Computer Simulation Applications

Discrete-Event Simulation for Synthesis and Analysis of Complex Systems

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DISCRETE-EVENT SIMULATION FOR SYNTHESIS AND ANALYSIS OF COMPLEX SYSTEMS

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To Nora, Marc, and Randa
for whom simulation
has been the real thing

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Preface

This book gives system designers, engineers, and analysts a new computer-aided design tool—discrete-event simulation. Such a method for representing complex systems in a computer language is useful in system design and analysis. It is specifically suggested for those systems in which relationships between key variables cannot be expressed analytically or the major system attributes are characterized by stochastic processes or probability distributions. Resource management, command and control-system analysis, information and traffic-flow problems, chemical-plant design, reliability and maintainability analysis, and weapons-system cost-effectiveness trade-offs are examples of system problems that can benefit from the application of discrete-event simulation.

This book should give the reader the confidence to solve complex system problems by using a digital computer and one of the available discrete-event simulation languages with a minimum of support from mathematicians and programmers. Access to a computer and prior experience in running problems on computers in any language are helpful. The General Purpose Simulation System (GPSS) and SIMSCRIPT are the two most widely used languages. Except for one example, which is treated in SIMSCRIPT II, the simulations used as examples are in the GPSS language.

Readers already knowledgeable in GPSS or SIMSCRIPT may choose to skip the initial treatment of these languages in Chapters 2 and 7. Those who find these chapters too advanced should consult one of the elementary books on simulation languages.

The degree of success expected from simulation depends primarily on the accuracy of problem definition. Fortunately this is one of the first and most important products of the use of simulation languages.

The purpose of this book is to instill in the reader confidence in the application of simulation and to provide an understanding of how to approach difficult problems. The variety of applications cover a sufficiently broad range that the reader will feel that each new problem has a relationship to something described in one or another of the applications. Discrete-event simulation is not something to be applied to trivial problems. The applications concentrate on those complex problems that require this powerful tool.

This book is divided into three parts. Part I begins with an introductory section covering the background and development of discrete-event simulation, the illustration of a specific simulation example using GPSS V; some brief background on the peculiarities of simulation and computer languages; a review of how random numbers are used and obtained; a comparison of different approaches to using computer languages for simulation; a second GPSS V look at the simulation example with the broader perspective developed from the additional material; and another version of the example using SIMSCRIPT II.

Part II is the specific review of five different applications. Limitations of space and interest reduce the coverage of each application to an understanding of the approach followed. Any of the applications could be expanded to an entire volume. This level of detail is unnecessary. The reader must learn by doing. The five applications cover scheduling and cost analysis of passenger railroad system operation, resource allocation in production scheduling, prediction of effectiveness for a weapons system, simulation of a computer system, and an evaluation of alternative automobile traffic control through a series of intersections.

Part III is devoted to relating the applications to each other and to placing the role of simulation into perspective. In particular, it relates the obvious successes of simulation with the less obvious difficulties overcome. The human factor in computer-aided system design is not overlooked, since there is so much more to be achieved toward the effective use of computers.

An extensive bibliography is included at the end of each chapter. As far as possible, references are made to available books, periodicals, and conference proceedings. Documents from the Defense Documentation Center are not included, because they are not readily available in libraries or bookstores, or from professional societies, and are preempted for use by defense industries. As a result, the application area without adequate references is the analysis of weapons systems.

References to pseudorandum number generation are extensive. Usually this is not the concern of the system analyst, but there are so many different approaches to generating and evaluating pseudorandom numbers that the reader may wish to consult the literature in order to be knowledgeable on this arcane subject.

Undergraduate and graduate students should be able to use this material in a variety of engineering areas: systems analysis, computer science, applied mathematics, and statistics. Until now, discrete-event simulation has mainly been taught in industry, since the subject is still rarely treated in a comprehensive manner in university curricula.

The problems are structured to provoke thought and understanding of concepts rather than to help in finding answers. Toward this end the problems are not designed to teach GPSS or SIMSCRIPT, inasmuch as there are specific books devoted to teaching simulation languages. Access to a computer will greatly extend the understanding of the possibilities of discrete event simulation.

Many people have helped in the development of this book. On a general level, I am indebted to Geoffrey Gordon for introducing me to GPSS, and Harold Chestnut, Ed Hall, and L. T. E. Tommy Thompson for their views of the role of discrete event simulation. I also thank those who helped me with specific chapters: Chapter 7, Phil Kiviat; Chapter 4, Harry Felder; Chapter 11, John Maneschi; and Chapter 12, Al Blum. Many thanks, too, to those who offered encouragement: Dick Baxter, John Bult, Dave Eig, Gene Ehrlich, Ivan Flores, Howard Halpern, Harold Hixson, Dick Horton, Sherman Hunter, Jerry Katzke, John Lovkay, Arnold Ockene, Frank Preston, Bernard Radack, Ted Rosenberg, Sandy Seidler, Jon Shapiro, and Burt Smith. Finally, I extend my appreciation to Shirley Lawrence and Sharon Luciani for typing the manuscript.

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Norwalk, Connecticut
March 1971

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Part I

BACKGROUND

The term simulation in the sense used in this book describes a strange aggregate of elements. Simulation is a practical, application-oriented procedure. In order to use it, however, one must construct an abstraction of the problem, transfer the problem to a foreign device, the computer, and then obtain indications pertaining only to the representation of the system. Therefore there must be strong forces advocating simulation. The goal of Part I is, first, to delineate these forces and, second, to provide a perspective on the simulation technology—not just the present state of the art, but also some background on how it has been reached. Once this background has been established, we can investigate specific applications.

The powerful forces advocating simulation start with problem definition, follow through during system synthesis and analysis, and continue into operational evaluation. There are alternative approaches which may be quicker, cheaper, or easier if they work. Therefore we must learn when to use which tool, how to use computers, and how to express the problem clearly. Since the precision of answers obtained from simulation is different from an analytical result, we must understand when to utilize relative rather than absolute results. Hence, little attention is paid here to the theoretical aspect of pseudorandom number generation or to elegant distinctions among simulation languages.

The material is organized to familiarize the novice with the field and prepare him to simulate specific complex problems. The challenge is not to get the computer to provide a useful result, but rather to learn to achieve useful results quickly, with adequate accuracy, and within available funds, and for the method to be accepted by the customer.

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Discrete-Event Simulation—A New Tool for System Designers, Engineers, and Analysts

The modern system designer or analyst is frequently confronted with problems which, upon study, are extremely difficult or impossible to solve using conventional analytical techniques. In general he has relied on intuition to solve them. A better approach must be used, however, especially since these problems are not exotic, only highly complex. Figure 1.1 is an attempt to compare the rapidly increasing complexity of one type of implemented system—long haul transportation.

Long haul transportation is one example of complex system design problems which range over a broad spectrum. At one end are the strategic, global, or economic problems. An example would be the repercussions of an income tax hike on the gross national product or on the force structure of the U.S. armed forces—very complex and usually not the concern of system designers. At the other end of the spectrum are the defined analytical problems, such as designing the control system of an aircraft—problems whose complexity can be restricted and readily partitioned into manageable pieces. Between these two extremes, as shown in Figure 1.2, are the tactical type of problems faced by the system designer.

The following examples indicate the wide range of these problems:

- Scheduling the items processed by a job shop so as to provide a long-term, high-level output and to satisfy immediate demand but use limited resources.
- Determining the number of new higher-speed passenger cars needed to reequip a railroad.
- Estimating the computer system throughput for a mix of program tasks.
- Contrasting different policies for inventory level, shipping schedule, and available resources with overall cost and performance of an enterprise.

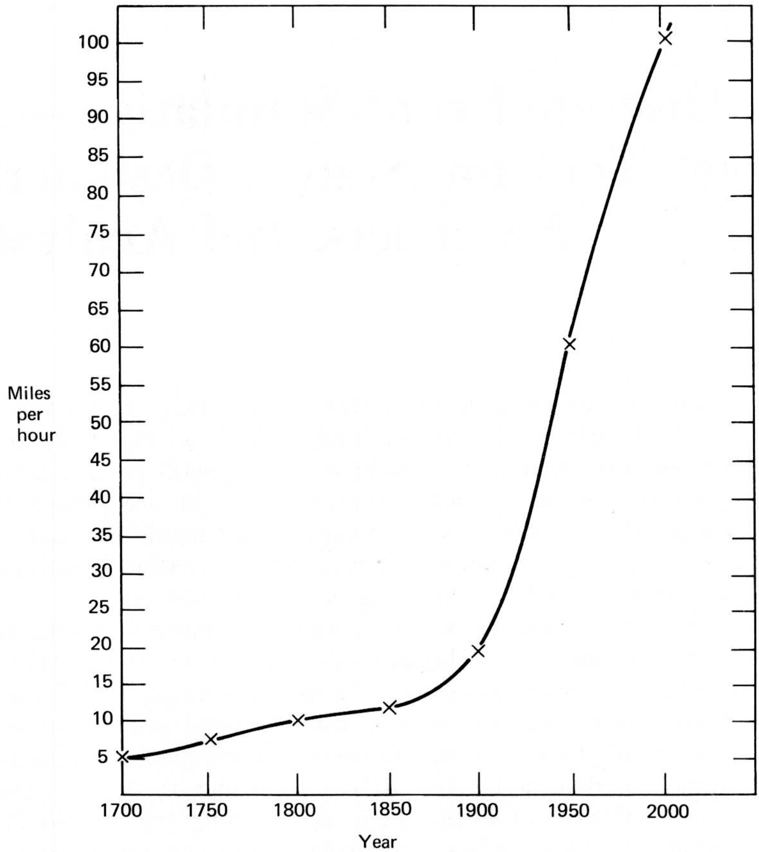

Figure 1.1 Long haul transportation speed as a measure of system complexity.

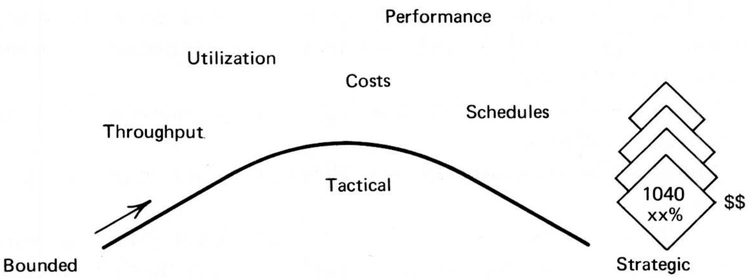

Figure 1.2 Spectrum of problems.

- Anticipating the number and mix of toll booth attendants and automatic gates needed to improve traffic flow.
- Comparing the life-cycle costs of initially using reliable and expensive parts to replacing and repairing less dependable and less expensive parts.
- Predicting the effect of increased accuracy on overall performance of a weapons system.
- Evaluating alternative configurations of playground equipments for elementary school-age children.

These few examples illustrate the type of problems requiring new techniques for solution. In the past such problems have been included in queuing theory, system behavior prediction, job shop analysis, systems effectiveness, and management information. Some analytical techniques have been effective, but frequently they have been too laborious to apply or have reduced the problem to an oversimplified shadow of its full self. A tool for solving these problems is now available through use of digital computers. Before discussing how to use the computer let us characterize typical problems.

Problem Characteristics

Three major characteristics of system design problems[1-9] are complexity, poor definition, and mathematical unpleasantness. The presence of any one of these is cause for trouble in the system design process. For example the problem of determining the minimum number of high-speed cars to maintain a specified level of service after reequipping a railroad is easy to define, but difficult to solve. All facets of the problem are interrelated. The number of cars depends on the schedule; the schedule, in turn, depends on car speed and terminal turnaround time. Then if the schedule is fast and frequent, a greater number of passengers may be attracted by the service—if the fares are not raised. Whichever way the problem is turned in an attempt to find some straightforward analytical expressions, the number of variables and expressions relating the different facets of the problem cannot be reduced to expressions solvable by conventional means. There are interrelated factors involving too many possible combinations of actions and situations, and an overwhelming number of possible states needed to fully describe the system.

In addition to the lack of analytical relationships representing the problem, there is frequently a lack of input data. For example what would happen if scheduled train service were increased? Would more passengers be attracted? And when would the additional passengers request service? An empirical relationship for passenger demand could be represented as a probability distribution of the number of passengers requesting service for each 10-minute interval during the day. This is certainly not a straightforward expression, and is further complicated by the fact that all days are not alike.

The determination of railroad fleet size should be a well-defined problem. Investigation, however, reveals large gaps in our understanding of the problem. One aspect is the choice between running an express train to a limited number of stations or stopping at every station. Now modify the problem to intermix some of the trains, expresses that make a few stops and locals that skip a few stations. The rules governing this choice are restrictions on train headway, passenger demand, and car storage yards. The problem may be stated easily. The actual definition of the problem, however, is expressed only in generalities that offer little help to the problem solver who must keep the trains from colliding and make sure that all the cars do not end up in a storage yard farthest from the next day's passengers.

Paradoxically there are many mathematical solutions lacking problems to which they can be applied. Unfortunately the mathematical tools for solving problems of a combinational nature have not yet been developed. If the railroad would only run point to point—Boston to New York—and the passengers appear with equal frequency during the 24-hour day, numerous techniques could be used to provide adequate, if not optimal, solutions. But in the real world there are stops in Providence, New Haven, Bridgeport, and so on, and passenger demand is high in the morning and evening and very low during the rest of the day.

The problems the system designer, engineer, or analyst must solve involve the performance of a system—that mixture of capital and labor organized to meet specified objectives within specified constraints, either minimum cost for specified performance or maximum performance for a specified cost.[10–12] Examples of these systems or subsystems are found in the design of computers, streets, right-of-ways, runways, machine tools, communication lines, military hardware, telephone switchboards, supermarkets, toll plazas, and so on. The measure of use made of the system—computer throughput, traffic flow, passengers carried, items machined, messages transmitted, missiles on target, calls placed, customers satisfied, motorists on their way—provides some of the criteria on how well a system meets its problems of services, delays, processes, failures, confusions, misses, losses, and so on, and at what cost. Notice that