McMILLAN
and
GONZALEZ

Systems Analysis
A Computer Approach to Decision Models

Irwin Series in Quantitative Analysis for Business

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Preface

When the first edition of *Systems Analysis* appeared in 1965, it was one of only two or three books about computer simulation. Today there are many books about the subject. Some focus on methodology, while others specialize in one or another of the problem-oriented simulation languages. The literature now reports applications of simulations in every discipline. Recently two major volumes were published in which a wide range of behavioral simulations were described. There is little question that materials such as those included in this edition are necessary for various curricula, and we remain committed to the design and purpose of the earlier editions of *Systems Analysis*.

Computer simulation permits students with modest backgrounds in mathematics to build and process systems models which produce useful information about the behavior of those systems. Simulation is not offered as a substitute for formal analysis, and we are aware of many unanswered questions about its methodology. As a means to understanding complex systems, computer simulation is a legitimate and interesting activity for students of the physical and social sciences.

Simulation requires the use of computer models, and early in the text the student is introduced to a general programming language. From that point on the presentation is dependent upon that language. We have reviewed the question of language dependence through the several revisions of this text and continue to believe that it is essential for students to translate systems concepts into computer processable models using either general or special purpose simulation languages. We have selected FORTRAN as the general language. It continues to be the most widely used and, with the exception of input/output statements, the programs listed in the text can be processed with little modification. If FORTRAN is not available, the programs are documented so that they may be written in another language.

In addition, we have included, in the appendix, BASIC language listings of all programs listed in the text. Solutions for the exercises in both languages are part of the manual which accompanies *Systems Analysis*.

Organization of the Text

This text is characterized by progression from particular to general models. It also moves from consideration of subsystems to the consideration of whole systems. Usually we undertake analysis in order to describe a system generally. Yet we are coming to appreciate the utility, if not the elegance, of focusing attention on specific situations and then, as Forrester has said, "We generalize as far as we dare." Decision makers in real life are interested in solutions for particular problems, and we think that this approach is meaningful to the student as well. Moving from analysis of subsystems to analysis of the whole system reflects the fact that it is still convenient to deal with major subsystems of an organization before attempting to model and analyze the interconnections which exist among subsystems.

Chapters 1 and 2 serve to define generally the notion of system and to apply it to various systems. The subject of model building, particularly the nature and use of computer models, precedes the discussion in Chapter 2 of the methodology of simulation.

Chapters 3, 4, and 5 serve as an introduction to FORTRAN programming, with emphasis on the basic statements which are required to build computer programs. The use of control statements is illustrated in Chapter 5 by reference to the inventory system under conditions of certainty in which the problem is to determine an optimum inventory reorder rule. This problem has an analytical solution which may be obtained directly; however, the manner of computation using the computer employs an enumeration method which qualifies as an elementary search procedure (combing). Using this model, a number of possible reorder rules may be evaluated. At this point the student may challenge the assumptions on which the inventory system is proposed. Information about demand as well as lead time is not perfect, and in fact these two variables are usually treated as random. In Chapter 6 the inventory system is analyzed by constructing a computer model and conducting experiments with that model. Random processes are simulated and the resulting model is more realistic.

Chapter 7 is a new chapter which introduces the modeling of systems by use of flow graphs. Graph theory is used primarily when modeling electrical and communications networks. The notion of network is much more pervasive, however. It applies to transportation systems of all kinds; in fact, any system through which some kind of resource, including information, flows can be modeled as a network. Flow graph methods offer a general scheme for conceptualizing systems, and it is presented in Chapter 7 at an elementary level.

In Chapters 8, 9, and 10 the model of the single channel queue is developed. This model describes many of the physical distribution or service systems which we see in the real world. The queueing system model is first developed analytically, and then computer simulation of the system is presented in Chapter 11. Modeling queueing systems requires that random samples be drawn from various nonuniform distributions. Chapter 10 is devoted to developing generators for obtaining such samples.

A second new and relatively large chapter, Chapter 12 on GPSS, follows. This is the contribution of T. J. Schriber. The first edition of *Systems Analysis* included brief mention of GPSS and a discussion of SIMSCRIPT. Increased use of problem-oriented simulation languages led to the decision in this third edition to include a complete enough discussion of GPSS that students could build models in GPSS. It was chosen as the language for instruction because it is perhaps the most widely used language of its type and is implemented on various IBM systems. The student should conclude that it is a powerful aid in simulation; and true to its claim, it is learned with a minimum of difficulty.

Chapter 13, "Management Planning Models," reflects some special concerns of analysis in simulating business systems. A variety of short-range planning and forecasting routines are discussed. Partial revision of this chapter includes the treatment of some topics in light of the flow graph discussion in Chapter 7.

For the analysis of complex systems, matrix methods are essential; and in this revision we retained those materials in Chapter 14.

This includes development of the simplex algorithm and an efficient FORTRAN routine for processing it.

Chapter 15 has been revised to present some discussion of the work being done in the simulation of human behavior. The body of literature in this field is very large and growing rapidly. Reference to the inventory clerk of Chapter 4 is made, and a behavioral model constructed of his observed decision making. A second situation involving interaction of two human decision makers is presented in the chapter. The work of Bonini is also discussed here. His simulation of the decision and information systems of the firm continues as a significant contribution in the design and conduct of simulation experiments.

Chapter 16 introduces Industrial Dynamics, a particular form of simulation. Conceptually, in Industrial Dynamics continuous change models are used as contrasted to those discussed in the text, which are discrete change models. Industrial dynamics models composed in FORTRAN are presented so the student may distinguish the two model types.

In Chapter 17 a hypothetical firm, made up of various subsystems which were modeled in earlier chapters, is presented. Our purpose is not only to construct the model of a large organization but to use it in order to test and evaluate various decisions and policies.

Finally, in Chapter 18, we call to the student's attention the fact that many methodological questions involving the use of computer simulation have yet to be answered. There are some guides and procedures which the students should follow to avoid grossly inefficient experiments. A proposal by P. Gilmour is included as one way in which an experimenter may choose from among the many statistical measures and procedures available to him.

From the preceding it is perhaps evident that not all materials included in this text can be covered in a single one-term course. At the undergraduate level, assuming that Chapters 3, 4, and 5 required detailed treatment, it has been possible for a three-quarter-hour course to cover the material through about Chapter 11, plus some modified experiments involving the SIMCO model of Chapter 17. At the graduate level, teaching FORTRAN outside the class, and omitting Chapter 14, it is possible to cover most of the text.

As a reminder to both instructor and student, it is strongly recommended that regular assignments of exercises be made. The procedure of conceptualizing a problem and obtaining a computer model is an ill-defined procedure which can only be learned through practice. The same applies to acquisition of even minimum programming skills. No amount of discussion substitutes for the experience and confidence gained from the successful composition of a computer program and its use to obtain information for improving the quality of decision making.

To summarize, systems analysis in the physical and social sciences constitutes a significant and growing discipline. The analysis of complex systems is done economically by the student utilizing simulation. At one point early in our experience, it was our thought that simulation should be the vehicle to carry a course which would essentially be the first introduction of the student to the computer. So many changes have occurred in curriculums as well as hardware and software that an instructor has a variety of alternatives so far as the introduction of the student to the machine. Simulation in its own right is sufficiently important and challenging that it ought to be taught as a form of analysis and frequently in parallel or complement with courses in which formal (mathematical) models are discussed. It is well for the student to understand the potential as well as the limitations of both forms of analysis.

March 1973

C. McMillan
R. F. Gonzalez

Contents

chapter 1

Systems and Models

BEFORE describing particular physical or social systems and methods for analyzing them, it is necessary to consider what is meant by the word *system*. The term is used in many ways and has reserved meaning in all disciplines and areas of research. We speak of the education system, information systems, ecological systems, transportation systems, political systems, and so on. Whenever we wish to connote relatedness or interaction with respect to a set of *entities* we use the word system. For our purposes a somewhat ambiguous definition of system will serve.

A system is a set of entities (components) together with relationships between the entities.

The number of system entities may be large and their nature diverse. In physical systems the components are tangible. Biological systems, for example, contain animal populations, water, and food. Abstract objects may be system components—in an economic system we might find profit goals, sales quotas, production standards, and costs.

System components are described by their properties or *attributes*. An individual who is part of a social system would possess a long list of attributes—age, sex, group memberships, memory, beliefs, attitudes, and so on.

Relationships that exist between entities tie the system together. Were it not for relationships the concept of system would be meaningless. Given the set of components and attributes of a system we would be able to identify or postulate a great many relationships. The study of the system focuses on those relationships we think necessary to describe the system and explain the way it undergoes change.

Our definition of system is incomplete without the notion of system *environment.*

The environment is the set of all entities, a change in whose attributes affects the system, and also those entities whose attributes are changed by the behavior of the system.

From the definitions of system and environment it seems that given a set of interacting components we must subdivide it into system and environment. Exactly how this is done is not always clear and sometimes the impression is gained that the division is done quite arbitrarily. The system analyst has discretion and is often guided by what is most convenient for him. Some system models of the business firm have been constructed in which the consumer is made part of the environment. Describing the consumer in terms of taste and income—where a change in either attribute would affect the firm—seems in line with our definition of environment. One might argue, however, for including the consumer within the firm without violating the definition of system.

From the definition of system and environment it follows that a system can be subdivided into subsystems. The complex system we know as the university contains, for example, subsystems for the preparation and delivery of educational "products" to its students. Other subsystems in this complex provide for the creation and maintenance of physical facilities, exchanges of information, and academic and civil governance. These subsystems in turn can be further subdivided. Components belonging to one subsystem may be part of the environment of another subsystem. From the concepts of system and subsystem we can agree with the frequent observation that all systems are subsystems of the next higher system.

In studying a system one may focus on the detailed behavior of subsystems (microscopic behavior), or elect to study the behavior of the system as a whole (macroscopic behavior). Both approaches are necessary to understand the behavior of large systems. An important step is taken when we move from subsystem analysis to analysis of the whole system. Macroscopic analysis forces an investigation of relationships among subsystems. As many systems develop, chance influences the design of subsystems, and rarely is there a practical means to ensure that the designs of the subsystems are compatible. Frequently subsystems are observed whose objectives are not consistent nor mutually reinforcing.

SYSTEMS CLASSIFICATIONS

There are several useful schemes for classifying systems. The first distinguishes between natural and man-made systems. Social, economic, and political systems are man-made, while physical and biological systems are mostly natural. The distinction is blurred these days as our understanding of the concept of system develops. Man's concern about his natural environment has led to the specification of ecosystems in which he uses the natural environment for agricultural or industrial production and recreation.

A second distinction contrasts *open* and *closed* systems.

> Most . . . systems are open, meaning they exchange materials, energies, or information with their environments. A system is closed if there is no import or export of energies in any of its forms, such as information, heat, physical materials, etc.[1]

An open system may become closed in two ways. If interaction with the environment is cut off, or if we later choose to include in the system that part of the environment which involved the interchange of energy, materials, or information, the system becomes closed.

A third classification separates systems which are adaptive and those which are not. Adaptive systems react to environmental changes in a way that is desirable considering the purpose the system was designed for. March and Cyert[2] describe the firm as an adaptive system, meaning that environmental change or shock elicits a response (decision) which results in a new system state. Successive shocks and responses, and the observation concerning how successful the response was, become part of the "experience" of the firm. Organizational learning is said to take place through time as those responses that led to preferred system states are recalled and applied.

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[1] "The Definition of System," *Yearbook for the Advancement of General Systems Theory,* 1956, p. 18. See also A. D. Hall, *A Methodology for Systems Engineering* (Princeton, N.J.: D. Van Nostrand Co., Inc., 1962).

[2] Richard M. Cyert and James G. March, *A Behavioral Theory of the Firm* (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963).