THE INSTITUTE OF MANAGEMENT SCIENCES

NEWSLETTER OF THE
TIMS COLLEGE on SIMULATION AND GAMING

BRUCE SCHMEISER and LEE SCHRUBEN, EDITORS VOL. 4, NO. 2 SPRING 1980

CONTENTS

CHAIRMAN'S COLUMN

This issue of the Newsletter has a change in one of its two editors. Professor Averill Law, who is one of the two co-founding editors, has retired. I thank Averill on behalf of the College for his services. Professor Lee Schruben is the new Co-editor, and he and the continuing Co-founding Editor, Professor Bruce Schmeiser, will now be producing the Newsletter.

As announced in the last Newsletter, the College will publish bibliographies, so please prepare and forward bibliographies in your area of specialization for the College to publish and distribute. There are three bibliographies on specific topics in Simulation contained within this issue of the Newsletter.

The College has been and continues to be busy with conferences and meetings. We are a co-sponsor of the Winter Simulation Conference. The 1979 Conference, held in San Diego, was successful, and the 1980 Conference will be held December 3-5 in Orlando, Florida. At the ORSA/TIMS meetings in Milwaukee in October, a Social Mixer was held, and due to its success, another Mixer is going to be held at the ORSA/TIMS Meeting in Washington, D.C., in May. Please see the announcements at the meeting for the time and place.

A business meeting of the College will take place Monday evening, May 5, at 6:00 p.m. at the National ORSA/TIMS Meeting in Washington, D.C. I hope you will be able to attend; the meeting held at the 1979 Winter Simulation Conference was excellent.

As noted in the last Newsletter, *Management Science* now has a Department of Simulation for which Professor George S. Fishman is editor. This is an excellent place to publish your simulation papers.

I urge each of you to become involved with our College in some way, and if you have any ideas for the College, please contact any of its offices. Our strength is dependent upon you, the members.

Robert G. Sargent
Department of Industrial Engr.
& Operations Research
Syracuse University
Syracuse, NY 13210

RECEPTION AT THE TIMS/ORSA MEETING IN WASHINGTON, D. C.

You should have all received your bulletins, so you know there are many sessions on simulation, as usual. What you may not know, because it is not in the bulletin, is the we are planning the second semiannual reception of the TIMS College on Simulation and Gaming. It will be Tuesday, May 6, from about 8 P.M. to about 11 P.M. The location is still up in the air, but it will be announced at each of the TIMS College on Simulation and Gaming sessions, as well as on the message board.

The reception in Milwaukee went well, despite lack of publicity. It was not fancy, being held in my room (BWS) and with Averill Law carrying in the refreshments (Thanks). About 40 people attended and it seemed to me that most everyone had a good time and had a chance to meet others with simular (get it?) interests.

AN OFFER: TECHNIQUES OF EFFICIENT MONTE CARLO SIMULATION

Professor Richard E. Beckwith has a number of three-volume sets of **TECHNIQUES FOR EFFICIENT MONTE CARLO SIMULATION** by McGrath, et al. He is willing to distribute the excess copies on a First-Come First-Serve basis. Dick's address is

Professor Richard E. Beckwith
Graduate School of Business Administration
Tulane University
New Orleans, LA 70118

These volumes seem to be little known, but are quite good (opinion, BWS). The first volume is on selection of probability distributions, the second is on random number generation, and the third is on variance reduction techniques. These were done about 1973-4 with support of the Office of Naval Research.

CALL FOR PAPERS

Lee Schruben has begun serving as an associate editor for **SIMULATION**. His area is discrete models and methodology. **SIMULATION** is a fully referred journal. Anyone wishing to have a general interest paper on discrete simulation considered for publication should send four copies to

Natalie Fowler, Managing Editor
Attn: Lee Schruben
SIMULATION
P.O. Box 2228
La Jolla, CA 92038

STANDARDIZATION OF SIMULATION LANGUAGES

On September 20-21, 1979, the Sorrento Workshop for the International Standardization of Simulation Languages was held in St. Agata, Italy. Attendance at the workshop was by invitation only, and the group included a mix of persons working in the areas of discrete event and continuous simulation. After introduction and an opening statement by the workshop organizers, several attendees presented position papers developed for the workshop. The issues surfacing during the presentation ranged from very general (at what level should standardization even be contemplated) to rather specific (improvements to the CSSL specification developed by IMACS several years ago).

Following the presentation of position papers, discussion evolved around some major points:

(1) What is a language? What is a model? Should there be a base language?
(2) Should there be a combined modeling language?
(3) Is the user community identifiable?
(4) Where do problem oriented languages fit in?
(5) Do current hardware developments have any implications for simulation model or base model languages?

Following extended discussion, several issues were identified and through a vote of the attendees, some concensus was reached regarding the importance of the various issues. The decision was made to establish an ongoing effort through two task forces and an executive committee. Elected as Chairman of that Executive Committee was MAURICE S. ELZAS (The Netherlands), Vice Chairman, RICHARD E. NANCE (U.S.A.), Secretary, FRANCOIS CELLIER (Switzerland).

Subcommittee Chairman also elected were:

(1) Vocabulary development: Professor Tuncer Ören (Canada)
(2) Simulation and Modeling Formalisms: Professor Bernard Zeigler (Israel)

ABSTRACTS OF RECENT PAPERS

The response to our publishing abstracts of recent work has been quite favorable, both in terms of comments and the number of people submitting abstracts. The current batch is characterized by an increase in thesis abstracts.

We encourage especially abstracts from thesesand technical reports, since these are often of interest (being timely) but also the hardest to be aware of. Of course, recently published papers are also welcome.

The address for abstracts is:

Dr. Lee Schruben
School of Operations Research and
Industrial Engineering
Cornell University
Ithaca , NY 14853

The Application of Regression Methods to the Initial Transient Problem in Computer Simulation, Mark K. Snell Ph D. Dissertation, School of Operations Research and Industrial Engineering, Cornell University 14853.

Using general families of growth models in regression, transient data can be included in estimators characterizing long-term behavior of simulations. These estimators offer an alternative to output truncation and can be used when runs are short relative to initial transient periods.

Small-sample Behavior of Weighted Least Squares in Experimental Design Applications, Jack Kleijnen, Renée Brent, Rien Brouwers, Department of Business and Economics, Tilburg University (Katholieke Hogeschool Tilburg) Tilburg, Netherlands.

In experimental design applications unbiased estimators s_i^2 of the variances σ_i^2 are possible. These estimators may be used in Weighted Least Squares (WLS) when estimating the parameters β. The resulting small-sample behavior is investigated in a Monte Carlo experiment. This experiment shows that an asymptotically valid covariance formula can be used if s_i^2 is based on, say, at least 5 observations. The WLS estimator based on estimators s_i^2 gives more accurate estimators of β, provided the σ_i^2 differ by a factor, say, 10.

Validation of Simulation Models, Robert G. Sargent, Department of Industrial Engineering and Operations Research Syracuse University, Syracuse, New York 13210.

This is a tutorial paper on validation of simulation models. Included in this tutorial are what is meant by validation, the problem dependent characteristics of simulation model validation, descriptions of the various validation techniques and their use and a discussion on the statistics used in validation techniques (but not the detailed statistical tests themselves).

A Significance Test for Initalization Bias in Simulation Output, Lee W. Schruben, School of Operations Research and Industrial Engineering, Cornell University, Ithaca, New York 14853.

In running simulation experiments there is often concern whether or not the starting conditions have caused a serious bias in the results. A procedure is presented for testing the significance of initialization bias in simulation output. The test is based on easily computed statistics and should offer guidance for simulation initialization in a variety of situations.

Estimation of the Sum of Differences Distribution, Stuart Jay Deutsch, Georgia Institute of Technology, Atlanta, Georgia 30332; Bruce Wayne Schmeiser, Purdue University, West Lafayette, Indiana 47907.

Consider the distribution of $\sum_{i=1}^{n} d_i$, where the d_i's are differences independently, identically and symmetrically distributed with mean zero. The problem is to determine properties of the sdd given the distribution of the d_i's and the sample size n. The standardized moments as a function of the moments of the d_i's are developed. A variance reduction technique for estimating the quantiles of the sdd using Monte Carlo methods is developed based on using the randomization sample consisting of the 2^n values of $\sum_{i=1}^{n} \pm d_i$ rather than the singe observation $\sum_{i=1}^{n} d_i$ corresponding to each sample $d_1, d_2, \ldots d_n$. The randomization sample is shown to produce unbiased and consistent estimators of the moments and biased and consistent estimators for the quantiles of the sdd. For small sample sizes, variance reduction of up to 99.7% is achieved.

An Introduction to Statistical Analysis of Simulation Output Data, Robert G. Sargent, Department of Industrial Engineering and Operations Research, Syracuse University, Syracuse, New York 13210; *Proceedings of the AGARD Symposium on Modeling and Simulation of Avionics Systems and Command, Control and Communication Systems,* Paris, France, October 1979.

This paper is a tutorial paper on how to obtain point and interval estimates (confidence intervals) of means for both terminal and steady state simulations. The simple methods of replication, batch means, and regenerative cycles are presented in detail and applied to a model of a simple time-shared computer system to illustrate their use. A brief discussion is included on sequential procedures and time series methods for obtaining these estimates. The advantages and disadvantages of the various methods are given, including specific recommendations as to when certain methods might be used.

Beta Variate Generation via Exponential Majorizing Functions, Bruce Schmeiser and A. J. G. Babu, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

Two acceptance/rejection algorithms for generating random variates from the beta distribution are developed. The algorithms use piece-wise linear and exponential majorizing functions coupled with a piece-wise linear minorizing function. The algorithms are exact to within the accuacy of the computer and are valid for all parameter values greater than one. Marginal execution times are relatively insensitive to parameter values and are faster than any previously published algorithms.

Generation of Variates from Distribution Tails, Bruce Schmeiser, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

The well-known acceptance/rejection algorithm for generating random values on a computer is specialized for distribution tails. Using an exponential majorizing function and a linear minorizing function, the tail algorithm becomes particularly efficient. Specific algorithms are given for the normal, gamma, Weibull and beta distributions. While the algorithms can be used alone, it is anticipated that their major value will be to serve as components of algorithms for complete distributions.

An Introduction to the Selection and Use of Simulation Languages, Robert G. Sargent, Department of Industrial Engineering and Operations Research, Syracuse University, Syracuse, New York 13210; *Proceedings of the AGARD Symposium on Modeling and Simulation of Avionics Systems and Command,Control and Communications Systems,* Paris, France, October 1979.

This paper contains an introduction to the selection and use of simulation languages for digital computers. The topics discussed are the hierarchy of computer languages and their relationship to simulation, the advantages and disadvantages of using simulation languages, the factors to consider in selecting simulation languages for an organization and a language for solving a specific problem, some charactertistics of the simulation languages GASP, GPSS, SIMSCRIPT, SIMULA, and SLAM, and future developments in simulation languages. The emphasis is on discrete and combined simulation languages.

A Stopping Rule for Data Collection in Queuing Simulations, Veena G. Adlakha and George S. Fishman, Curriculum in Operations Research and Systems Analysis, University of North Carolina at Chapel Hill, Chapel Hill, NC 27514.

This paper proposes a stopping rule (Rule 2) for terminating data collection in a queueing simulation experiment. The appeal of the rule lies in the fact that data collected in this way can be used to compute interval estimates with coverage rates that compare favorably with theoretically specified rates. The rule relies on a comparison between *a priori* information on the activity level (traffic intesity) p and a corresponding sample estimator computed during the course of simulation. Experiments with simulations of the M/M/c queue with c = 1,2,4 and p = .7, .8, .9, .95 were conducted to evaluate the rule. The experiments used a starting rule (Rule 1) proposed in Adlakha and Fishman (1979) to reduce bias due to the initial conditions and also used the autoregressive method to obtain interval estimates of the steady-state mean. For p = .7, .8, .9, the coverage rates are close to the specified theoretical coverage rates and are higher than those reported in the literature for other methods of interval estimation. The data reveal a degradation in the coverage rate for increasing values of activity level. For p = .95 the coverage rates are somewhat lower than those expected theoretically, indicating room for some improvement in technique. The sample sizes used to obtain the coverage rates are moderate and are insenstive to variation in the number of servers and the activity level. The rule can be easily generalized to a wider class of queueing simulations. Furthermore, experiments with a fixed truncation starting rule and a fixed sample size stopping rule clearly demonstrate the superiority of using Rule 1 and Rule 2 together. This is very encouraging, for it indicates a procedure now exists for controlling the detrimental effects of initial conditions and skewness on interval estimation in queueing simulations.

A Starting Rule for Data Collection in Queueing Simulations, Veena G. Adlakha and George S. Fishman, Curriculum in Operations Research and Systems Analysis, University of North Carolina at Chapel Hill, Chapel Hill, NC 27514.

This paper proposes a rule for determining when to start collecting data in a queueing simulation. The rule is designed to reduce dependence between the empty (queue) and idle (servers) *initial conditions* and the collected sample record. The rule is an outgrowth of earlier work by Fishman and Moore (1978) and relies on a comparison between *a priori* information on the activity level (traffic intensity) and a corresponding sample estimate computed during the course of simulation. Experiments with simulations of the M/M/c queue with c = 1, 2, 4 and p = .7, .8, .9, .95 reveal that the rule reduces and in most cases removes the dependence on the empty and idle initial conditions. In particular, the rule begins data collection when the simulation is in a congested state or in the steady state. The rule is well behaved in that it has low probabilities of requiring long runs before data

collection is started. Although our data suggests an association between the rule's performance and activity level, the performance is insensitive to variation in the number of servers. Since the rule is based upon the activity level, a parameter that frequently can be computed from the input parameters of the simulation, the rule is easily generalized to a wider class of queueing simulations. A subsequent study (Adlakha and Fishman 1979) demonstrates the appeal of the starting rule when used with a proposed stopping rule for computing interval estimates of parameters of interest.

Multivariate Modeling in Simulation: A Survey, Bruce Schmeiser, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907, Ram Lal, Department of Operations Research and Engineering Management, Southern Methodist University, Dallas, TX 75275.

Modeling of correlated random variables is surveyed, with emphasis on non-negative random variables and quality control and reliability contexts. Particularly of interest is the use of multivariate input models for digital computer simulation. Both sequential (time series and point processes) and non-sequential systems are considered.

Analysis of Simulation with Common Random Numbers: A Note on Heikes et al. (1976), Jack P. C. Kleijnen, Department of Business and Economics, Katholieke Hogeschool Tilburg, Tilburg, Netherlands.

If different random number streams are used then traditional Analysis of Variance can be applied, but the standard errors of the estimated effects should account for heterogeneity of variance. If common random numbers are used then the quite complicated procedure propsed by Heikes et al. in 1976 may be replaced by the simple Student t-statistic combined with the so-called Bonferroni - inequality. The statistical techniques are illustrated with a simple case study.

Regression Analysis for Simulation Practitioners, Jack P. C. Kleijnen, Department of Business and Economics, Katholieke Hogeschool Tilburg, Tilburg, Netherlands.

Based on elementary regression analysis as found in standard textbooks and computer software packages this tutorial presents some simple extensions useful in the analysis of simulation experiments. In simulation one usually has variance estimates (standard errors) available. These estimates often conflict with the assumption of constant variances maintained in elementary regression analysis. Therefore two options are available: (1) Switch to Generalized Least Squares, (2) Continue to use Ordinary Least Squares. The consequences of both approaches are surveyed. How to test the model's adequacy is discussed in detail.

Optimization of Stochastic Systems Through Simulation Using Stochastic Approximation Method, Farhad Azadivar Ph. D. Dissertation, Purdue University, West Lafayette, IN 47907.

An algorithm is developed for optimizing the response function of simulation models with stochastic behavior. Principles of stochastic approximation are used which guarantees convergence to the optimum, if a large number of observations are made. The algorithm can be used when the decision variables are subject to a set of linear constraints.

A Design of Experiments Approach to the Evaluation of the Effects of Initial Conditions and Run Length in Simulation Experiments, Robert J. Hannan Jr., M. S. Thesis, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

This thesis treats initial conditions, run length and replications as factors in the design of the simulation experiment. Two designs were used for this purpose: (1) the completely randomized design; and (2) the randomized complete block design. The objective of the research was to determine if either design is sensitive to the effects that are present.

CANSAM: A Simulation Model for Computer-Aided Manufacturing Systems, Jeffrey A. Runner, M. S. Thesis, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

A Q-GERT simulation model was developed to analyze Computer-Aided Manufacturing Systems (CAM). A currently existing CAM system was studied which consists of nine (9) numerically controlled machines and an automatic inspection station linked together by an addressable pickup and delivery cart type transport system. A detailed analysis of the system is included.

Incorporation of Database Systems Concepts into Simulation Modeling, Charles Robert Standridge, Ph. D. Dissertation, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

A database system tailored for use in simulation modeling has been designed and implemented in the FORTRAN computer programming language. This system is a tool for use by simulation modelers in the organization, storage and retrieval of all data concerning a simulation study.

Variance Reduction Techniques for the Simulation of Queueing Networks, James Reed Wilson, Ph. D. Dissertation, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

This research formulates, implements, and experimentally assesses procedures for applying two variance reduction techniques (poststratified sampling and control variates) in combination with two confidence interval estimation techniques (replication and regeneration in the simulation of queueing networks.) On the basis of the experimental results, guidelines are formulated for the effective application of the developed procedures in practical queueing simulations.

The Use of Cutsets in Monte Carlo Analysis of Stochastic Networks, C. E. Sigal, A. A. B. Pritsker, and J. J. Solberg, School of Industrial Engineering, Purdue University, West Lafayette, IN 47907.

Monte Carlo methods utilizing a new network concept, Uniformly Directed Cutsets (UDCs), are presented for analyzing directed, acyclic networks with probabilistic arc durations. The procedures involve sampling arc values for arcs not on a UDC and utilizing known probability information for arcs on a UDC. This approach results in less sampling effort and less associated variance than a straightforward simulation approach. A proof of this variance reduction is offered. The procedures provide estimates for project completion time distributions, criticality indices, minimum time distributions and path optimality indices. All of these network performance measures are useful to decision makers in project planning. Application areas include PERT-type network planning, equipment replacement analysis, reliability modeling, stochastic dynamic programming, and maximal flow problems.

Current Issues in Computer Simulation (Academic Press, NY 10003), Nabil R. Adam, Graduate School of Business Administration, Rutgers University, New Brunswick, NJ 08903; Ali Dogramaci, School of Engineering and Applied Science, Columbia University, New York, NY 10027.

This book is a collection of previously unpublished papers on computer simulation methodology and applications. The papers included have been reviewed by two to five referees. Each paper constitutes a chapter. The book is divided into three parts: (1) computer simulation languages; (2) simulation applications; (3) statistical aspects of simulation and linkage with optimization and analytical models. Each section starts with an introductory chapter that helps relate the different chapters included in this section to each other and provides a frame of reference to the reader.

The first part includes chapters on three of the most widely used simulation languages: GPSS, SIMSCRIPT, and GASP. The developers of each of these languages present their own account of the language's present state as well as their ideas for possible future research and development. This part also includes chapters on the following language related issues: (1) The future event set algorithms for simulation of closed queueing systems; (2) model development and documentation standards in discrete event simulation.

The chapters included in the second section illustrate the application of simulation to diverse applications including marketing, corporate planning, hospital facilities, and computer networks.

The chapters presented in the final part focus on the following topics: (1) the linkage between simulation models and analytical and optimization models; (2) three statistical issues in simulation, variance reduction techniques, random numbers generation for bivariate and multivariate distributions, and experimental design. A chapter on concepts related to efficient and effective use of simulation in studying inventory systems is also included in this part of the book.

BIBLIOGRAPHY ON FUTURE EVENT ALGORITHMS (January 1980)

William M. McCormack, *Virginia Polytechnic Institute & State University* and
Robert G. Sargent, *Syracuse Univeristy*

[1] Comfort, J.C., "A Taxonomy and Analysis of Event Set Management Algorithms for Discrete Event Simulation," *Proceedings of the 12th Annual Simulation Symposium*, March 1979, pp. 115-146.

[2] Conway, R.W., Johnson, B.M., and Maxwell, W.L., "Some Problems of Digital Systems Simulation," *Management Science*, Vol. 6, No. 1, pp. 92-110.

[3] Davey, D. and Vaucher, J., "An Analysis of the Steady State Behaviour of Simulation Sequencing Set Algorithms," University of Montreal, December 1976.

[4] Englebrecht-Wiggans, R. and Maxwell, W.L., "Analysis of the Time Indexed List Procedure for Synchronization of Discrete Event Simulations," *Management Science*, Vol. 24, September 1978, pp. 1417-1427.

[5] Franta, W.R. and Maly, K., "An Event Scanning Algorithm of Nearly Constant Complexity," Technical Report 75-18, Computer, Information, and Control Sciences Department, University of Minnesota, November 1975.

[6] Franta, W.R. and Maly, K., "An Efficient Data Structure for the Simulation Event Set," *Communications of the ACM*, Vol. 20, No. 8, pp. 596-602.

[7] Franta, W.R. and Maly, K., "A Comparison of HEAPS and the TL Structure for the Simulation Event Set,"*Communications of the ACM*, Vol. 21, No. 10, pp. 873-875.

[8] Gonnet, G.H., "Heaps Applied to Event Driven Mechanisms," *Communications of the ACM*, Vol. 19, No. 7, pp. 417-418.

[9] Henriksen, J.O., "An Improved Events List Algorithm," *Proceedings of the Winter Simulation Conference*, December 1977, pp. 554-557.

[10] Jonassen, A. and Dahl, O.J., "Analysis of An Algorithm for Priority Queue Adminstration," *BIT*, Vol. 15, No. 4, pp. 409-422.

[11] Knuth, D.E., *The Art of Computer Programming, Vol. 1: Fundamental Algorithms*, Reading, Massachusetts: Addison-Wesley, 1969.

[12] Landson, B.M., *A Comparison of Sequential and Associative Computing of Priority Queues With Applications to Discrete Simulation and Time Flow Mechanisms*, Ph. D. Dissertation, Syracuse University, 1976.

[13] Laughlin, G.W., "Reducing the Run Ratio of a Multiprocessor Software System Simulator," *Proceedings of the 8th Annual Simulation Symposium*, 1975, pp. 115-134.

[14] Lave, R.E., "Timekeeping for Simulation," *Journal of Industrial Engineering*, Vol. 18, No. 7, pp. 389-394.

[15] McCormack, W.M., *Analysis of Future Event Set Algorithms For Discrete Event Simulation*, Ph. D. Dissertation, Syracuse University, 1979.

[16] McCormack, W.M. and Sargent, R.G., "Comparison of Future Event Set Algorithms for Simulations of Closed Queueing Systems," in *Current Issues in Simulation*, edited by Adam, N.R. and Dogramaci, A., New York: Academic Press, 1979.

[17] Nance, R.E., "On Time Flow Mechanisms for Discrete System Simulation," *Management Science*, Vol. 18, September 1971, pp. 59-73.

[18] Philips, N. and Tellier, J., "Efficient Event Manipulation - The Key to Large Scale Simulation," Proceedings of Cherry Hill Test Conference, October 1978.

[19] Pritsker, A.A.B., "Ongoing Developments in GASP," *Proceedings of the Winter Simulation Conference*, December 1976, pp. 81-83.

[20] Taneri, D., "The Use of Subcalendars in Event Driven Simulations," *Proceedings of the Summer Simulation Conference*, July 1976, pp. 63-66.

[21] Ulrich, E.G., "Event Manipulation for Discrete Simulations Requiring Large Numbers of Events," *Communications of the ACM*, Vol. 21, No. 9, pp. 777-785.

[22] Vaucher, J.G. and Duval, P., "A Comparison of Simulation Event List Algorithms," *Communications of the ACM*, Vol. 18, No. 4, pp. 223-230.

[23] Vaucher, J.G., "On the Distribution of Event Times for the Notices in a Simulation Event List," *INFOR*, Vol. 15, No. 2, pp. 171-182.

[24] Vuillemin, J., "A Data Structure for Manipulating Priority Queues," *Communications of the ACM*, Vol. 21, No. 4, pp. 309-315.

[25] Wickham, W.K., "Time Flow Mechanisms of Discrete Event Simulation Models," Ph.D. Dissertation, Southern Methodist University, 1971.

[26] Wyman, F.P., "Improved Event Scanning Mechanisms for Discrete Event Simulations," *Communications of the ACM*, Vol. 18, No. 6, pp. 350-353.

BIBLIOGRAPHY ON RESEARCH AND DEVELOPMENT SYSTEM DYNAMICS (October 1979)

Edward B. Roberts, *Massachusetts Institute of Technology*

1. R&D Projects

Carlson, R.H. 1968. Better schedules automatically. *IEEE Transactions on Engineering Management, 15*, No. 4, 188-192.

Holman, F.S. 1963. *A Dynamic Analysis of a Large System Development* (unpublished S.M. thesis, M.I.T. School of Industrial Management).

Katz, A. 1959. An industrial dynamic approach to the management of research and development. *IRE Transactions on Engineering Management, 6*, No. 3, 75-80.

Kelly, T.J. 1970. *The Dynamics of R&D Project Management* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Nay, J.N. 1966. *Choice and Allocation in Multiple Markets: A Research and Development Systems Analysis* (unpublished S.M. thesis, M.I.T. Department of Electrical Engineering).

Roberts, E.B. 1964. *The Dynamics of Research and Development*. New York: Harper and Row, Publishers, Inc. Also available in Japanese: 1967. Tokyo: Toyo Keizei Shinpo Sha.

Roberts, E.B. 1964. Research and development policy-making. *Technology Review, 66*, No. 8, 3-7. Also reprinted in Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 283-292.

Roberts, E.B. 1974. A simple model of R&D project dynamics. *R&D Management, 5*, No. 1, 1-15. Also reprinted in Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978, 293-314.

Schlager, K.J. 1964. How managers use industrial dynamics. *Industrial Management Review, 6*, No. 1, 21-29. Also reprinted in Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 145-153.

Watanabe, K. 1964. Industrial dynamics applied to research and development. *Industrial Engineering* (Japan), *6*, No. 12, 995-999.

2. R&D Organizations

Addison, L.E., Litchfield, J.W. and Hansen, J.V. 1976. Managing growth and change in an R&D organization: the role of dynamic modeling. *R&D Management, 6*, No. 2, 77-80.

Baker, R.J. 1972. *Interaction Between Overhead Functions and Operating Functions in R&D Organizations* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Beaumariage, D.C. 1960. A *Dynamic Model Study of a Military Product Development Organization* (unpublished S.M. thesis, M.I.T. School of Industrial Management.

Blackman, A.W. 1966. *The Growth of an Industrial Research Laboratory in the Aerospace Industry* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Blackman, A.W. 1974. The use of dynamic modeling for conditional forecasts of resource allocation policies. *Technological Forecasting and Social Change, 6*, 191-208. Also reprinted in Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 355-372.

DiLorenzo, R. 1973. A case study of organization dynamics. *IEEE Transactions on Engineering Management*, August, 86-92.

Fischer, W.A. and McLaughlin, C. 1979. *MBO and R&D Productivity: Revisiting the System's Dynamics* (unpublished paper, University of North Carolina, School of Business Adminstration).

Lett, P.W. 1961. *An Industrial Dynamics Analysis of a Defense Product Development Organization* (unpublished S.M. thesis. M.I.T. School of Industrial Management).

Pedraglia, R.M. 1967. *A Dynamic Model of the Budgeting-Hiring System of A Typical R&D Organization* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Perrine, C.H., Jr. 1968. *The Dynamics of Transition in a Large Government Research and Development Center* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Piselli, J.R. 1963. *The Design of an R&D Engineering Organization* (unpublished S.M. thesis, M.I.T. School of Industrial Management).

Poziomek, E.J., Rice, D.W. and Andersen, D.F. 1977. Management by objectives in the R&D environment a simulation. *IEEE Transactions on Engineering Management, 24*, No. 2, 45-51.

Rice, D.W., Poziomek, E.J. and Andersen, D.F. 1976. *A System Dynamics Model of R&D Productivity as Influenced by MBO Policies.* M.I.T. System Dynamics Group Memorandum D-2419.

Roberts, E.B. 1967. The problem of aging organizations. *Business Horizons, 10,* No. 4, 51-58. Also reprinted in Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 315-324.

Ruskin, A.M. and Lerner, R. 1972. Forecasting costs and completion dates for defense research and development contracts. *IEEE Transactions on Engineering Management, 19,* No. 4, 128-133.

Salba, L. 1967. *A Planning Model for the NASA Electronic Research Center* (unpublished, S.M. thesis, M.I.T. Sloan School of Management).

Spencer, R.W. 1966. Modelling strategies for corporate growth. In Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 341-354.

Troutner, J.R. 1968. *Electromagnetic Compatibility Program Management: An Industrial Dynamics Study* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Wachold, G.R. 1963. *An Investigation of the Technical Effectiveness of a Government Research, Development, Test, and Evaluation Organization* (unpublished S.M. thesis, M.I.T. School of Industrial Management).

Weil, H.B., Bergan, T.B. and Roberts, E.B. 1973. The dynamics of R&D strategy. In Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 325-340.

Welles, G., III. 1963. *An Analysis of the Dynamic Behavior of an R&D Organization* (unpublished S.M. thesis, M.I.T. School of Industrial Management).

3. **R&D and the Company as a Whole**

Fryling, G.P., II. 1964. *The Dynamic Problems of Introducing a Competitive Product to the Market* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Hayes, W.F. and Tucker, H.G. Undated. A simple innovation cycle model and its implications. *Simulation Today,* No. 19.

Hoskins, J.H. 1967. Designing a technical company. *International Science and Technology,* April, 85-100.

Jones, C.R. 1968. *A Dynamic Analysis of a Company's Interaction with the Aerospace Market* (unpublished S.M. thesis, M.I. T. Sloan School of Management).

Kanter, L.E. 1964. *An Investigation of the Interaction Between the Depth and Breadth of R&D Endeavor and the Growth of the Company* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Miller, T.G. Jr., and L.P. Kane, 1965. Strategies for survival in the aerospace industry. *Industrial Management Review, 7,* No. 1, 19-35.

Roberts, E.B. 1970. *The System Approach in Engineering and Management* (unpublished paper, M.I.T. Sloan School of Management).

Stolze, W.J. 1962. Decisions making as it affects long-range planning. *IRE Transactions on Engineering Management,* March, 33-36.

4. **Other Related Areas**

Ames, M. 1966. *A Model of Hiring Practices and Implementation Decisions in a Research Oriented Organization* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Andrews, R.A. 1976. *Federal Funding of Solar Energy R&D* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Blackman, A.W. 1972. Forecasting through dynamic modeling. *Technological Forecasting and Social Change, 3,* 291-307.

Hartman, R.L. 1973. *Limits to Growth of Physics* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Hirsch, M.S. 1965. *A Behavioral Model of Professional Performance* (unpublished S.M. thesis, M.I.T. Department of Electrical Engineering).

Jacobson, A., and D. Forman. 1962. *A Dynamic Interaction between the United States and the Soviet Union.* The MITRE Corporation: Working Paper W-5053.

Lenz, R.C., Jr. 1959. *A Development of Explicit Methods in Technological Forecasting* (unpublished S.M. thesis, M.I.T. School of Industrial Management). Reprinted in 1962, as *Technological Forecasting* (Second Edition). United States Air Force: Aeronautical Systems Division Report No. ASD-TDR-62-414 (AD No. 408085).

Love, P.E. 1976. Applying a system concept to R&D management. *R&D Management, 7,* No. 1, 9-13.

Pathak, S.K. 1968. *Systems Analysis of the Process of Implementing an Innovation* (unpublished S. M. thesis, M.I.T. Sloan School of Management).

Peterson, V.L. 1973. *Effects of Funding Policies on Technical Manpower Utilization* (unpublished S.M. thesis, M.I.T. Sloan School of Management).

Roberts, E.B. 1969. Exploratory and normative technological forecasting: A critical appraisal. *Technological Forecasting, 1,* No. 2, 113-127. Also reprinted in Roberts, E.B. (editor), *Managerial Applications of System Dynamics* (Cambridge: The M.I.T. Press, 1978), 373-387.

Sharif, M.N. and Kabir, C. 1976. System dynamics modeling for forecasting multilevel technological substitution. *Technological Forecasting and Social Change, 8,* No. 4.

*Copies of M.I.T. theses may be obtained in microfilm or Xerox form by direct order from the M.I.T. Microreproduction Laboratory, Room 14-0551, Cambridge, Massachusettts 02139.

BIBLIOGRAPHY ON VALIDATION OF SIMULATION MODELS
(January 1980)

Osman Balci and Robert G. Sargent, *Syracuse University*

1. Aigner, D.J., "A Note on Verification of Computer Simulation Models," Management Science, Vol. 18, No. 11, July, 1972, pp. 615-619.
2. Beilner, H.; Waldbaum, G., "Statistical Methodology for Calibrating a Trace-driven Simulator of a Batch Computer System," Statistical Computer Performance Evaluation, Freiberger, ed., Academic Press, New York, 1972.
3. Berman, M.B., "Notes on Validating/Verifying Computer Simulation Models," Rand Report P-4891, August, 1972.
4. Bhushan, B.; Prater, W.E., "Simulation Verification of a Computer Communication System," Proceedings, Sixth Annual Conference on Modeling and Simulation, Pittsburgh, 1975, pp. 737-742.
5. Bhushan, B.; Prater, W.E., "A Simulation Validation Technique-Design and Use of Load Emulators," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 676-677.
6. Billik, M., "Energy Information Agency - Role and Interest in Validation Efforts," Proceedings of the Workshop on Validation of Computer-based Mathematical Models in Energy Related Research and Development, Texas Christian University, October, 1979, pp. 41-46.
7. Blunden, W.R.; Pollnow, E.H., "A Time Dependent Approach to Queue Simulation, I: Validation Problems in Existing Techniques," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 63-74.
8. Brown, R.A.; Tytula, T.P., "The Use of System Identification Techniques in a Rigorous Validation of Aerospace Simulations," Bulletin of TIMS/ORSA, No. 7, April 30-May 2, 1979.
9. Chattergy, R.; Pooch, U.W., "Integrated Design and Verification of Simulation Programs," Computer, Vol. 10, No. 4, April, 1977, pp. 40-45.
10. Cohen, K.J.; Cyert, R.M., "Computer Models in Dynamic Economics," Journal of Economics Quarterly, Vol. 75, 1961, pp. 112-127.
11. Conway, R.W., "Some Tactical Problems in Digital Simulation," Management Science, Vol. 10, No. 1, October, 1963, pp. 44-61.
12. Cutler, M.M., "Proving Properties of Simulation Programs for System Verification and Validation," Proceedings 1979 Summer Computer Simulation Conference, July, 1979, Toronto, Canada, pp. 610-616.
13. Cyert, Richard M., "A Description and Evaluation of some Firm Simulations," Proceedings, IBM Scientific Computing Symposium on Simulation Models and Gaming, IBM, White Plains, New York, 1966.
14. Damborg, M.J.; Fuller, L.F., "Model Validation Using Time and Frequency Domain Error Measures," ERDA Report 76-152, September, 1976.
15. Deeter, C.R.; Hoffman, A.A.J., "An Annotated Bibliography of Mathematical Models Classified by Validation and Error Analysis Methods," Texas Christian University, April, 1978.
16. Deland, E.C., "Validation of Very Large Simulations of Human Biochemistry," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 843-850.
17. Dieudonne, J.E., "Verification and Validation of the NASA *Terminal Configured Vehicle's* (TCV) Wind Analysis Program Using Real-Time Digital Simulation," Proceedings, 1979 Summer Computer Simulation Conference, July, 1979, Toronto, Canada, pp. 584-590.
18. Driscoll, T.R.; Stockdale, R.C., "Validation Methodology of a 6-DOF Tactical Missile Simulation Model," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1217-1222.
19. Dupont, E.R., "Validation of Large Models: Philosophy and Practice," Proceedings of the Workshop on Validation of Computer-Based Mathematical Models in Energy Related Research and Development, Texas Christian University, October, 1979, pp. 61-67.
20. Emshoff, J.R.; Sisson, R.L., "Design and Use of Computer Simulation Models," MacMillan, 1970.
21. Fishman, G.S., "Concepts and Methods in Discrete Event Digital Simulation," Wiley, 1973.
22. Fishman, G.S., "On Validation of Simulation Models," Proceedings, AFIPS 1973 National Computer Conference, Vol. 42, 1973, p. 51.
23. Fishman, G.S.; Kiviat, P.J., "The Analysis of Simulation Generated Time Series," Management Science, Vol. 13, No. 7, March, 1967, pp. 525-557.
24. Fishman, G.S.; Kiviat, P.J., "The Statistics of Discrete Event Simulation," Simulation, April, 1968, pp. 185-195.
25. Fishman, G.S.; Kiviat, P.J., "Digital Computer Simulation: Statistical Considerations," *Memorandum RM-5387-PR*, The Rand Corporation, November, 1967.

26. Forrester, Jay W., "Industrial Dynamics," MIT Press, Cambridge, 1961.

27. Gafarian, A.V.; Walsh, J.E., "Methods for Statistical Validation of a Simulation Model for Freeway Traffic Near an On-Ramp," Transporation Research, Vol. 4, 1970, pp. 379-384.

28. Gafarian, A.V.; Walsh, J.E., "Statistical Approach for Validating Simulation Models by Comparison with Operational Systems," The Proceedings of the Fourth International Conference on Operational Research, John Wiley and Sons, New York, 1969, pp. 702-705.

29. Gallant, A.R.; Gerig, T.M.; Evans, J.W., "Time Series Realizations Obtained According to an Experimental Design," Journal of the American Statistical Association, Vol. 69, No. 347, Applications Section, September, 1974.

30. Garratt, M., "Statistical Validation of Simulation Models," Proceedings, 1974 Summer Computer Simulation Conference, 1974, pp. 915-926.

31. Gass, Saul, I., "A Procedure for Evaluation of Complex Models," Proceedings, First International Conference on Mathematical Modeling, University of Missouri, 1977, pp. 247-258.

32. Gass, Saul I., "Evaluation of Complex Models," Computers and Operations Research, Vol. 4, March, 1977, pp. 27-35.

33. General Accounting Office, "Guidelines for Model Evaluation," PAD-79-17, U.S. G.A.O., Washington, D.C., January, 1979.

34. Giammo, Thomas, "Validation of a Computer Performance Model of the Exponential Queueing Network Family," Proceedings of the International Symposium on Computer Performance Modeling, Measurement and Evaluation, P.P.S. Chen and M. Franklin, Eds., March, 1976, pp. 44-57.

35. Gilmour, Peter, "A General Validation Procedure for Computer Simulation Models," The Australian Computer Journal, Vol. 5, No. 3, November, 1973, pp. 127-131.

36. Gilsinn, J.F., "Validation of an Airport Simulation Model," Proceedings, 1976 Winter Simulation Conference, 1976, pp. 273-276.

37. Golub, Jerome, "The Validation of "Medusa","Proceedings, 1976 Summer Computer Simulation Conference, 1976.

38. Grabill, T.B.; Walker, W.E.; Kolesar, P., "Validation of a Police Patrol Simulation Model," Proceedings, Eight Annual Simulation Symposium, March, 1975, pp. 229-247.

39. Grant, A.J.; Capehart, B.L., "Validation of Digital Radar Landmass Simulation Utilizing Terrain Elevation Data Compression," Proceedings, 1973 Summer Computer Simulation Conference, 1973, pp. 1094-1102.

40. Greig, Ian D., "Validation, Statistical Testing, and the Decision to Model," Simulation, August, 1979, pp. 55-60.

41. Griner, G.M.; Hazel, L., "Implementation and Validation of an AD-10 Multi-Processor in a Hardware-in-the-Loop Missile Simulation," Proceedings, 1979 Summer Computer Simulation Conference, July, 1979, Toronto, Canada, pp. 591-595.

42. Grossman, S.; Rivers, R., "A Multivariate Statistical Analysis for Validation and Verification of a Cash Budget Simulation," Bulletin of TIMS/ORSA, No. 6, November 13-15, 1978.

43. Gruhl, J.; Wood, D.O., "Independent Assessment of Complex Models," Proceedings of the Workshop on Validation of Computer-Based Mathematical Models in Energy Related Research and Development, Texas Christian University, October, 1979, pp. 100-129.

44. Hamil, Patrick; McGill, Louise, "A Determination of the Predictive Capability of the EPA Real-Time Air-Quality-Simulation Model," Proceedings, The Sixth Annual Conference on Modeling and Simulation, Vol. 6, Part 2, Pittsburg, April, 1975.

45. Hamming, R.W., "How Do You Know the Simulation is Relevant?," Simulation, November, 1975, pp. 163-167.

46. Hermann, C.F., "Validation Problems in Games and Simulations with Special Reference to Models of International Politics," Behavioral Science, Vol. 12, May, 1967, pp. 216-231.

47. Hoffman, A.A.J.; Deeter, C.R., "Proceedings of the Workshop on Validation of Computer-Based Mathematical Models in Energy Related Research and Development," Texas Christian University, October, 1979.

48. Hollis, Martha S., "Methodological Issues in the Validation of Fiscal Impact Budgeting Simulation Models," unpublished report, November, 1978.

49. House, P.W., "Diogenes Revisited - The Search for a Valid Model," Simulation, October, 1974, pp. 117-125.

50. Howrey, P.; Kelejian, H.H., "Simualtion Versus Analytical Solutions," The Design of Computer Simulation Experiments, T.H. Naylor, Editor, Duke University Press, Durham, N.C., 1969.

51. Hsu, Der-Ann; Hunter, J.S., "Validation of Computer Simulation Models Using Parametric Time Series Analysis," Proceedings, 1974 Winter Simulation Conference, 1974, pp. 727-728.

52. Hunt, A.W., "Spectral Analysis Applied to Digital Simulation Models," Paper Presented at the Tenth American Meeting of TIMS, October 3, 1969, Atlanta.

53. Hunt, A.W., "Statistical Evaluation and Verification of Digital Simulation Models Through Spectral Analysis," Ph.D. Dissertation, The University of Texas at Austin, 1970.

54. Iman, R.L.; Helton, J.C., "Risk Methodology for Geologic Disposal of Radioactive Waste: Sensitivity Analysis Techniques," Report No. NIREG/CR-0390, SAND 78-0912, Sandia Laboratories, October, 1978.

55. Kahne, Stephen, "Model Credibility for Large-Scale Systems," IEEE Transactions on Systems, Man, and Cybernetics, August, 1976, pp. 586-590.

56. Kheir, N.A.; Holmes, W.M., "On Validating Simulation Models of Missile Systems," Simulation, April, 1978, pp. 117-128.

57. Kheir, Naim A., "A Validation Procedure for Missile Systems Simulation Models," Seventh Annual Conference on Modeling and Simulation, Pittsburg, 1976, pp. 534-539.

58. Knasel, M.T., "Validation of Mathematical Models in Solar Heating and Cooling," Proceedings of the Workshop on Validation of Computer-Based Mathematical Models in Energy Related Research and Development, Texas Christian University, October, 1979, pp. 37-40.

59. Kosovac, S.M.; Shortle, G.E., "Ballistic Missile Defense Simulation Validation," Proceedings, 1976 Summer Computer Simulation Conference, 1976.

60. Law, Averill M., "Validation of Simulation Models, I: An Overview," Technical Report 78-14, University of Wisconsin, August, 1979.

61. Lawrence, M,; Ricci, R.; Concannon, P., "The Scot Model: Calibration and Freeway Validation," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1201-1212.

62. Lichtig, B.A., "Simulation and Measurement: A Marriage of Convenience," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1213-1222.

63. Low, W.C.; Cowles, W.W., "Validation and Evolution of Models," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1178-1188.

64. Maisel, H., "The Credibility of Management Simulations," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1223-1227.

65. Mazur, Allan, "Simulation Validity," Simulation and Games, September, 1973, p. 44.

66. McKenney, J.L., "Critique of: "Verification of Computer Simulation Models "," Management Science, Vol. 14, No. 2, October, 1967, pp. B-102-103.

67. Members of SCS Technical Committee on Model Credibility, "Terminology for Model Credibility," Simulation, March, 1979, pp. 103-104.

68. Merlino, G.; Unger, B.W., "Validation of a Computer Resource Allocation Simulation Model," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 658-662.

69. Mihram, G.A., "Simular Credibility," Proceedings, 1973 Summer Computer Simulation Conference, 1973, pp. 96-99.

70. Mihram, G.A., "Are System Scientists Not Scientists?," Proceedings, Sixth Annual Conference on Modeling and Simulation, Pittsburg, 1975, pp. 795-799.

71. Mihram, G.A., "Telecybernetics: An Essential Feature of Simular Credibility," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1235-1244.

72. Mihram, G.A., "Some Practical Aspects of the Verification and Validation of Simulation Models," Operations Research Quarterly, Vol. 23, No. 1, 1972, pp. 17-29.

73. Mihram, G.A.; et al., " What Makes Simulation Credible? ," Proceedings, The Fifth Annual Conference on Modeling and Simulation, Vol. 5, Part 2, Pittsburg, April, 1974.

74. Miller, D.K., "Validation of Computer Simulations in the Social Sciences," Proceedings, Sixth Annual Conference on Modeling and Simulation, Pittsburg, 1975, pp. 743-746.

75. Miller, D.R., "Recent Developments in Approaches to Validation of Simulation Models," Bulletin of the Operations Research Society of America, Supp. 2, Vol. 23, 1975.

76. Miller, D.R., "Model Validation Through Sensitivity Analysis," Proceedings, 1974 Summer Computer Simulation Conference, 1974, pp. 911-914.

77. Miller, D.R., "Sensitivity Analysis and Validation of Simulation Models," J. Theor. Biol., Vol. 48, April, 1974, pp. 345-360.

78. Miller, D.R.; Butler, G.; Bramall, L., "Validation of Ecological System Models," Journal of Environmental Management, Vol. 4, 1976, pp. 383-401.

79. Miller, F.L., "Validation of Time Series Models," Proceedings of the Workshop on Validation of Computer-Based Mathematical Models in Energy Related Research and Development, Texas Christian University, October, 1979, pp. 177-191.

80. Mitroff, I.I., "Fundamental Issues in the Simulation of Human Behavior: A Case in the Strategy of Behavioral Science," Management Science, Vol. 15, No. 12, August, 1969.

81. Naylor, T.H.; Balintfy, J.L.; Burdick, D.S.; Chu, K., "Computer Simulation Techniques," John Wiley and Sons, New York, 1966.

82. Naylor, T.H.; Finger, J.M., "Verification of Computer Simulation Models," Management Science, Vol. 14, No. 2, October, 1967, pp. B-92-101.

83. Naylor, T.H.;Wertz, K.; Wonnacott, T.H., "Methods for Analyzing Data from Computer Simulation Experiments," Communications of the ACM, Vol. 10, No. 11, November, 1967, pp. 703-710.

84. Nicholson, G.E.; Sewell, W.E., "Review of Model Validation Seminar," Proceedings, U.S. Army Operations Research Symposium, May, 1970, pp. 73-84.

85. Noe, J.D.; Nutt, G.J., "Validation of a Trace-Driven CDC 6400 Simulation," Proceedings, AFIPS 1972 Spring Joint Computer Conference, Vol. 40, pp. 749-757.

86. Nolan, R.L., "Verification/Validation of Computer Simulation Models," Proceedings, 1972 Summer Computer Simulation Conference, 1972, pp. 1254-1265.

87. Nordhaus, W.D., "World Dynamics: Measurement Without Data," Economic Journal, Vol. 83, December, 1973, pp. 1156-1183.

88. Partridge, J.E.; et al., "Air Pathway Exposure Model Validation Study at the Monticello Nuclear Generating Plant," Report EPA/520/5-76-015, 1976.

89. Reggiani, M.G.; Marchetti, F.E., "On Assessing Model Adequacy," IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-5, No. 3, May, 1975, pp. 322-330.

90. Ricci, J.J.; Moran, D.D.; Bullock, M.V., "Validation of the Seakeeping Response Prediction Capability of Digital and Hybrid Air-Cushion-Supported Craft Motion Simulations," Proceedings, 1979 Summer Computer Simulation Conference, July, 1979, Toronto, Canada, pp. 579-583.

91. Richards, F.M.; Weatherbee, J.E.; Williams, T., "A Validation Procedure for Discrete Digital Simulation Models," Proceedings, 1973 Summer Computer Simulation Conference, 1973, pp. 1145-1149.

92. Rose, C.A., "Validation of a Queueing Model with Classes of Customers," Proceedings of the International Symposium on Computer Performance Modeling, Measurement and Evaluation, P.P.S. Chen and M. Franklin, Eds ., March, 1976, pp. 318-326.

93. Rosen, L.H., "Verification and Validation of a Broadcast Communications Model," Proceedings, 1979 Summer Computer Simulation Conference, July, 1979, Toronto, Canada, pp. 767-772.

94. Rowland, J.R.; Holmes, W.M., "Simulation Validation with Sparse Random Data," Computers and Electrical Engineering, Vol. 5, No. 1, March, 1978, pp. 37-49.

95. Salaway, G.; Siler, K.F., "Validation Considerations During Parameter Development for Simulations Models," Proceedings, 1979 Summer Computer Simulation Conference, July, 1979, Toronto, Canada, pp. 624-628.

96. Sargent, R.G., "Validation of Simulation Models," Proceedings, 1979 Winter Simulation Conference, December, 1979, San Diego, California.

97. Sargent, R.G., "Validation of Discrete Event Simulation Models," Proceedings of the Workshop on Validation of Computer-Based Mathematical Models in Energy Related Research and Development, Texas Christian University, October, 1979, pp. 47-60.

98. Schaefer, B.M., "Model Validation Using Simulation and Sequential Decision Analysis," Bulletin of the Operations Research Society of America, Vol. 23, 1975.

99. Schatzoff, M.; Tillman, C.C., "Statistical Validation of a Trace-Driven Simulator," Sigmetrics Performance Evaluation Review, Vol. 3, No. 4, December 1974, pp. 82-93.

100. Schatzoff, M.; Tillman, C.C., "Design of Experiments in Simulator Validation," IBM Journal of Research and Development, May, 1975, pp. 252-262.

101. Schellenberger, R.E., "Criteria for Assessing Model Validity for Managerial Purposes," Decision Sciences, Vol. 5, No. 4, October, 1974, pp. 644-653.

102. Schlesinger, S.; Buyan, R.; Callender, E.D.; Clarkson, W.K.; Perkins, F.M., "Developing Standard Procedures for Simulation Validation and Verification," Proceedings, 1974 Summer Computer Simulation Conference, 1974, pp. 927-933.

103. Schrank, W.E.; Holt, C.C., "Critique of:"Verification of Computer Simulation Models"," Management Science, Vol. 14, No. 2, October, 1967, pp. B-104-106.

104. Schruben, L.W., "Establishing Simulation Credibility," Technical Report No. 421, School of Operations Research and Industrial Engineering, Cornell University, April, 1979.

105. Senge, P.M., "Some Issues in Evaluating the Validity of Social System Models," Proceedings, 1973 Summer Computer Simulation Conference, 1973, pp. 1176-1177.

106. Shannon, R.E., "Systems Simulation: The Art and Science," Prentice-Hall, 1975.

107. Stafford, E.F., "Techniques of Model Validation," Unpublished Paper, University of Oklahoma, September, 1976.

108. Stafford, Edward F., "Technical Validation of a Simulation Model," Working Paper 76:7, University of Oklahoma, June, 1977.

109. Tawari, P.V., "A Systematic Procedure for Validating and Evaluation Dynamic Models," Ph.D. Dissertation, University of Washington, 1974.

110. Teorey, T.J., "Validation Criteria for Computer System Simulations," Simuletter, Vol. 6, No. 4, 1975, pp. 9-20; Also Published in Symposium on the Simulation of Computer Systems III, August, 1975, pp. 161-169.

111. Theil, H., "Economic Forecasts and Policy," North-Holland Publishing Co., Amsterdam, 1961.

112. Turing, A.M., "On Computable Numbers with an Application to the Entscheidungs Problem," Proceedings, The London Mathematics Society, 1936 and 1937, pp. 230-265, 544.

113. Turing, A.M., "Computing Machinery and Intelligence," Computers and Thought, Edited by Feigenbaum, E.A. and Feldman, J., McGraw-Hill, New York, 1963, pp. 11-15.

114. Tytula, T.P., "A Method for Validating Missile System Simulation Models," U.S. Army Missile R&D Command, Technical Report E-78-11, June, 1978.

115. Van Horn, R., "Validation," The Design of Computer Simulation Experiments, T.H. Naylor, Ed., Duke University Press, Durham, N.C., 1969, pp. 232-251.

116. Van Horn, R.L., "Validation of Simulation Results," Management Science, Vol. 17, No. 5, January, 1971, pp. 247-257.

117. Watts, Donald, "Time Series Analysis," The Design of Computer Simulation Experiments, T.H. Naylor, Ed., Duke University Press, Durham, N.C., 1969, pp. 165-179.

118. Wavel, R.B.; Van Hook, J.K., "Validation and Verification Procedures for Hybrid Computer Simulation Models," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1228-1234.

119. Wigan, M.R., "The Fitting , Calibration and Validation of Simulation Models," Simulation, May, 1972, pp. 188-192.

120. Wilson, S.R., "The Use of Statistics in Model Validation," Simulation and Modelling, M.R. Osborne and R.O. Watts, Editors, University of Queensland Press, 1977, pp. 30-42.

121. Winn, C.B.; Craun, R.L.; Johnson, G.R., "Validation of a Computer Aided Design Model for Solar Heating and Cooling of Buildings," Proceedings, 1975 Summer Computer Simulation Conference, 1975, pp. 1427-1431.

122. Winter, E.M.; Wisemiller, D.P.; Ujihara, J.K., "Verification and Validation of Engineering Simulations with Minimal Data," Proceedings, 1976 Summer Computer Simulation Conference, 1976, pp. 718-723.

123. Winter, E.M.; Wisemiller, D.P., "Validation of Sensor Observations of Star Fields," Proceedings, 1974 Summer Computer Simulation Conference, 1974, pp. 934-940.

124. Wright, R.D., "Validating Dynamic Models: An Evaluation of Tests of Predictive Power," Proceedings, 1972 Summer Computer Simulation Conference, 1972, pp. 1286-1296.

125. Zettel, L.F., "Verifying the Accuracy of a Model of a Large Plating Machine," Proceedings, 1973 Summer Computer Simulation Conference, 1973, pp. 1121-1124.

BRUCE SCHMEISER and LEE SCHRUBEN, EDITORS
VOL. 4, NO. 2 SPRING 1980

THE INSTITUTE OF MANAGEMENT SCIENCES

NEWSLETTER OF THE
TIMS COLLEGE
on
SIMULATION AND GAMING

College on Simulation and Gaming

THE INSTITUTE OF MANAGEMENT SCIENCES