THE INSTITUTE OF MANAGEMENT SCIENCES

NEWSLETTER OF THE

TIMS COLLEGE on SIMULATION AND GAMING

DAVID KELTON and JOHN CARSON, CO-EDITORS

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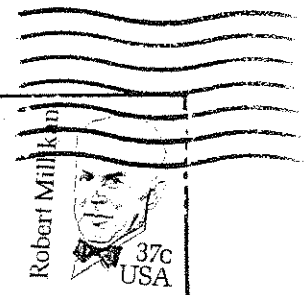

COLLEGE ON SIMULATION AND GAMING
THE INSTITUTE OF MANAGEMENT SCIENCES
146 WESTMINSTER STREET
PROVIDENCE, RI 02903

FIRST CLASS

CHAIRMAN'S MESSAGE

As Chairman of the TIMS College on Simulation and Gaming for the two-year period July 1982 through June 1984, I shall endeavor to sustain the leadership and initiatives of our Past Chairman, Dr. Averill M. Law, and to seek your commitment to renewed vitality and a quality effort for the College. I believe that we are only beginning to witness opportunities for expanded application of computer simulation in business, industry and government. The researchers and practitioners who populate the membership roster of the TIMS College on Simulation have a responsibility to foster this expansion in the best way possible.

A number of studies over the last decade or so have revealed that computer simulation has been regarded by practitioners as the most useful tool in the array of Operations Research and Management Science techniques. Yet only in recent years - and through vigorous activity by this College - has *Management Science* had a Departmental Editor for Simulation (Dr. George Fishman). Volume 28, Number 5, May 1982 finally presents a sample of the fruits of that effort. The five simulation papers appearing in that issue approaches the level of simulation articles for the entire previous two years. Dr. Fishman's efforts are applauded, but we must strive to do even more in the journal publication area.

New opportunities await us. The now widespread availability of inexpensive 16-bit microcomputer systems with both large storage capacity and reasonably high operating speeds offers an exciting vista for the growth of simulation applications in business, industry and government. An entire session on microcomputer-based simulation is planned for the 1983 Spring TIMS/ORSA Conference, April 25-27, 1983 in Chicago.

A College business meeting is scheduled for Tuesday, October 26, 1982 from 5:30-6:30 PM in the El Camino Room, Town and Country Hotel, San Diego, CA. Please mark this slot on your calendar of activities for the 1982 Fall ORSA/TIMS Conference. Join us in planning the activities of the College of the coming year.

William E. Biles
Chairman

NEW COLLEGE OFFICERS

Outgoing College Chairman Averill Law received ten ballots in the election for new college officers of the College, and the results were Bill Biles for Chairman, Bruce Schmeiser for Vice Chairman, and Lee Schruben for Secretary/Treasurer.

JOHN CARSON NEW CO-EDITOR OF NEWSLETTER

As a result of having been elected Secretary/Treasurer of the College, Lee Schruben resigned as Newsletter Co-Editor. I (WDK) will stay on as Co-Editor with John Carson of the School of Industrial and Systems Engineering at Georgia Tech. We both encourage all members of the College to submit more material for inclusion in upcoming issues (see "Call for Newsletter Contributions" in this issue).

CALL FOR NEWSLETTER CONTRIBUTIONS

We would like the Newsletter to serve *all* the several hundred members of the College with their diverse interests and activities in simulation. This can only occur, however, if more members take a moment to send us material for publication. This has usually taken the form of abstracts of papers and technical reports, which we continue to encourage. There are many other possibilities, a few of which might be:

Announcements of short courses and seminars
Reports on applications of simulation in industry and business
Open questions for some of our member consultants or researchers
Teaching aids, such as homework or exam questions
Moves, promotions, awards, etc.
Job openings in simulation or related fields
Preliminary reports of findings from ongoing research or applications projects

Please help us make the Newsletter more useful to you by sending us material on these or other topics -- it would only take a few minutes of your time! Our addresses are:

David Kelton
Dept. of Administrative Sciences
Kent State University
Kent, Ohio 44242
(216) 672-2750

John Carson
School of Industrial and Systems Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
(404) 894-2308

MINUTES OF COLLEGE BUSINESS MEETING IN DETROIT

Tuesday, April 20, 1982
TIMS/ORSA Joint National Meeting, Detroit

Attending: A.J.G. Babu, Bill Biles, George Bridges, Jim Cogliano, Ron Dattero, Floyd Grant, John Hebert, Alfred Jones, Voratas Kachitvichyanukul, Keebom Kang, Marc Meketon, Joseph Polito, Bob Sargent, Bruce Schmeiser, Tom Schriber, Lee Schruben, B. Vinod, Dave Withers.

1. Bill Biles called the meeting to order at 5:20 PM.
2. Bill Biles reported on the status of the college session at the spring 1983 Chicago meeting. We will sponsor five sessions. The session chairmen have been selected.
3. Bruce Schmesier reported there is about $9000 in the treasury. Not reported then, but for the record now, the college has

$2033.26	TIMS Headquarters
806.02	checking account
3964.00	Shearson American Express Daily Dividend (Money Market)
2000.00	advance to the 1982 Winter Simulation Conference
$8803.28	Total

   as of January 1, 1982. Since then there have been no expenses and some interest has accrued.
4. At the Houston (fall 1981) ORSA/TIMS meeting and the Atlanta (1982) Winter Simulation Conference, the college had discussed pursuing joint affiliation with ORSA. The hope had been that the college would be able to impact more people with the same effort. Based on preliminary information from ORSA, as well as the comments from several people at the Atlanta meeting, it appears that ORSA has much tighter rules on how their special interest groups are run than TIMS has for their colleges. It was also mentioned that the number of people belonging to ORSA but not TIMS who would be interested in joining the college appeared to be small. Therefore the decision was made to not pursue joint affiliation with ORSA.
5. The College's award for the best paper published in *Management Science* during the year attracted three nominations. The ballot was distributed in the Spring 1982 *Newsletter*. The award will be given in San Diego.
6. Bob Sargent suggested that the college by-laws need to be updated. The consensus was this made sense and Averill Law, the out-going president, was encouraged to appoint a committee to draft a new version.
7. Lee Schruben reported the response to the special mailing asking for *Newsletter* items was quite good. The *Newsletter* itself went out about three weeks ago.
8. The meeting adjourned at 6:00 PM.

Bruce Schmeiser
Secretary

EDITORIAL POLICY FOR SIMULATION DEPARTMENT OF IIE TRANSACTIONS

The policies for the Simulation Department of the *IIE* (Institute of Industrial Engineers) *Transactions* were recently announced:

The department's interpretation of simulation, although limited to the digital computer context, is relatively broad. Discrete-event, continuous, and hybrid simulation, as well as Monte Carlo evaluation of models having no time component, are considered. Issues of interest include, but are not limited to, uniform (0, 1) random number generation, selection of input models, random variate generation, language design, time keeping, file manipulation, verification, validation, starting conditions, the initial transient, stopping rules, variance reduction, assessing output accuracy, design of experiments, optimization, ranking and selection, and implementation.

The journal publishes papers describing applications, surveying topics, presenting new algorithms, and developing new theory. *Application* papers should illustrate quality simulation practice in the context of a system or problem related to industrial engineering. How and why each aspect of the simulation study was performed is of particular interest. *Survey* papers must give structure to the area discussed and include a complete up-to-date bibliography. Papers presenting new *algorithms* must clearly state the algorithm, the context in which it is appropriate, and limitations. In addition, evidence must be presented that the algorithm is not dominated by existing methods. This evidence will usually be computational results over a range of systems and/or parameter values. If possible and appropriate, a specific example should be given. Computer codes will occasionally be published as an appendix. Papers presenting new *theory* must clearly state the results. The results may be substantiated by mathematical proofs or computer experimentation.

When computer experimentation is used, either to support an algorithm or a theoretical result, enough information must be given so that the reader could duplicate the results. This information includes the computer, language, compiler, and random number generators used. The experimental design should be stated, including the number of replications. Some measure of experimental error must be given. The editor or referees may request copies of the computer program and output that support the results of the paper.

Bruce Schmeiser
School of Industrial Engineering
Purdue University
DEPARTMENT EDITOR

LETTERS TO THE EDITORS

We received the following two letters concerning an abstract in the last Newsletter:

The last edition of the newsletter of the TIMS College on Simulation contained an abstract by Andrew F. Seila entitled "On Waiting Times for a Queue in Which Customers Require Simultaneous Service from a Random Number of Servers." The author refers to a paper written by me and purports that his paper "corrects" the major result given in my paper. Professor Seila sent me a copy of this paper in February at which time I reviewed it and found it to be in error. My original result has been validated in several ways and is correct.

Linda Green
Graduate School of Business
Columbia University

The following abstract is for a revision of an earlier draft report with the same title. In the earlier report, it was incorrectly stated that Green's expression for the Laplace-Stieltjes transform of waiting time was in error. Green's expression (*Operations Research*, 28, p. 1340) is correct.

ON WAITING TIMES FOR A QUEUE IN WHICH CUSTOMERS REQUIRE SIMULTANEOUS SERVICE FROM A RANDOM NUMBER OF SERVERS, Andrew F. Seila, University of Georgia.

We consider a queueing system, first introduced by L. Green in 1980, in which customers from a Poisson arrival stream request simultaneous service from a random number of identical servers with exponential service times. Computational formulas for first and second moment of time in queue for all customers and for customers requesting exactly j servers are given, along with tables of these values for selected systems.

Andrew F. Seila
Department of Quantitative Business Analysis
University of Georgia

CONFERENCE ANNOUNCEMENTS

Winter Simulation Conference (San Diego, December 1982)

Contact:

General Chairman
Yen W. Chao
FEDSIM/MV
U. S. Air Force
Washington, D.C. 20330
(202) 274-8015

Program Chairman
Orlando Madrigal
Computer Science Dept.
California State University
Chico, California 95929
(916) 895-6442

Associate Program Chairman
Bruce Schmeiser
School of Industrial and Systems Engineering
Purdue University
West Lafayette, Indiana 47907
(317) 494-5422

16th Annual Simulation Symposium (Tampa, March 1983)

Contact:

Annual Simulation Symposium
P. O. Box 22621
Tampa, Florida 33622

TIMS/ORSA Joint National Meeting (Chicago, April 1983)

Contact:

General Chairman
Robert Abrams
Dept. of Quantitative Business Analysis
University of Illinois at Chicago
Box 4348
Chicago, Illinois 60680

Program Chairman
Linus Schrage
Graduate School of Business
University of Chicago
1101 E. 58th Street
Chicago, Illinois 60637

SCS Conference on Computer Simulation in Emergency Planning (San Diego, January 1983)

Contact:

Program Chairman
John M. Carroll
Dept. of Computer Science
Univ. of Western Ontario
London, Ontario, Canada N6A5B9

International 83 Bermuda Winter Symposium on Modelling & Simulation, organized by AMSE, the Association for the advancement of Modelling and Simulation techniques in Enterprises (Bermuda, March 1983)

Contact:

AMSE
16 Avenue de Grange Blanche
Tassin-la-Demi-Lune
France

David W. Russell
Danyl Corporation
310 Cooper Center
Pennsauken, N. J. 08109

International Symposium on Simulation of Dynamic Systems in Engineering Sciences (Nantes, France, May 1983)

Contact:

Symposium Secretariat
AFCET
156 Boulevard Pereire
75017 Paris Cedex
France

Fourth International Conference on Mathematical Modelling (Zurich, Switzerland, August 1983)

Contact:

Xavier J. R. Avula
Department of Engineering Mechanics
University of Missouri-Rolla
Rolla, Missouri 65401
(314) 341-4581

SESSIONS AT SAN DIEGO ORSA/TIMS MEETING

Two sessions sponsored by the College were inadvertently left out of the Bulletin. They are:

State-of-the-Art Surveys on Simulation Methodologies, I

Chairman: Averill M. Law, Dept. of Management Information Systems, Unv. of Arizona, Tucson, Arizona 85721

"Quantile Estimation in Discrete Event Simulation," Andrew F. Seila, Dept. of Quantitative Business Analysis, Univ. of Georgia, Athens, Georgia 30602

In this paper we survey state-of-the-art techniques for quantile estimation in both terminating and steady-state simulations.

"Point and Interval Estimators for Steady-State Simulations: The State of the Art 1982," Averill M. Law, Dept. of Management Information Systems, Univ. of Arizona, Tucson, Arizona 85721, and W. David Kelton, Dept. of Administrative Sciences, Kent State Univ., Kent, Ohio 44242

We survey recent significant developments in simulation output data analyses.

State-of-the-Art Surveys of Simulation Methodologies, II

Chairman: Averill M. Law, Dept. of Management Information Systems, Univ. of Arizona, Tucson, Arizona 85721

"Simulation on Microcomputers and Minicomputers," William E. Biles, Dept. of Industrial Engineering, Louisana State Univ., Baton Rouge, Louisiana 70803

We discuss available software and other methodological considerations for performing discrete event simulations on "small" computers.

"Discrete Random Variate Generation," Bruce W. Schmeiser, School of Industrial Engineering, Purdue Univ., West Lafayette, Indiana 47907

After reviewing general concepts for generating discrete random variates, the state of the art for various discrete distributions is surveyed.

These sessions will probably be scheduled for the TC and TD time slots on Tuesday afternoon; check for time and place announcements when registering. The College is also sponsoring the following sessions:

Statistical Techniques in Simulation (TA7)
New Developments in Simulation Languages (TB7)

Other sessions of potential interest to members of the College would include:

On-Line Simulation Software Demonstrations (MA1)
Simulation - I (MC7)
Simulation - II (MD7)
Queueing Systems: Time Dependent Parameters, Transient Responses (MA4)
Queueing Models - I (MB5)
Stochastic Models (ME13)
Queueing: Theory and Application (TA5)

Queueing Applications (TB5)
Queueing Models - III (TC5)
Queueing Models - IV (TD5)

In Addition, a business meeting for the College is scheduled for 5:30-6:30 on Tuesday in the El Camino room.

SHORT COURSES AND SEMINARS

Simulation and Model Building Simplified with SIMSCRIPT II.5

November 15-19, 1982, Washington, D.C.
February 14-18, 1983, Washington, D.C.

This proven course was designed to provide a working understanding of simulation modelling methods and techniques. The course is intended for participants who already know at least one programming language and may have a need to use simulation. Those using other simulation methods will undoubtedly benefit from exposure to state-of-the-art simulation and modelling techniques. The SIMSCRIPT II.5 programming language is used as the primary teaching vehicle; however, emphasis is on applying this language to real-world simulation tasks. A brochure is available from CACI.

Contact: E. C. Russell, (213) 476-6511

Simulation Modeling and Analysis

November 9-12, 1982, San Francisco
January 10-13, 1983, Tampa
March 15-18, 1983, Princeton, N.J.
April 26-29, 1083, Washington, D.C.

This course is designed for systems analysts, management scientists, and engineers who are interested in using simulation techniques to analyze and/or optimize existing or proposed real-world systems. It will also be of interest to managers who must supervise simulation projects. The course will cover all of the important aspects of a simulation study including modelling, simulation languages, selection of input probability distributions, validation, experimental design, and analysis of the output. The four course days will be divided equally between modelling and statistical analysis. This seminar has been previously attended by more than 1000 people from industry, government, the military, and universities. Private seminars can also be arranged. The instructor is Dr. Averill M. Law, Associate Professor at the University of Arizona, Tucson.

Contact: University Associates, P.O. Box 541, Princeton, N.J. 08540. (609) 924-5656

Simulation Modeling for Decision Making

November 17-19, 1982, Washington, D.C.
December 15-17, 1982, Phoenix
January 24-26, 1983, Washington, D.C.
February 23-25, 1983, San Francisco
March 16-18, 1983, Washington, D.C.

This seminar will teach participants the basic concepts of digital simulation. The focus of the seminar is on the development and validation of simulation models and the use of these models in solving the complex and yet practical problems faced by every decision maker. The seminar is presented at a basic level and requires no prior experience in the analysis of systems through simulation. Each topic discussed will be accompanied by practical examples illustrating its application to the solution of real problems. At the beginning of the seminar, participants will receive a set of notes covering the topics in the course including a large number of illustrative examples. The instructor is Dr. J. William Schmidt, Professor of Industrial Engineering and Operations Research at Virginia Polytechnic Institute and State University.

Contact: The Institute for Professional Education, 1515 N. Court House Rd., Suite 303, Arlington, Virginia 22201, (703) 527-8700

Simulation with GPSS

October 1982, Washington, D.C.
January 1983, Washington, D.C.

This intensive five-day course includes lectures and hands-on experience with GPSS in computing center workshops. In addition, about 25 hours of directed private study is required before the course begins.

Contact: Wolverine Software Corp., 7630 Little River Turnpike, Suite 208, Annandale, Virginia 22003, (703) 750-3910

SLAM II

November 14-17, 1982
January 18-21, 1983

This is a four-day comprehensive course on the SLAM II simulation language. Course outline:

Day 1: Simulation methodology and modeling perspectives. Network modeling with SLAM II.
Day 2: Discrete event simulation using SLAM II. SLAM II inputs and outputs.
Day 3: Combined network - discrete event modeling with SLAM II. Continuous models.
Day 4: Combined network - discrete event - continuous modeling with SLAM II. Applications of simulation.

Contact: Pritsker & Associates, Inc., P.O. Box 2413, West Lafayette, Indiana 47906, (317) 463-557.

NEWS

Lee Schruben is a Visiting Associate Professor this year in the School of Industrial Engineering, Purdue University, West Lafayette, Indiana 47907, (317) 494-5416.

ABSTRACTS OF PAPERS

A DUAL ESTIMATOR APPROACH TO DETERMINING SIMULATION STABILITY, POINT ESTIMATE ACCURACY AND STOPPING POINT, J. E. Barker, Honeywell, Inc., W. R. Franta, University of Minnesota, and R. Y. Kain, University of Minnesota.

In this paper we present a new procedure for producing a point estimate with confidence interval for the mean value of a stationary stochastic output variable. The procedure applies two estimators, the sample mean and recursive low pass digital filter, to generate the point estimate and confidence interval. The procedure is sequential in nature, is simple to implement, is computationally efficient, and is efficient in its use of (need for) observations. The procedure accepts as input the confidence level and acceptable confidence interval half-length, and attempts to both minimize the effect of transient phase observations and maximize the effect of the "steady state" phase observations in producing its point estimate and confidence interval. It does so by utilizing the very different convergence characteristics of the two estimators, especially their different characteristics in the transient phase of the simulation where the digital filter exhibits a larger variance than does the sample mean. By using these different convergence properties, the two estimators can be used in a pair-wise fashion to realize confidence interval half-lengths (of given confidence level) with fewer observations than is generally possible with other sequential approaches.

We give theoretical support for the procedure, discuss determination of the digital filter parameter(s), present the procedure as an algorithm, and indicate its performance merit via its use in a number of sample simulations. For our purposes, merit is determined by comparison with other sequential methods using the number of observations necessary to achieve a given confidence interval half-length and the percent of coverage as measures. We conclude that specified confidence level (say 90%) coverages can be obtained with up to 50% fewer observations (on average) than required by other sequential methods.

The procedure's simplicity, efficiency, good performance and general applicability to stationary simulation output variables make it an attractive alternative to other sequential techniques.

AN INTERACTIVE COMPUTER PACKAGE FOR DETERMINING THE MAXIMUM LIKELIHOOD ESTIMATORS FOR WEIBULL PARAMETERS, Edward J. Fisher, Central Michigan University.

This article describes an interactive computer package useful in the classroom and in research for determining maximum likelihood estimators (MLE) for the parameters of the Weibull distribution. The user enters failure data (real or simulated) from the terminal or a file. Results include MLE for the shaping and scaling parameters and related confidence intervals.

SIMULATING A MARKOV CHAIN WITH A SUPEREFFICIENT SAMPLING METHOD, George S. Fishman, Curriculum in Operations Research and Systems Analysis, University of North Carolina, Chapel Hill, North Carolina.

This paper describes an algorithm and a FORTRAN subprogram, CHAIN, for simulating the behavior of an (n+1) state Markov chain using a variance reducing technique called *rotation sampling*. The simulation of k *microreplications* is carried out in parallel at a mean cost $\leqslant O(\ln k)$ and with variances of sample quantities of interest $\leqslant O((\ln k)^2/k^2)$. The program allows for independent *macroreplications*, each of k microreplications, in order to facilitate estimation of the variances of sample quantities of interest. The paper describes theoretical results that underly the algorithm and program in Section 1 and presents applications of interest for first passage time and steady-state distribution in Section 2. Section 3 describes the algorithm and CHAIN and an example in Section 4 illustrates how CHAIN works in practice. Section 5 describes the options available for restarting the simulation.

SIMULATION RUN LENGTH CONTROL IN THE PRESENCE OF AN INITIAL TRANSIENT, Philip Heidelberger and Peter D. Welch, IBM Thomas J. Watson Research Center, Yorktown Heights, New York.

A practical procedure for automatic run length control of steady state simulations is described. The procedure operates on a single simulation run and includes a test for stationarity and the deletion, if necessary, of the initial transient. The procedure is based on a spectral method for estimating the variance of the sample mean and on Schruben's Brownian Bridge model for the detection of nonstationarity. The procedure is evaluated empirically for a variety of output sequences. The performance measures considered are bias, confidence interval coverage, mean confidence interval width, mean run length and mean amount of deleted data. If the output sequence contains a strong transient, then inclusion of a test for stationarity in the run length control procedure results in point estimates with lower bias, narrower confidence intervals and shorter run lengths than when no check for stationarity is performed. If the output sequence contains no initial transient, then the performance measures of the procedure with a stationarity test are only slightly degraded from those of the procedure without such a test. If the run length is short relative to the extent of a weak initial transient, the stationarity tests may not be powerful enough to detect the transient resulting in a procedure with unreliable point and interval estimates.

THE TRANSIENT BEHAVIOR OF CERTAIN MULTISERVER QUEUES, WITH SIMULATION APPLICATIONS, W. David Kelton, Department of Administrative Sciences, Kent State University, Kent, Ohio, and Averill M. Law, Department of Management Information Systems, University of Arizona, Tucson, Arizona.

Although the transient behavior of a queueing system is often of interest, available analytical results are often quite restricted or are very complicated. We consider a queueing model with Poisson arrivals, FIFO queueing discipline, s ($s \geqslant 1$) parallel servers with independent and identically distributed exponential service times, and an arbitrary number of customers present at time zero. Probabilities in a relatively simple closed form are obtained which allow the evaluation of several measures of system performance, among them the expected delay in queue of each arriving customer. A numerical examination is carried out to see how the choice of initial condition would affect the nature of convergence of the expected delays to their steady-state values. These results have implications for the initialization of steady-state simulations.

GENERATING AUTOCORRELATED PSEUDO-RANDOM NUMBERS WITH SPECIFIC DISTRIBUTIONS, V. Chris Lakhan, Department of Geography, University of Toronto (in *J. Statist, Comput. Simul.*, Vol. 12, 1981).

An easily implemented and computationally efficient procedure is presented for the generation of autocorrelated psuedo-random numbers with specific probability distributions. A plot illustrates the relationship among the autocorrelations of the uniform, Rayleigh, and exponential distributions corresponding to a given autocorrelation in the normal generating distribution.

FACTOR SCREENING IN SIMULATION: EVALUATION OF A RANDOM BALANCE/PLACKETT-BURMAN STRATEGY, Carl A. Mauro and Dennis E. Smith, Desmatics, Inc., State College, Pennsylvania.

ON MIXTURE METHODS FOR THE COMPUTER GENERATION OF RANDOM VARIABLES, Arthur V. Peterson and Richard A. Kronmal, Department of Biostatistics, University of Washington, Seattle, Washington (in *The American Statistician*, Vol. 36, 1982).

The general mixture method for the computer generation of random variables from a source of (pseudo) uniform (0, 1) random numbers is reviewed. It is shown that several of the general tools commonly used in generating random variables can be described as mixture methods. Such descriptions seem useful for illuminating and unifying the methods, and also for suggesting possible variations. The latter point is illustrated by a variation of the acceptance-rejection method that avoids repetition of steps.

OPTIMAL ALLOCATION OF COMPUTER TIME IN MONTE CARLO STUDIES OF INTERVAL PROCEDURES, Randall W. Potter, Western Electric Company, Engineering Research Center, Princeton, N. J. (in *J. Statist, Comput. Simul.*, Vol. 13, 1981).

This paper describes three ways of designing Monte Carlo studies to estimate the inclusion probability of a prediction interval procedure. It discusses the problem of computer time allocation during these Monte Carlo studies, develops the relationships between variances of the estimators and computer times required to obtain any given variance, and gives guidelines for choosing the optimal allocation of computer time for specific problems.

APPLICATION OF RESPONSE SURFACE METHODOLOGY TO SIMULATION EXPERIMENTS, Hossein Safizadeh, Department of Administration, Wichita State University, Wichita, Kansas, and Billy M. Thornton, Department of Management, Oklahoma State University, Stillwater, Oklahoma.

The objective of many simulation studies is to find the values of some set of factors (i.e., controllable conditions) that will optimize a desired response function. If the form of the response function could be written "cleanly and nicely," analytical techniques could probably be used to determine the optimal set of values. However, because simulation is involved, it is most probable that the form of the response function is not known. Response surface methodology (RSM) is a powerful approach to estimating the form of the relationship and determining the optimal values of the factors. Unfortunately, the literature of RSM, though well developed, is scattered through several disciplines (e.g., statistics, chemical engineering, etc.), and is not oriented toward simulation. This paper gathers under one cover the experimental designs useful for simulation uses of RSM, and provides two tree diagrams to help the simulator choose an appropriate design. An example is given to illustrate the use of RSM and its experimental designs as applied to simulation analysis.

CONFIDENCE INTERVAL ESTIMATION FROM STANDARDIZED SIMULATION OUTPUT, Lee W. Schruben, School of Operations Research and Industrial Engineering, Cornell University, Ithaca, New York (currently visiting in the School of Industrial Engineering, Purdue University, West Lafayette, Indiana).

The output series from a simulation of a stationary process can be transformed into a "standardized time series" whose asymptotic properties are known under quite general conditions. Confidence intervals for unknown parameters of the simulated process can be constructed using this standardized output series. For illustration, two simple interval estimation procedures are derived using this approach.

MULTIVARIATE ESTIMATION IN REGENERATIVE SIMULATION, Andrew F. Seila, Department of Quantitative Business Analysis, University of Georgia, Athens, Georgia.

A definition is given of regenerative simulation that applies to simulations with multiple responses. Then, a multivariate regenerative estimator of the statationary mean response is presented and shown to be asymptotically normal. Methods for computing confidence regions and simultaneous confidence intervals are also presented.

PERCENTILE ESTIMATION IN DISCRETE EVENT SIMULATION, Andrew F. Seila, Department of Quantitative Business Analysis, University of Georgia, Athens, Georgia.

This paper discusses the current state-of-the-art in percentile (quantile) estimation from a simulation practitioner's perspective. Three methods that have been developed for regenerative simulations are presented and compared with respect to statistical efficiency, computational efficiency, and ease of implementation. Two additional methods are proposed for nonregenerative simulations and their relative merits are discussed.

DATA INTEGRATION: COMBINING REAL-WORLD AND SIMULATION DATA, Dennis E. Smith, Desmatics, Inc., State College, Pennsylvania.

THE SCS SIMULATION SERIES

This is a series of hardbound volumes covering a wide range of topics in simulation applications, methodologies, and languages; more information is available from Simulation Councils, Inc., P. O. Box 2228, La Jolla, California 92038.

SYSTEMS AND SIMULATION IN THE SERVICE OF SOCIETY, D. D. Sworder, Editor.

RECENT DEVELOPMENTS IN URBAN GAMING, Philip D. Patterson, Editor.

COMPUTER SIMULATION IN DESIGN APPLICATIONS, Said Ashour, Editor.

SIMULATION SYSTEMS FOR MANUFACTURING INDUSTRIES, Marvin M. Johnson *et al*, Editors.

ANNOTATED BIBLIOGRAPHIES OF SIMULATION, Tuncer J. Oren, Editor.

SPANNING THE APPLICATIONS OF SIMULATION, Paul Brock, Editor.

NEW DIRECTIONS IN THE ANALYSIS OF ECOLOGICAL SYSTEMS -- PARTS 1 & 2, George S. Innis, Editor.

TOWARDS REAL-TIME SIMULATION . . . Languages, Models, and Systems -- PARTS 1 & 2, Ray Crosbie *et al*, Editors.

AN OVERVIEW OF SIMULATION IN HIGHWAY TRANSPORTATION -- PARTS 1 & 2, James E. Bernard, Editor.

SIMULATION OF ENERGY SYSTEMS -- PARTS 1 & 2, Kenneth E. F. Watt, Editor.

SIMULATION IN BUSINESS AND DECISION MAKING, Thomas H. Naylor, Editor.

SIMULATING THE ENVIRONMENTAL IMPACT OF A LARGE HYDROELECTRIC PROJECT, Normand Therien, Editor.