Simulation Modeling:

A Guide to Using SIMSCRIPT

Forrest Paul Wyman

Wiley Series in Management and Administration

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A Guide to Using SIMSCRIPT

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JOHN WILEY & SONS, INC.

NEW YORK · LONDON · SYDNEY · TORONTO

Library of Congress Catalogue Card Number: 70-114014

SBN 471 96892 7

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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Preface

This book has been designed as a text, not as a computer manual. Computer manuals, as a result of editorial standards of terseness, have developed a reputation of requiring "circular" reading. By the term "circular" I mean that several chapters need to be referenced in order to understand a single chapter. For instance, a reader may find several terms used in Chapter One not defined until Chapter Two. Thus, a prospective user must become acquainted with the manual's contents by means of a series of minor crises, each of which requires a major perusal of the entire manual.

The objective of this book is to hew a straight path through a complex set of concepts. The book presents a logical sequence of ideas, none of which are defined in terms that are to be defined three chapters later.

Another reason why this book (hopefully) will not be considered as a computer manual is that I have made a deliberate effort to implant the symbols of the language, SIMSCRIPT, in the midst of nonmathematical descriptions of realistic conditions and situations that illustrate how the symbols can most profitably be used. Furthermore, *Simulation Modeling* strives for a level of verbal simplicity that will not be beyond the grasp of any student with an elementary programming background.

From my personal experience, it seems that when a student stops reading and starts programming, he relies more heavily on example programs than on text. Undoubtedly, all of the specific needs of a given student cannot be anticipated by any author. When the student raises detailed questions that were not anticipated by the author, he needs to refer to *examples* in order to answer these queries. For this reason, ten example programs are presented in the text. One example comes at the end of each of the first six chapters, illustrating the concepts from those chapters. The next four chapters are each dedicated to explaining in detail a fairly sizable simulation program.

The simulation programs were all run on a Control Data 6400 Computer at the Graduate School Computing Center, at the University of Colorado. Six appendixes have been added to briefly describe the implementation of SIMSCRIPT on this computer, and to give general assistance in debugging SIMSCRIPT programs.

Forrest Paul Wyman

Acknowledgments

The credit for this work must be shared with several distinguished persons, while any shortcomings are entirely the responsibility of the author. Professor William McPhee initially introduced me to the SIMSCRIPT language in his course "Logical Models of Social Processes." The idea for the Zilch Company problem in Chapter 6 was supplied by Professor Oliver Galbraith of San Diego State College. The idea and terminology for a single facility queuing problem program was originated by Professor Claude McMillan of the University of Colorado, who also suggested and encouraged the writing of this book. Kay Charlotte Johnson devised and programmed The Plague Simulation in Chapter 10. The Machine Shop Program in Chapter 9 was developed by Markowitz, Hausner, and Karr of the RAND Corporation.

A very special acknowledgment must be given to my wife, Gen, who encouraged my perseverance while tolerating my neglect. She participated fully in this project by keypunching all programs and typing the entire manuscript. My daughter, Julie, must be given credit for expediting the project by her imminent nascency.

F. P. W.

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A Comparison of Simscript to Fortran

I. NATURE AND SCOPE OF SIMULATION

There are many problems in the social sciences, physical sciences, engineering, and business fields that can be stated in mathematical terms, but for which there are no analytical methods of solution. Increasingly, computer simulation is being used to study such problems. As the cost of computation continues to fall, it is becoming economical for more and more systems to be studied by simulation rather than by direct mathematical analysis.

The process of simulation involves the design and study of a model of some physical, economic, or sociological system. The motivation for simulation stems from two sources. First, as an abstract model becomes more realistic, it becomes more and more intractable mathematically. We cannot easily determine the behavior of systems whose variables are discontinuous, stochastic, and intimately related to many other such variables in a multiplicative fashion. Yet complexities such as these abound in the real world. A person in an administrative position, or an advisor to an administrative person, is compelled to depict reality as faithfully as possible. Simulation cannot provide optimal solutions, but it can yield very useful insights into the behavior of a complex system.

Second, engineering, economic, and sociological systems are often unavailable for experimentation. In simulation, a computer program depicting some type of system is executed by tracing out the implications of the program's equations over time. Thus, a form of experimentation is provided. It must be noted, however, that the results of the "experimentation" characterize solely the interaction of the underlying assumptions incorporated into the model. The experimentation tests a hypothesis in an environment approximating reality, not in reality itself.

J. D. Tocher in *The Art of Simulation,* gives a terse definition of simulation:

> Simulation is the process of determining the sampling distribution of a highly irregular and intricately defined statistic.*

The definition has an important implication about the limitations of simulation. Given a model that approximates satisfactorily the current behavior of an actual system, a manager or administrator might wish to assess the effects of implementing a certain policy. Suppose the statistic of interest is some measure of performance, for example, the total transportation cost in a distribution system. The results can be determined only as a distribution of possible values of total transportation costs. The difference between the status quo distribution and the experimental distribution can be evaluated by appropriate statistical testing. The important thing to note is that the model cannot be used for specific predictions or as a control device. For instance, we cannot predict from a simulation model the level of inventory of a given product on a given day. We could, however, give the distribution of the inventory over a period of time. We can characterize the amplitudes and the period of a variable's cycles, but we cannot predict accurately the value at a given moment in time.

The general technique of designing a simulation model has certain basic steps. First, we must understand the system thoroughly. Each part of an organization or socioeconomic structure interacts in some manner with every other part. The simulation analyst must discover which of these interactions are significant, and which are not. This discovery requires defining the goals and boundaries of the simulation project. Second, the analyst must separate the variables of interest into exogenous and endogenous. Exogenous variables are those which are beyond the scope of the study, whose originating causes are unknown, and whose behavior can be characterized solely by a statistical distribution. Endogenous variables are those whose cause and effect relations are known, and which may be controllable. Third, the analyst must define specific entities, and their important attributes. The choice of entity is not obvious; it is subjective and depends upon the goals of the study. Fourth, the entities must be related to one another in some structure that cor-

*J. D. Tocher, *The Art of Simulation.* Princeton, N.J.: D. Van Nostrand Co. Inc., 1963.

responds to the structure in reality. The entities, their attributes, and the shape of the system's structure constitute the "state vector" of the system.

The process of the system is the path of the state vector over time. This path is what we seek to characterize. The behavior of the state vector is complicated, since some "global" variables are functions of "intervening variables." The profit of a corporation, for example, is a function of sales, production costs, inventory levels, research, financial solvency, and so forth. The model specifies some theorized relations between the intervening and the global variables. The fourth step mentioned above involves designing these internal mappings or transformation functions. This task can be aided by sophisticated analysis of data, when data is available. Where it is not, the analyst may have to rely on his intuition to characterize these internal processes.

At the heart of all representations of random variables in simulation lies the technique known as "Monte Carlo." We assume that the random variables behave according to some specified statistical distribution. If we have actual data, we may fit a distribution to the data. Otherwise, we commonly use one of several theoretical distributions including the binomial, poisson, uniform, normal, exponential, gamma, or beta. The objective of the Monte Carlo procedure is to provide simulated values of the random variable. In theory, we first form the cumulative density function of the variable. The input to such a function is a value of the random variable, and the value of the function lies somewhere in the unit interval. Next, we *invert* the cumulative density function to get a new function. Then we can input some value along the unit interval into the new function, and obtain a corresponding value of the random variable. Frequently, the cumulative distribution function is difficult to invert, or we have an empirical cumulative distribution function that may be discontinuous. In such cases, a computer program segment can be used to determine the appropriate value of a random variable.

Designing a simulation model entails several difficulties, the most serious of which may be a lack of general understanding of the system and how the parts interrelate. The implementation of a simulation model requires a computationally feasible scheme to represent the model. Several researchers who have used general purpose computer languages for modeling highly complex systems have encountered immense programming difficulties. Frequently, the effort required is not worth the information gained. Once such a model is finally running properly, the analyst may not proceed to investigate the implications of the model. There exist today several special purpose simulation languages including GASP, GPSS, DYNAMO, and SIMSCRIPT. None of these is a "perfect" simu-