giving methods to simplify or solve the problems, while others calculate the complexity of network reliability problems. In 1975, Rosenthal showed that certain fault tree and network reliability problems are inherently difficult and almost certainly have no fast algorithm. Since then, this class has grown to contain a number of other network reliability problems, and some of the questions that he raised regarding other related problems have been answered.

Most network reliability problems are, in the worst case, NP-hard. Network reliability problems are, in a sense, more difficult than many standard combinatorial optimization problems. That is, given a tentative solution to a combinatorial problem, often its correctness can be determined in polynomial time. However, given a purported solution to a reliability problem it cannot even be checked without computing the reliability of the network from the beginning.

Although the above remarks sound very discouraging, there are in fact linear and polynomial time algorithms for network reliability problems of special structure.

We review general methods for network reliability computation and discuss the central role played by domination theory in network reliability computational complexity. We also point out the connection with the more general problem of computing the reliability of coherent structures [c.f. Barlow and Proschan (1981)]. The class of coherent structures contains both directed and undirected networks as well as logic (or fault) trees *without* not gates. This is a rich area for further research.

Attachment 2

A BAYESIAN METHOD FOR MODEL DISCRIMINATION USING THE KALMAN FILTER*

by

Paul George Wakim

Department of Statistics
University of California, Berkeley

Ph.D. Dissertation

June 1983

Abstract

The multi-process Kalman filter introduced by Harrison and Stevens consists of two or more dynamic linear models, each model defining a state. However, the models differ only by the variance of the error terms; and the final updated mean and variance of the common parameters are respectively the weighted mean and variance of the same parameters when each model is considered separately; the weights are the probability that each model obtains at that time period.

The compound model-probability Kalman filter described in this study is different from the multi-process Kalman filter in several ways: first, the models may have nothing in common except the observation vector; moreover, the probabilities that each model obtains are computed and forecasted leading to the decision about the correct model, only one model being selected at every time unit; finally, the parameters of the correct model are the only parameters to be updated after an observation is made.

*This research was supported in part by Air Force Office of Scientific Research Grant AFOSR-81-0122 and National Science Foundation Grant MCS78-25301.

The compound M-P Kalman filter consists of two parts: the Kalman filter models which represent different states of the process and the probability Kalman filter which is used to select the correct model for the next period.

Two numerical examples are used to compare the suggested method with several other known models including the multi-process Kalman filter. The first numerical example is a simulated time series and the second represents the industrial production of primary metals from January of 1978 to December of 1981. In both cases, the compound M-P Kalman filter leads to the smallest error in one step ahead forecasting.

Professor Richard E. Barlow
Chairman, Thesis Committee

The Role of Randomization in Inference.

Dennis V. Lindley.

It is argued that randomization has no role to play in the design or analysis of an experiment. If a Bayesian approach is adopted this conclusion is easily demonstrated. Outside that approach two principles, of conditionality and similarity, lead, via the likelihood principle, to the same conclusion. In the case of design, however, it is important to avoid confounding the effect of interest with an unexpected factor and this consideration leads to a principle of haphazardness that is clearly related to, but not identical with, randomization. The role of exchangeability is discussed.

This paper has been submitted to Philosophy of Science Association, Vol. 2 (1982).

A BAYESIAN LADY TASTING TEA

Dennis V. Lindley*

SUMMARY: The paper discusses a famous experiment suggested by Fisher, and two others considered by Neyman, for testing a lady's claim to be able to tell whether the tea or the milk were added first to the cup. It is supposed that both the lady and the statistician are Bayesians. The likelihood functions are evaluated and combined with a prior to find the resulting posterior distributions. Another lady, tasting wine, is considered, where the prior is different, and the results compared with tea. The probabilities are contrasted with the significance levels. Shannon information is calculated as a tool for selecting the best experiment.

KEY WORDS AND PHRASES: Significance test. Significance level. Likelihood. Prior probabilities. Posterior probabilities. Tea. Wine. Shannon information. Personal probability. Logistic distribution. Legendre functions of the second kind. Maximum likelihood.

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BIASES OF METHODS USED FOR UTILITY ASSESSMENT

DENNIS V. LINDLEY[†]

It is shown that some methods that have been proposed for assessing utility functions are biased and the bias is found, together with the precision. Some comments on normative and descriptive models of decision-making are offered.

(UTILITY; NORMATIVE DECISION-MAKING; BIAS; ERROR ANALYSIS; RISK AVERSION)

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