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During the two years of research supported by this grant, the PI worked on several different problems in reliability theory, both statistical estimation and stochastic modeling as well as topics in manufacturing.





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# FINAL REPORT TO THE AFOSR

Grant Number F49620-92-J-0101



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December 1993

During the two years of research supported by grant number F49620-92-J-0101, the PI worked on several different problems in reliability theory, both statistical estimation and stochastic modeling, as well as some topics in manufacturing. The results obtained are summarized as follows. For convenience, the results have been categorized by paper in which they have been submitted for publication.

**Title of Paper**: "Cumulative Operating Time Distributions for a Class of Non-Markovian Series Systems"

**Co-authors**: Norman A. Marlow

**Status of Paper**: Submitted to *OR Letters*

**Summary**: Consider a series system of separately and independently maintained components. The failure and repair process of each component is assumed to be an alternating renewal process. It is supposed that, for each component, the failure time distribution is exponential whereas the repair time distribution is general. We derive the Laplace-Stieltjes transform of the distribution of $U_c(T)$, the cumulative time that the series system is operating in $[c, c+T]$, for arbitrary $c$, $T \geq 0$, with respect to $T$, and obtain the limiting distribution of $U_c(T)$ as $c$, $T \rightarrow \infty$.

**Title of Paper**: "The Asymptotic Distribution of the Number of Failures of a Separately Maintained System"

**Co-authors**: Norman A. Marlow

**Status of Paper**: Being corrected prior to resubmission

**Summary**: Consider an arbitrary coherent system of separately maintained components whose failure patterns are alternating renewal processes. We derive the asymptotic (i.e. large $t$) distribution of $N(t)$, the number of system failures in $(0,t]$, as $t \rightarrow \infty$.

**Title of Paper**: "Estimation from Quasi Life Tables"

**Co-authors**: None

**Status of Paper**: Submitted to *Biometrika*.

**Summary**: A large number of identical components are simultaneously set into operation at each of a regular sequence of times and, on failure, a component is instantaneously replaced. The functional form of the distribution of the component lifelength is assumed to be known and it is desired to estimate the parameters of this distribution. However, no observations of the lifelengths of individual components have been recorded: the only information available is the numbers of components which fail between successive time points. It is shown how this information, in conjunction with the theory of recurrent events, may be used to construct the nonparametric maximum likelihood estimate of the discretized lifelength distribution. This estimate is then used to estimate the unknown parameters.

**Title of Paper**: "Applications of the EM Algorithm to the Analysis of Lifelength Data"

**Co-authors**: Jose Ramon G. Albert

**Status of Paper**: Submitted to *Applied Statistics*

**Summary**: It is desired to estimate the parameters of the lifelength distribution of a given component. The observations on which inference is to be based are field data which are incomplete in some fashion. Thus, for example, the reported lifelength may include a period of unknown duration during which the component is not in use; the lifelength distribution may be affected by an unobserved environmental factor; or the component may be part of a larger system, and failure mode analysis reveals only the module containing the failed component, not the identity of the latter. It is shown how the EM algorithm can be used to calculate the maximum likelihood estimates of the parameters of interest in such cases.

**Title of Paper**: "Nonparametric Confidence Intervals for the Renewal Function and the Point Availability"

**Co-authors**: Linxiong Li

**Status of Paper**: Submitted to the *Scandinavian Journal of Statistics*

**Summary**: A large sample nonparametric method for constructing confidence intervals for the renewal function and the point availability is investigated. The method is based on a linearization and on the fact that the empirical distribution function converges weakly to a Gaussian process as the sample size increases. The technique is illustrated by the analysis of some hitherto unpublished data.

**Title of Paper**: "Nonparametric Confidence Intervals for the Renewal Function with Censored Data"

**Co-authors**: Linxiong Li

**Status of Paper**: Submitted to the *Journal of Nonparametric Statistics*

**Summary**: An asymptotic nonparametric method for constructing confidence intervals for the renewal function using censored data is presented. The method is based on the fact that the product limit estimator of the renewal function converges weakly to a Gaussian process as the sample size increases.

**Title of Paper**: "On the Optimal Assembly of Series-Parallel Systems II"

**Co-authors**: Farid Harche

**Status of Paper**: Submitted to *OR Letters*

**Summary**: A heuristic is proposed for the optimal assembly of series-parallel systems in which th modules are of unequal size. The heuristic is analyzed in detail for the special case where the system comprises two modules. A numerical study illustrates the efficiency of the heuristic.

**Title of Paper**: "A Simple Heuristic to Minimize Makespan on Parallel Processors with Unequal Capacities"

**Co-authors**: Farid Harche & Craig A. Tovey

**Status of Paper**: Submitted to *Operations Research*

**Summary**: Jobs with fixed processing times must be assigned to $m$ parallel processors to minimize makespan. There is a limit on the number of jobs that may be assigned to each processor. When these limits are equal, there are several fast and effective heuristics available. However, when processor capacities are not identical, the heuristic performance degrades. We present a new simple greedy heuristic for nonidentical limits. The key idea is to forecast makespans from partial solutions. For the case $m = 2$, the heuristic has asymptotically optimal performance.

**Title of Paper**: "Minimizing the Variability of the Waiting Times in a Globally Gated Elevator Polling System"

**Co-authors**: Farid Harche

**Status of Paper**: In preparation

**Summary**: A polling system comprising $n$ queues and a single server is considered. Service is performed according to an elevator scheme with global gating. The problem of arranging the channels to minimize a measure of the variability of the waiting times is addressed.