THE INSTITUTE OF MANAGEMENT SCIENCES

NEWSLETTER OF THE
TIMS College on Simulation and Gaming

LOUIS MOORE, EDITOR and BARRY NELSON, ASSISTANT EDITOR VOL. 10 NO. 1 SPRING 1986

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CHAIRMAN'S MESSAGE

This is my last message as the College chairman. The new officers will take office over this summer. Lee Schruben, as chairman-elect, will become the next chairman. The ballot for vice-chairman/chairman-elect and secretary/treasurer is in this issue of the Newsletter. Please vote!

This issue of the Newsletter also contains the Call for Nominations for both the Outstanding Service Award and the Outstanding Simulation Publication Award. The deadline for nominations is September 1, 1986. The success of these new awards depends critically upon the number and quality of the nominees, which, in turn, depends upon the willingness of the members of the College to prepare quality nomination papers. If you are aware of an individual or publication that you think is worthy of one of these awards, please contact the appropriate committee.

I want to thank the members of the College who have accepted my invitation to participate on the award committees. The last three chairmen of the College, Bill Biles, Averill Law and Bob Sargent, comprise the Outstanding Service Award Committee, with terms of three, two and one years, respectively. As the second-year member, Averill Law chairs this committee. Gordon Clark, David Withers and Bill Schmidt will serve on the Outstanding Simulation Publication Committee, with terms of three, two and one years, respectively. David Withers will be chairman.

In addition to maintaining our regular activities — cosponsoring the Winter Simulation Conference, sponsoring sessions at the Spring and Fall Joint National Meetings of ORSA and TIMS and at the International TIMS Meeting, publishing the *Newsletter*, and (until now) awarding the best simulation paper in *Management Science* — and developing the two new awards discussed above, we have also been considering new College bylaws. A draft set of bylaws was published in the last issue of the *Newsletter* and discussed informally at our business meeting without a quorum at the Winter Simulation Conference in San Francisco. The consensus of the group was that the new bylaws look pretty good, with only a couple of changes being suggested beyond the single suggestion that arose due to the publication of the draft.

However, in the nomination process this last month, I have developed some concern about our move toward real elections. Until the last election, most of you will recall, single nominations led almost automatically to election. I and several others lobbied for real elections, which I thought would encourage wider involvement in the College. Now, however, I am at least equally concerned that in a real election someone must lose, and losing an election is quite a disincentive for further participation. In talking with several people the last month, I have found that there is some sentiment for returning to the procedure of nominating only one person.

Since the election process is a crucial part of the College bylaws and since this doubt has arisen, I have withheld printing the slightly revised draft, thereby holding up the draft's possible adoption at the business meeting in Los Angeles. I'm disappointed at not being able to complete this final objective that we set two years ago. However, I think the draft is in good shape in all other respects and hope that we can continue to pursue the new bylaws after further discussion of the election procedure.

I have enjoyed serving as College chairman these last two years. I want to thank the other officers of the College, who have been a pleasure to work with and who have been so helpful: Lee Schruben, vice-chairman; Jim Wilson, secretary/treasurer; Louis Moore and Barry Nelson, Newsletter editors; David Kelton, award chairman; Alan Pritsker, Winter Simulation Conference representative; and Arne Thesen, who drafted the bylaws of the College.

Bruce Schmeiser, Chairman
March 1985

TREASURER'S REPORT

The 1985 Financial Report to TIMS Headquarters is summarized below.

REVENUES:

Interest on checking accounts (Interfirst Bank NW Austin and Purdue National Bank)	$ 179.77
Interest on money market savings (Purdue National)	215.73
Interest on 180-day 11.3% CD due 4/7/85 (Interfirst)	400.42
Interest on 12-month 9.25% CD due 4/16/86 (Purdue)	359.04
Advance on the 1984 Winter Simulation Conference (WSC)	2000.00
Profit share for the 1984 WSC	2010.27
Total Revenues	$ 5165.23

DISBURSEMENTS:

Advance on the 1985 WSC	$ 2000.00
College-sponsored mixer at the Boston meeting	62.16
College-sponsored mixer at the Atlanta meeting	88.91
Collection fee to close Interfirst checking account	5.00
Expenses for the June meeting of WSC Board of Directors	117.00
"Best Paper" award plaques	120.00
"Best Paper" cash awards	500.00
Total disbursements	$ 2893.07

ACCOUNT SUMMARY AS OF 12/31/85:

Checking account (Purdue National)	$ 1209.12
Money market savings account (Purdue National)	3726.00
12-month 9.25% CD due 4/16/86 (Purdue National)	7944.94
Total bank funds	$12880.06

As of December 31, 1984, the College had $10,607.90 in bank funds plus $278.84 in funds held at TIMS Headquarters so that the net worth of the College amounted to $10,886.74. As of December 31, 1985, the College owed TIMS Headquarters $382.05 so that its net worth amounted to $12,498.01, a 15% increase over the previous year. Because College dues are expected to restore a surplus of funds held at TIMS Headquarters, we do not anticipate a disbursement of bank funds for this purpose.

Since December 31, 1985, we made an advance of $2,000.00 to the 1986 WSC, and we received our previous advance of $2,000.00 from the 1985 WSC.

Respectfully Submitted,
James R. Wilson,
College Treasurer

OFFICERS AND COMMITTEE MEMBERS
TIMS COLLEGE ON SIMULATION AND GAMING MARCH 1986

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ELECTION OF COLLEGE OFFICERS

Officers of the TIMS College on Simulation and Gaming are elected for a two-year term of office, with the vice-chairman/chairman-elect moving automatically into the chairmanship. The current term ends this summer, with Lee Schruben automatically becoming chairman. The ballot for the election of a new vice-chairman/chairman-elect and for a new secretary/treasurer should be returned by June 1, 1986, to Bruce Schmeiser — Code 55Sc, Department of Operations Research, Naval Postgraduate School, Monterey, CA 93943-5100.

BIOGRAPHICAL SKETCHES OF CANDIDATES FOR OFFICE

Arne Thesen, a professor of Industrial Engineering and Computer Sciences at the University of Wisconsin-Madison, maintains an active research program in areas related to decision support systems and computer simulation with particular emphasis on micro-computer based applications in the manufacturing area. His research has appeared in journals such as *Management Science*, *Networks*,

Naval Research Logistics Quarterly, Simulation, Software, and *Project Management*. He is the author of "Computer Methods in Industrial Engineering" and co-author of "Systems Tools for Development Planning." Dr. Thesen serves as consultant to a number of institutions both in the public and private sector in the United States, Europe and Asia. He is a member of The Institute of Management Sciences, the Operations Research Society of America, and the Association for Computing Machinery.

James R. Wilson is an Associate Professor in the School of Industrial Engineering at Purdue University. He has served as the Secretary-Treasurer of the TIMS College on Simulation and Gaming since September 1984. From 1979 to 1984, he was on the faculty of The University of Texas at Austin. He received a BA in mathematics from Rice University in 1970 and MS and PhD degrees in industrial engineering from Purdue in 1977 and 1979, respectively. His current research interests focus on the probabilistic and statistical aspects of computer simulation. His papers have appeared in *American Journal of Mathematical and Management Sciences, Journal of Statistical Computation and Simulation, Management Science, Operations Research Letters, Simulation,* and other journals. He is a member of ACM, IIE, ORSA, SCS, and TIMS.

David Kelton is Assistant Professor of Industrial and Operations Engineering at the University of Michigan. He received his PhD in industrial engineering from the University of Wisconsin in 1980. His research interests are in the statistical and probabilistic methodology of simulation, stochastic models, and statistical inference on estimated stochastic processes. He has published papers in *Management Science, Operations Research, Naval Research Logistics Quarterly, Networks, Communications in Statistics,* and in other journals. He co-authored the book *Simulation Modeling and Analysis* (McGraw-Hill, 1982), with Averill Law. He co-edited the College's Newsletter for three years.

Louis R. Moore is a Systems Analyst for the RAND Corporation in Santa Monica, California. From 1979 through 1985 he was Assistant Professor of Quantitative Methods in the School of Business Administration at the University of North Carolina at Chapel Hill. He received a BS in mathematics from Villanova University in 1970 and MS and PhD degrees in statistics from the University of North Carolina in 1978 and 1979. His research interests include computational statistics, computer assisted decision support processes and the simulation of large complex systems. Dr. Moore has published in the *Journal of the American Statistical Association,* the *Journal of the Association for Computing Machinery,* the *Journal of Statistical Computation and Simulation,* and other journals. He is a member of IMS, ASA, ORSA and TIMS.

TIMS/CSG OUTSTANDING SERVICE AWARD
CALL FOR NOMINATIONS

The first TIMS/CSG Outstanding Service Award, to recognize longstanding, exceptional service to the simulation community, will be presented next fall. Nominations for the award must be received by the chairman of the Award Committee by September 1, 1986: Professor Averill Law, Department of Management Information Systems, BPA #71, University of Arizona, Tucson, AZ 85721.

The complete set of rules governing the Award was printed in the fall 1985 issue of the TIMS/CSG *Newsletter*. Anyone may nominate any person without restriction, and the burden for offering evidence of merit falls on the nominator.

TIMS/CSG OUTSTANDING SIMULATION PUBLICATION AWARD
CALL FOR NOMINATIONS

The first TIMS/CSG Outstanding Simulation Publication Award, to recognize outstanding contributions to the simulation literature, will be presented at the Spring 1987 TIMS/ORSA Joint National Meeting. Nominations for the award must be received by the chairman of the Award Committee by September 1, 1986: Dr. David H. Withers, T. J. Watson Research Center, IBM Corp., Yorktown Heights, NY 10598.

The complete set of rules governing the Award was printed in the fall 1985 issue of the TIMS/CSG *Newsletter*. In summary, anyone is eligible to win the award. Journal articles, proceedings articles, books, and monographs copyrighted in the last three years are eligible; technical reports, research memoranda, working papers, and dissertations/theses are not eligible. Nominations can be made by anyone, including the author(s). Nominations may not be anonymous and shall include (a) a copy of the written work including bibliographical information, (b) a short statement suitable for reading at the award ceremony if the work is chosen and (c) any other information thought relevant by the nominator.

ABSTRACTS OF PAPERS

J. G. Shanthikumar
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"Discrete Random Variate Generation Using Uniformization," *European Journal of Operations Research*, 21 (1985), 387-398.

In this paper we show that a discrete random variable can be uniformized so that it could be represented as the first passage time of a discrete stochastic process Z associated with a point process N. This process N is generated by an independent sequence of identical geometric random variables with parameter equal to the uniformization constant of the discrete random variable of interest. An approach using this result is proposed to generate samples for discrete random variables with nonstandard probability distribution functions.

J. G. Shanthikumar
School of Business Administration
University of California
Berkeley, CA 94720

M. Shaked
Department of Mathematics
University of Arizona
Tucson, AZ

"The Total Hazard Construction, Antithetic Variates and Simulation of Stochastic Systems," Management Science Working Paper No. MS-18, Berkeley Business School, University of California.

This paper combines recent developments in the area of generation of dependent random variables with the advantages of the use of common and antithetic random numbers. This combination yields new efficient methods for estimating complicated stochastic quantities by simulation. Some theoretical and practical aspects of the use of antithetic and common random numbers for variance reduction while using the total hazard construction are given. A proof of their optimality in estimating the expected value of the response sum or the response difference of functions of vector arguments with dependent components is presented. Some numerical examples illustrate the theory.

Peter W. Glynn
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Donald L. Iglehart
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"Large-Sample Theory for Standardized Time Series: An Overview," Technical Report No. 35, Dept. of Operations Research, Stanford University, August 1985.

There are two basic approaches to constructing confidence intervals for steady-state parameters from a single simulation run. The first is to consistently estimate the variance constant in the relevant central limit theorem. This is the approach used in the regenerative, spectral, and autoregressive methods. The second approach (standardized time series, STS) due to Schruben [10] is to "cancel out" the variance constant. This second approach contains the batch means method as a special case. Our goal in this paper is to discuss the large-sample properties of the confidence intervals generated by the STS method. In particular, the asymptotic (as run size becomes large) expected value and variance of the length of these confidence intervals is studied and shown to be inferior to the behavior manifested by intervals constructed using the first approach.

"The Theory of Standardized Time Series," Technical Report No. 32, Department of Operations Research, Stanford University, April 1985.

Building on work of Schruben, we have developed a general framework for the analysis of standardized time series. Under mild assumptions on the output process (see (3.1)), the method of standardized time series produces asymptotically valid confidence intervals for steady-state parameters. However, these intervals are asymptotically larger (see (5.16)) and more variable (see 5.33)) than those steady-state intervals obtained by a method which consistently estimates the appropriate steady-state variance constant (such as the regenerative method). In this sense, standardized time series confidence intervals are asymptotically less desirable than those constructed by consistent estimation.

These results do not, however, preclude the possibility that standardized time series may be superior in certain small sample context; this remains an area for future work.

"Confidence Intervals Using the Regenerative Method for Simulation Output Analysis," Technical Report No. 27, Department of Operations Research, Stanford University, September 1984.

The regenerative method is a mathematically rigorous method for obtaining confidence intervals for steady-state parameters. In this paper the qualitative structure of asymptotic confidence intervals is discussed in general. This structure is then specialized to confidence intervals for steady-state parameters produced by the regenerative method.

"Recursive Moment Formulas for Regenerative Simulation," Technical Report No. 29, Department of Operations Research, Stanford University, October 1984.

Let $X = \{X(t) : t \geq 0\}$ be a regenerative semi-Markov process with countable state space E and f a real-valued function on E. Denote by $Y_1(f)$ the area under the function $f(X(.))$ in the first regenerative cycle. This paper gives a recursive method for computing moments of the form $E\{Y^m_1(f)Y^n_1(g)\}$ for arbitrary f and g, and $m, n \geq 1$. These moments are needed to improve the accuracy of confidence intervals for steady-state parameters obtained when using the method of regenerative simulation.

"A Joint Central Limit Theorem for the Sample Mean and Regenerative Variance Estimator," Technical Report No. 30, Department of Operations Research, Stanford University.

Let $\{V(k): k \geq 1\}$ be a sequence of independent, identically distributed random vectors in Rd with mean vector μ. The mapping g is a twice-differentiable mapping from R^d to R^1. Set $r = g(\mu)$. A bivariate central limit theorem is proved involving a point estimate for r and the asymptotic variance of this point estimate. This result can be applied immediately to the ratio estimation problem that arises in regenerative simulation. Numerical examples show that the variance of the regenerative variance estimator is not necessarily minimized by using the "return state" with the smallest expected cycle length.

"Estimation of Steady-State Central Moments by the Regenerative Method of Simulation," Technical Report No. 36, Department of Operations Research, Stanford University, August 1985.

Let X be a positive recurrent regenerative process on state space S with steady-state distribution π. Given a function $f : S \to R$, we consider the problem of estimating the steady-state central moments $\mu_\alpha(f) = \int_S (f(x) - r)^\alpha \pi(dx)$ where r is the steady-state mean of $f(X(.))$. We obtain strong laws, central limit theorems, and confidence intervals for our estimators, and present numerical results.

Barry L. Nelson
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"A Perspective on Variance Reduction in Simulation Experiments," Working Paper Series No. 1984-011, Department of Industrial and Systems Engineering, The Ohio State University.

A unifying perspective on variance reduction is presented that emphasizes broadly defined variance reduction strategies rather than specific variance reduction techniques (VRTs). The perspective is based on a new taxonomy of VRTs, which is reviewed in detail. The variance reduction problem is formulated as a constrained optimization problem, and results that guarantee the effectiveness of variance reduction strategies are summarized.

David W. Sullivan
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James R. Wilson
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"Restricted Subset Selection Procedures for Simulation," Technical Report.

This paper develops two extensions of the Gupta-Santner restricted subset selection procedure. The exact procedure V_E uses random sampling to screen a set of k normal populations with unknown means and unknown variances so that the selected subset contains at most m populations and has at least the probability P^* of containing some population whose mean lies within distance d of the largest mean. The heuristic procedure V_S similarly screens a set of k stationary normal processes with unknown means and unknown covariance structures based on correlated sampling within each process. Whereas V_E is designed to compare a large number of transient or steady-state simulation models using independent replications of each model, V_S is tailored to comparison of steady-state simulations using a single prolonged run of each model. A complete justification is given for V_E together with appropriate tables of the constants required to apply the rule. The experimental performance of V_S is summarized for several types of stationary autoregressive-moving average processes.

W. David Kelton
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Ann Arbor, MI 48109-2117

"Robust Initialization for Steady-State Simulation," Technical Report 85-36.

When simulating a stochastic model to estimate steady-state parameters of processes of interest, the initial conditions used to start the simulation often bias the estimators, sometimes severely. A common method for ameliorating this bias is to delete, or truncate, an initial portion of the run. If the initial conditions are far from steady state, a large amount of data may have to be discarded from the beginning of each simulation run, increasing costs. We investigate feasible methods for initializing such simulations that lead to lower estimator bias or, alternatively, less requisite deletion. Deterministic and stochastic initialization rules are compared, with appropriately chosen stochastic rules being preferable. Forms for the initial distribution are suggested by the maximum entropy principle, and the parameters of these distributions may be specified from short pilot runs of the model. The goal throughout was to develop initialization methods that adapt to the particular model being simulated, yet are robust to variation in and misspecification of run parameters and conditions on the part of the analyst. These initialization rules are then applied to queueing models with both steady-state and transient properties known, to a computer model with known steady-state mean but unknown transient, and to a model of an actual manufacturing system with neither steady-state nor transient characteristics known.

"Replication Splitting and Variance for Simulating Discrete-Parameter Stochastic Processes," Technical Report 85-21.

Previous results for stationary continuous-time processes concerning allocation of a fixed amount of simulation effort across independent replications are extended both to stationary and certain nonstationary discrete-time processes. In particular, in the presence of positive

autocorrelation, variance is reduced if more short replications are designed. The magnitude, however, of the variance reduction is not great as long as the computation budget is not tight, suggesting that a good strategy is to design for a moderate number of replications in any case, which also mitigates potential bias problems.

Joseph R. Murray and W. David Kelton
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"The Transient Response of the $M/E_k/2$ Queue and Steady-State Simulation," Technical Report 85-29.

The probabilistic structure for the transient $M/E_k/2$ queue is derived in discrete time, where E_k denotes a k-stage Erlang distribution. This queue has a two-dimensional state space. Expressions in terms of transition probabilities are formulated for the expected delay in queue. Results are numerically evaluated for one case. The convergence behavior is similar to that seen in previous work on queues with one-dimensional state spaces. The implications for bivariate initialization of steady-state simulations are discussed.

Sekhar Venkatraman and James R. Wilson
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"The Efficiency of Control Variates in Multiresponse Simulation," to appear in *Operations Research Letters*.

When control variates are applied to a simulation with multiple responses, some of the potential efficiency improvement is lost if the optimal control coefficients must be estimated. To quantify this phenomenon, we formulate a variance ratio and a loss factor that are substantially simpler than the corresponding efficiency measures developed recently by Rubinstein and Marcus (1985).

"Using Path Control Variates in Activity Network Simulation," Research Memorandum No. 86-3.

In the simulation of a stochastic activity network (SAN), the usual objective is to obtain point and confidence interval estimators of the mean completion time for the network. This paper presents a new procedure for using path control variates to improve the efficiency of such estimators. Because each path control is the duration of an associated path in the network, the vector of selected path controls has both a known mean and a known covariance matrix. All of this information is incorporated into point- and interval-estimation procedures for both normal and nonnormal responses. To evaluate the performance of these procedures experimentally, we compare actual versus predicted reductions in point-estimator variance and confidence interval half-length for a set of SANs in which the following characteristics are systematically varied: (a) the size of the network (number of nodes and activities); (b) the topology of the network; (c) the percentage of activities with exponentially distributed durations; and (d) the relative dominance (criticality index) of the critical path. The experimental results indicate that large variance reductions can be achieved with these estimation procedures in a wide variety of networks.

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James R. Wilson
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"Modeling and Simulation of Sea State Variables as Nonhomogeneous Poisson Process"

An integrated method is proposed to analyze series of events and to develop a nonhomogeneous Poisson process model if a time trend exists. New results are presented to determine the functional form of models of phenomena which exhibit cyclic behavior. An algorithm based on the thinning method used in conjunction with a majorizing piecewise-linear rate function is developed to simulate nonhomogeneous Poisson process models.

Yih-Long Chang, Robert S. Sullivan, and Uttarayan Bagchi
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James R. Wilson
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West Lafayette, IN 47907

"Experimental Investigation of Real-Time Scheduling in Flexible Manufacturing Systems," to appear in *Annals of Operations Research*.

This paper presents a new two-phase (TP) approximate method for real-time scheduling in a flexible manufacturing system (FMS). This method combines a reduced enumeration schedule generation algorithm with a 0-1 optimization algorithm. In order to make the combined algorithm practicable, heuristic rules are introduced for the selection of jobs to be scheduled. The relative performance of the TP method vis-a-vis conventional heuristic dispatching rules such as SPT, LPT, FCFS, MWKR, and LWKR is investigated using combined process-interaction/discrete-event simulation models. An efficient experimental procedure is designed and implemented using these models, and the statistical analysis of the results is presented. For the particular case investigated, the conclusions are very encouraging. In terms of mean flow time, the TP method performs significantly better than any other tested heuristic dispatching rules. Also, the experimental results show that using global information significantly improves the FMS system performance.