THE INSTITUTE OF MANAGEMENT SCIENCES

Newsletter of the TIMS College on Simulation

Dave Goldsman and Jim Swain, Editors

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Contents

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Chairman's Message

In June of this year, Lee Schruben completed his service as Chairman of the College on Simulation. During his term of office, Lee directed a major restructuring and renewal of the ongoing activities of the College. With the implementation of the new College Bylaws and with the establishment of the new Service Award Committee and the new Publication Award Committee, Lee has set the College on a clear course for the future. We should also recognize that Lee's service to the simulation community has extended far beyond his work in various College offices (Secretary-Treasurer, Vice Chairman, and Chairman). He served as Analysis Track Coordinator for the 1986 Winter Simulation Conference; and for many years Lee has been an Associate Editor of *Operations Research, Operations Research Letters, Simulation*, and the *ORSA Journal on Computing*. These thankless tasks require large investments of time and energy on a daily basis, and Lee deserves personal thanks from each of us for his dedicated service.

Although Lee Schruben's contributions to the administrative side of our profession are important, they are overshadowed by his contributions in research and education. Unquestionably Lee is one of the most original thinkers in the field of simulation; and his work spans the full spectrum of topics including analysis, modeling, and applications in a wide variety of industries. He has won the College's Outstanding Simulation Publication Award on two different occasions, and he has received similar recognition from the American Society for Quality Control. Finally we should recognize Lee's contributions as an educator, accorded the least recognition. Lee has been the academic advisor to a large and distinguished group of M.S. and Ph.D. students who are themselves doing significant work in both industry and academia. These students are the best

evidence of Lee Schruben's impact on our profession. In many different ways, Lee is a tough act to follow.

During the next two years, I would like to see the College expand the scope of its ongoing activities and greatly increase the participation of professionals from government and industry in those activities. Both our membership and our financial resources are greater than ever before, and we have an opportunity to employ these human and financial assets in original and constructive ways. One suggestion has been to publish a series of monographs on various aspects of the practice and theory of simulation. Other suggestions are solicited.

Our new Vice Chairman, David Kelton, will arrange College-sponsored sessions at national and international meetings of TIMS. Our new Secretary-Treasurer, Barry Nelson, will manage our finances and records. Our continuing representative to the Board of Directors of the Winter Simulation Conference is Steve Roberts.

James R. Wilson
Chairman, TIMS College on Simulation

Treasurer's Report

For the period 8/1/88 through 11/21/88 the college had the following transactions, some at First Minnesota, Edina, and the remainder at BancOhio National Bank, Columbus, Ohio.

Balance forward:		$17,028.15
Revenues:		
Interest earned	900.86	
Non-TIMS member dues	9.00	
Return of WSC 87 seed money and profit sharing	7782.94	
Total revenues		8692.80
Disbursements:		
Seed money for WSC 88	2000.00	
Spring 1988 Newsletter	303.71	
Best Publication Award	563.66	
Reception at 1988 TIMS/ORSA	171.86	
Projector rental	44.52	
Travel for WSC Board Rep.	98.00	
Check printing charge	7.90	
College stationary	21.10	

Total disbursements	3210.75	
Net (revenues - disbursements)		5,482.05
Balance Forward (previous balance + net)		$22,510.20

All funds are in a money market checking account at BancOhio National Bank. In addition to these funds, the College has on account at TIMS Headquarters the sum of $524.87 (as of 9/30/88), bringing the College's net worth to $23,035.07.

Respectfully submitted,
Barry L. Nelson, Secretary/Treasurer
November 21, 1988

Operations Research Editorial Policy for Simulation

The Simulation Area focuses on digital-computer modeling and analysis of stochastic systems to estimate performance measures. Both dynamic-system simulation and Monte Carlo simulation of models having no time component are considered. Simulation gaming, simulation trainers, and deterministic difference- or differential-equation simulations lie outside the area.

Issues of interest include, but are not limited to, uniform (0,1) random number generation, selection of input models, random-variate and random-process generation, language and environment design, data structures, verification, validation, initial-transient bias amelioration, standard error estimation, confidence and prediction interval procedures, variance reduction, metamodels, simulation optimization over discrete feasible regions, and simulation optimization over continuous feasible regions, including gradient estimation. Papers using simulation to evaluate and compare non-simulation methodology will be processed by other areas or jointly with the Simulation Area.

Applications, survey, methodology, and basic theory papers are welcome. *Application* papers should illustrate quality simulation practice. How and why each aspect of the simulation study was performed is of primary interest. *Survey* papers should give structure to the topic discussed and include a complete bibliography. Papers presenting a new *method* should clearly state the method (usually in algorithmic form) and the context in which it is appropriate, including its limitations. Comparisons, either empirical or theoretical, should be presented to demonstrate the strengths and weaknesses of the new method with

respect to existing methods. Papers presenting new *theory* should clearly state the relationship to simulation practice, methods, and existing theory.

When empirical evaluations are presented, enough information should be given so that the reader could replicate the experiment(s). This information includes the computer, language, compiler, and random-number generators used. The experimental design should be stated, including the number of replications and whether and how the replications are correlated. Some measure of sampling error should be given. The authors may be asked to provide computer code and output for the refereeing process.

Bruce Schmeiser
Simulation Area Editor, *Operations Research*
October, 1988

Abstracts of Papers

David J. DeBrota, Stephen D. Roberts, Robert S. Dittus and James R. Wilson (1988), "Visual Interactive Fitting of Probability Distributions," Research Memorandum No. 88-3, School of Industrial Engineering, Purdue University.

We present a visual, interactive method for specifying a probability distribution when little or no data are available for formally identifying and fitting an input process. Using subjective information, the modeler provides values for familiar characteristics of an envisioned target distribution. These values are transformed into parameters for a bounded Johnson probability density function. The parameters of the fitted density function can then be indirectly manipulated, either by revising the desired numerical values of the function's specifiable characteristics or by directly altering the shape of the displayed curve. Interaction with a visual display of the fitted density permits the modeler to conveniently obtain a more realistic representation of an input process than was previously possible. The techniques involved have been packaged into a microcomputer-based software system called VISIFIT.

P. L'Ecuyer and S. Côté (1987), "A Random Number Package with Splitting Facilities," Research Report DIUL-RR-8705, Département d'Informatique, Université Laval.

Multiple generators are often required in simulation studies, for instance to facilitate synchronization for variance reduction purposes, and multiple independent streams per generator are helpful to make independent replications. This paper describes a portable set of software tools for uniform random variate generation. It provides for multiple generators running simultaneously, and each generator has its sequence of numbers partitioned into many long (disjoint) sub-

streams. Simple procedure calls allow the user to make any generator "jump" ahead to the beginning of its next substream, back to the beginning of its current substream, or back to the beginning of its first substream. A simple switch permits to change from regular to antithetic variates or vice-versa. Implementation issues are discussed. We also provide an efficient and portable code for computing (as $mod(m)$) for any positive integer values of $a < m$, $s < m$, and $m < 2^{b-1}$ on a b-bit computer.

R.D. Eisenhut, R.S. Dittus, S.D. Roberts and J.R. Wilson (1988), "Comparing Averaged-Out Utilities of Probability Trees with Random Parameters," Research Memorandum No. 88-18, School of Industrial Engineering, Purdue University.

This paper develops a procedure to approximate the distribution of each of the following performance measures defined on a forest of probability trees with random parameters: (a) the averaged-out utility of any single tree in the forest, and (b) the difference between the averaged-out utilities of any pair of trees in the forest. The parameters of a probability tree are its branching probabilities and node utilities, and they may be specified as mutually independent random variables with given distributions; moreover, any of these parameters may be duplicated at several places in the forest to represent parameter dependencies within and between trees. The approximation procedure incorporates an efficient numerically robust algorithm for computing up to the first four moments of the selected performance measure. To illustrate how the analysis of probability trees can directly incorporate uncertainty or random variation in the values of tree parameters, we apply the approximation procedure to the comparison of alternative medical protocols for managing patients following myocardial infarction.

George S. Fishman (1988), "Sensitivity Analysis Using the Monte Carlo Acceptance-Rejection Method," Technical Report No. UNC/OR/TR-88/3, Department of Operations Research, University of North Carolina at Chapel Hill.

This paper describes a Monte Carlo sampling plan for estimating how a function varies in response to changes in its arguments. Most notably, the plan effects this sensitivity analysis by applying the acceptance-rejection technique to data sampled at only one specified setting for the arguments, thus saving considerable computing time when compared to alternative methods. The plan which applies for a $0-1$ response on each replication has immediate application when estimating variation in system performance measures in reliability analysis. The paper derives the variances of the proposed estimators and shows how to use worst case bounds on these or on corresponding coefficients of variation to choose the arguments, at which to sample, that minimize the worst case bounds. Individual and simultaneous confidence intervals are derived and

an example based on $s - t$ reliability illustrates the method. The paper also compares the proposed method and an alternative Monte Carlo approach that uses an importance function.

George S. Fishman and Tien-yi Danny Shaw (1988), "Evaluating Reliability of Stochastic Flow Networks," Technical Report No. UNC/OR/TR-88/6, Department of Operations Research, University of North Carolina at Chapel Hill.

This paper describes a highly efficient Monte Carlo sampling plan for evaluating the probability that the flow value in a stochastic flow network is greater than or equal to a prespecified level d. A stochastic flow network can characterize communication, transportation and water or oil distribution systems. The paper first derives lower and upper bounds on the probability of interest and then describes how one can concentrate sampling in a specialized region of the arc capacity state space to increase the statistical efficiency of the resulting estimate. The paper also gives expressions for worst case sample sizes needed to meet specified bounds on variances and coefficients of variation and illustrates the proposed sampling plan with an example.

Robert D. Foley and David Goldsman (1988). "Confidence Intervals Using Orthonormally Weighted Standardized Time Series," Technical Report, School of Industrial and Systems Engineering, Georgia Institute of Technology.

We find new confidence intervals for the mean of a stationary process. The new intervals are based on orthonormally weighted standardized time series and are designed to have more degrees of freedom than their predecessors. The higher degrees of freedom result in smaller mean and variance of the length of the confidence intervals.

Bennett L. Fox and Peter W. Glynn (1988), "Simulating Discounted Costs," Technical Report No. 793, School of Operations Research and Industrial Engineering, Cornell University.

We numerically estimate, via simulation, the expected infinite-horizon cost d of running a stochastic system. A naive strategy estimates a finite-horizon approximation to d. We propose alternatives. All are ranked with respect to *asymptotic* variance as a function of computer-time budget and discount rate, when semi-Markov and/or regenerative structure or neither is assumed. In this setting, the naive estimator loses; it may be competitive, however, when the computer-time budget is modest, the discount rate is large, and the process simulated is not regenerative.

Bennett L. Fox and Peter W. Glynn (1988), "Discrete-Time Conversion for Finite-Horizon Markov Processes," Technical Report No. 790, School of Oper-

ations Research and Industrial Engineering, Cornell University.

To efficiently estimate expectations of general time integrals of continuous-time Markov chains with a fixed, finite horizon or a random horizon, we often subordinate them to a Poisson process. We reduce variance via discrete-time conversion, splitting, stratification, and antithetic variates; often several of these techniques are applied simultaneously. We detail specific algorithms and discuss practical implementation. Since our schemes require no truncation, they produce unbiased estimators which converge to the respective true parameter values at the canonical rate usually associated with simulation. We also discuss alternative estimators with very slight bias but smaller variance.

Mary A. Johnson and Michael R. Taaffe (1988a), "Matching Moments to Phase Distributions: Density Function Shapes," Research Memorandum No. 88-11, School of Industrial Engineering, Purdue University.

We study density function shapes of distributions selected by phase distribution selection methods developed in Johnson and Taaffe (1988b,c). In Johnson and Taaffe (1988b), analytic results for matching three moments to mixtures of two Erlang distributions of common order are presented. In Johnson and Taaffe (1988c), nonlinear programming methods are developed for matching three moments to mixtures of two Erlang distributions (not necessarily of the same order), real-parametered Coxian distributions with support on $(0, \infty)$, and phase (PH) distributions with support on $(0, \infty)$. In this paper, we investigate the effect of restricting selection to the above subsets of phase distributions. We also illustrate how to use the methods of Johnson and Taaffe (1988b,c) to effect changes in distribution characteristics.

Mary A. Johnson and Michael R. Taaffe (1988b), "Matching Moments with a Class of Phase Distributions: Mixtures of Erlang Distributions of Common Order," Research Memorandum No. 88-10, School of Industrial Engineering, Purdue University.

We investigate the use of mixtures of Erlang distributions for matching moments to distributions with support on $[0, \infty)$. Use of mixtures of Erlang distributions of *common* order allows for derivation of the following results. We show that, except for one case, the first k moments of any nondegenerate distribution with support on $[0, \infty)$ and finite first k moments can be matched by a mixture of $\lfloor k/2 \rfloor + 1$ n-stage Erlang distributions, for sufficiently large n. We consider the three-moment matching problem in detail. An expression is derived for the minimum order, n, needed to match a given set of first three moments to a mixture of n-stage Erlang distributions. Analytic expressions are also given for the parameters of the unique mixture of two n-stage Erlang distributions that matches a feasible set of three moments. Methods for implementation of these results are suggested and evaluated.

Mary A. Johnson and Michael R. Taaffe (1988c), "Matching Moments to Phase Distributions: Nonlinear Programming Approaches," Research Memorandum No. 88-14, School of Industrial Engineering, Purdue University.

We present a nonlinear programming (NLP) approach to the problem of matching three moments to phase distributions. We first discuss the formulation and implementation of a general NLP problem and then consider NLP problems for searching over two families of phase distributions: mixtures of two Erlang distributions and real-parametered continuous Coxian distributions. One property of all our formulations is that for at least some triples of moments the objective function surface is nonconvex. Restricting the search to select from a subset of phase distributions allows us to greatly simplify the NLP problem, resulting in more efficient and predictable search procedures. Conversely, the restriction also reduces the variety of distributions the search algorithm can select. Tradeoffs between the formulations are discussed. Possible refinements and extensions are also discussed.

Jack P.C. Kleijnen (1988), "Analyzing Simulation Experiments with Common Random Numbers, Part II: Rao's Approach," Research Memorandum, Department of Economics, Tilburg University.

This note uses Rao (1959)'s approach based on Hotelling's statistic, to analyze a linear regression model with correlated responses. Correlated responses arise if a simulation model uses common random numbers. Rao's approach is compared to Kleijnen (1988)'s approach. Rao's lack of fit test is superior, which is quantified by a Monte Carlo study. Confidence intervals for individual regression parameters differ only sightly, when using Rao's and Kleijnen's approach respectively.

J.P.C. Kleijnen, J. Kriens, M.C.H.M. Lafleur, and J.H.F. Pardoel (1988), "Sampling for Quality Inspection and Correction: AOQL Performance Criteria," Research Memorandum, Department of Economics, Tilburg University.

The Average Outgoing Quality Limit (AOQL) is a property of a sampling plan leading to inspection of the whole population, if the sample shows a number of defective items k exceeding an acceptance number k_o. The literature shows how this constant k_o can be chosen such that the expected value of $\tilde{p}$, the fraction of defectives after inspection and possible correction, does not exceed a prespecified constant $\tilde{p}_m$. The present paper estimates several other criteria ignored in the literature. These estimates are based on an extensive Monte Carlo simulation. The main conclusion is that the AOQL scheme is useful in practice, including applications in auditing. Yet the probability that the yearly average $\bar{\tilde{p}}$ exceeds $\tilde{p}_m$ is sizable, if the true underlying fraction p exceeds $\tilde{p}_m$ "mildly". The paper further investigates the effects of splitting the yearly population into subpopulations and the effects of underestimating p, as is often done in practice.

Ying Tat Leung and Rajan Suri (1988), "Convergence of a Single Run Simulation Optimization Algorithm," *Proceedings of the 1988 American Control Conference*, Atlanta, Georgia.

Conventional methods for simulation optimization may require a large number of simulation runs and are thus computationally expensive. To reduce computational effort, we have previously conducted experimental investigations of single run optimization algorithms which estimate the optimum in a single simulation run. Our earlier studies for queueing systems have focused on empirical results. In this study, we apply a single run optimization algorithm to a simple optimization problem related to an autoregressive process of order one. It is shown that the algorithm converges to the true optimum with probability one. This provides a first step towards analytical understanding of such single run simulation optimization algorithms.

Barry L. Nelson (1988), "Control-Variate Remedies," Working Paper No. 1988-004, Department of Industrial Engineering, The Ohio State University.

Other than common random numbers, control variates is the most promising variance reduction technique in terms of its potential for widespread use: Control variates is applicable in single or multiple response simulation, it does not require altering the simulation run in any way, and any stochastic simulation contains potential control variates. A rich theory of control variates has been developed in recent years. Most of this theory assumes a specific probabilistic structure for the simulation output process, usually joint normality of the response and the control variates. When these assumptions are not satisfied, desirable properties of the estimator, such as unbiasedness, may be lost. A number of remedies for violations of the assumptions have been proposed, including jackknifing and splitting. However, there has been no systematic analytical and empirical evaluation of these remedies. This paper presents such an evaluation, including evaluation of the small-sample statistical properties of the proposed remedies.

Acacio M. de O. Porta Nova and James R. Wilson (1988), "Estimation of Multiresponse Simulation Metamodels Using Control Variates," Research Memorandum No. 88-16, School of Industrial Engineering, Purdue University.

This paper provides a unified development of the method of control variates for simulation experiments in which the objective is estimation of a multiresponse metamodel – that is, a linear model for an output vector of simulation performance measures expressed in terms of an input vector of decision variables for the target system. In contrast to previous treatments of this topic, we allow both the input and output of the metamodel to be multidimensional so

that control variates can be applied to multipopulation, multiresponse simulation experiments. Assuming that the responses and controls are jointly normal with a homogeneous covariance structure across the points of the experimental design, we develop control variates procedures for point and confidence-region estimation and for hypothesis testing on the coefficients of a postulated metamodel. We derive a generalized minimum variance ratio to quantify the maximum efficiency that is achievable with a given set of controls, and we formulate a generalized loss factor to measure the degradation in efficiency that occurs when the optimal control coefficients are estimated by the method of least squares. A detailed example illustrates the application of these results.

Bruce Schmeiser and Wheyming Tina Song (1988), "Variance Estimators of the Sample Mean: Optimal Mean-Squared-Error Batch Sizes," Research Memorandum No. 88-15, School of Industrial Engineering, Purdue University.

When an estimator of the variance of the sample mean is parameterized by batch size, one approach for selecting batch size is to pursue the minimal mean squared error. We elaborate on the results of Goldsman and Meketon and obtain an explicit formula for the asymptotic optimal batch size as a function of sample size, estimator type, and the center of gravity of the nonnegative autocorrelations of the data process. In addition, we empirically conclude that the formula is an accurate approximation when used with finite-size samples from processes having geometrically decreasing autocorrelations, even when the ratio of the sample size to the sum of the autocorrelations is as small as five. Although we do not discuss batch-size estimation procedures, the formula is a foundation for estimating the optimal batch size from data in practice.

Rajan Suri (1988), "Perturbation Analysis: The State of the Art and Research Issues Explained Via the GI/G/1 Queue," Department of Industrial Engineering, University of Wisconsin, Madison.

Perturbation analysis (PA) of discrete event dynamic systems (DEDS) enables parameter sensitivities of DEDS to be obtained by observing a single sample path of the system. Since the original paper in 1979 by Ho, et al., the technique has evolved from a body of experimental results to a new theoretical area with a rigorous basis. In particular, consistency and efficiency of PA have been proved for certain systems, and several developments have greatly extended the domain of applicability of PA. The aim of this paper is to use a simple GI/G/1 system to give an introduction to PA and illustrate the basic theoretical issues involved in this technique. After this we briefly cover the application of PA to networks of queues, and then discuss some of the recent extensions to PA. It is shown that many interesting open questions remain for PA, and areas for research are indicated. The paper is written for a broad audience and no prior knowledge of discrete event systems or queueing theory is

assumed. It is hoped that the paper will be suitable for introducing students and researchers to the concepts of PA in a comprehensive and unified way.

James J. Swain and David Goldsman (1988). "Moments of Second Order Polynomials with Simulation Applications," Technical Report J-88-19, School of Industrial and Systems Engineering, Georgia Institute of Technology.

We give exact expressions for the first three moments of second order polynomials of independent and identically distributed random variables. These expressions yield some useful applications. For instance, we provide an example concerning the moments of the sample variance. We also give an Engineering Economy application for a present value under uncertainty. Finally, a control variate example is provided.

Announcements/Event Calendar

1988 Winter Simulation Conference WSC 1988 will take place December 11-14 at the San Diego Marriott in San Diego, Cal. The WSC will feature general and software-specific tutorials as well as application and methodology tracks. For further information, contact Dan Brunner (703)750-3910

Impact of Recent Computer Advances on O.R. This conference will take place January 4-6, 1989, in Williamsburg, Va. It is organized by the Computer Science Technical Section of ORSA. For further information, contact Ramesh Sharda (405)624-5113.

1989 SCS Western Multiconference This conference, sponsored by SCS, will take place January 4-6, 1989, in San Diego, Cal. For further information, contact SCS (619)277-3888.

1989 SCS Eastern Multiconference This conference, sponsored by SCS, will take place March 28-31, 1989, in Tampa, Fla. For further information, contact SCS (619)277-3888.

Joining the College on Simulation It is now possible to become a member of the College without being a member of TIMS. To join, send name, address, e-mail address (if applicable), and $3 to James R. Wilson, School of Industrial Engineering, Purdue University, West Lafayette, Ind. 47907. Make checks payable to "TIMS College on Simulation." Feel free to tell your friends about this bargain offer.

Editor's Corner

Below is the latest update of the e-mail directory. If you would like to have your address included, please send it to one of the *Newsletter* Editors.

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As usual, please send any announcements, abstracts, or other material which you may wish to contribute to the *Newsletter*. Finally, we would like to thank the outgoing Editor, Barry Nelson, for the wonderful job he did over the last two years. – DG,JJS