Computer Simulation in Management Science

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Preface

This book concentrates on the topics of simulation, model building,, and programming. I hope that it will aid analysts and students who wish to produce working computer simulations.

There are 3 sections.

SECTION I (Chapters 1 & 2): FUNDAMENTALS OF COMPUTER SIMULATION IN MANAGEMENT SCIENCE

This is a general introduction to the simulation methods commonly employed in management science. It is non-technical and requires no skill in computer programming. As well as introducing the rest of the book for specialist readers, it will give MBA and undergraduate business students a useful over-view of the subject.

SECTION II (Chapters 3 to 8): DISCRETE EVENT SIMULATION

Chapters 3–5 are devoted to model building for discrete event simulation. Chapter 3 introduces commonly used terminology and presents activity cycle diagrams. Chapters 4 and 5 describe the event, activity, process and three-phase approach to discrete event modelling. Particular emphasis is placed on the three-phase approach first suggested by Tocher. Examples of three-phase programs in BASIC are provided. Chapter 6 reviews the main simulation software available. Chapters 7 and 8 are concerned with the statistical aspects of the subject.

SECTION III (Chapters 9–11): SYSTEM DYNAMICS

Chapter 9 discusses the principles of modelling the type of feedback systems found in organizations. Chapter 10 describes the system dynamics approach and Chapter 11 presents 2 successful case studies.

Left to their own devices, most people who can program a computer can produce some sort of simulation. However, their approach is usually *ad hoc* and takes far longer than they imagined at the start. In most cases, the model is over-complicated and the program has grown into something with no obvious structure. This makes it very difficult to be sure that the simulation results are valid. This is particularly true of discrete simulations. It may also be impossible to enhance the programs if that later becomes necessary. By following the principles described here, the novice should be able to produce well-structured programs which produce valid simulations.

I have displayed most of the examples as flow diagrams because my experience suggests that novices find these easy to follow. Most of the programs are written in a standard, but very restricted, dialect of BASIC. This may not be the ideal language for simulation, but it is widely available and is easy to learn. Any readers unfamiliar with BASIC but knowing FORTRAN, ALGOL or Pascal ought to have no difficulty in following the examples. To follow Chapters 7 and 8, the reader should be familiar with elementary probability and statistics.

In discussing continuous simulation methods, I have chosen to concentrate on systems dynamics as developed by Forrester. It could be argued that management scientists ought to use rather more sophisticated methods. However, for a variety of reasons, practitioners do not make much use of the continuous simulation packages of the type favoured by engineers. Despite its limitations, system dynamics does find some use in practice. Hence its inclusion.

The book should be of use to four groups of readers. As a whole it should be of use to management science students and practitioners who need a detailed knowledge of the topics. It should also be valuable to business students who need an appreciation of the main methods in use. Finally, it will be of value to computer science students who need to be able to produce software simulations.

I am grateful to a number of my colleagues at Lancaster. Brian Parker carried out the work described in Chapter 11 and also provided useful criticisms of the rest of Section III. Stephen Taylor patiently reviewed Chapters 7 and 8. Mike Simpson who unfortunately died suddenly in July, encouraged me to get down to the job of writing, having recognized that I am easily diverted. Margaret Threlfall escaped the task of typing up most of my hieroglyphics, because I chose to use a simple word processor. However, she coped extremely well with the mathematics which my word processor could not handle. I am also grateful to the anonymous reviewers used by John Wiley & Sons.

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PART II: DISCRETE EVENT SIMULATION

PART I

FUNDAMENTALS OF COMPUTER SIMULATION IN MANAGEMENT SCIENCE

Chapter 1

The computer simulation approach

1.1 MODELS, EXPERIMENTS AND COMPUTERS

Management scientists are not easily separated from their computers and with good reason. Since the 1960s, computers have become smaller, cheaper, more powerful and easier to use by non-specialists. In particular, the development of powerful and cheap portable machines has opened up wide areas of work for the management scientist. Modern computers allow the analyst to explore the whole range of feasible options in a decision problem. These options could be explored without a computer but the process would be very slow and the problem may well change significantly before a satisfactory solution is produced. With a computer large amounts of data can be quickly processed and presented as a report. This is extremely valuable to the management scientist.

One way in which a management scientist uses a computer is to simulate some system or other. This is generally done when it is impossible or inconvenient to find some other way of tackling the problem. In such simulations, a computer is used because of its speed in mimicking a system over a period of time. Again, most of these simulations could (in theory at least) be performed without a computer. But in most organizations, important problems have to be solved quickly. Hence the use of computer simulation in management science.

Computer simulation methods have developed since the early 1960s and may well be the most commonly used of all the analytical tools of management science. The basic principles are simple enough. The analyst builds a model of the system of interest, writes computer programs which embody the model and uses a computer to imitate the system's behaviour when subject to a variety of operating policies. Thus, the most desirable policy may be selected.

For example, a biscuit company may wish to increase the throughput at a distribution depot. Suppose that the biscuits arrive at the depot on large articulated trucks, are unloaded and transferred onto storage racks by fork trucks. When required, the biscuits are removed from the racks and loaded onto small delivery vans for despatch to particular retail customers. To increase the throughput, a number of options might present themselves to the management. They could:

— increase the number of loading or unloading bays;
— increase the number of fork trucks;
— use new systems for handling the goods;
etc.

It would be possible to experiment on the real depot by varying some of these factors but such trials would be expensive and time consuming.

The simulation approach to this problem involves the development of a model of the depot. The model is simply an unambiguous statement of the way in which the various components of the system (for example, trucks and lorries) interact to produce the behaviour of the system. Once the model has been translated into a computer program the high speed of the computer allows a simulation of, say, six months in a few moments. The simulation could also be repeated with the various factors at different levels to see the effect of more loading bays, for example. In this way, the programmed model is used as the basis for experimentation. By doing so, many more options can be examined than would be possible in the real depot — and any disruption is avoided; hence the attraction of computer simulation methods.

To summarize, in a computer simulation we use the power of a computer to carry out experiments on a model of the system of interest. In most cases, such simulations could be done by hand — but few would wish to do so. Now that microcomputers offer significant computer power for a minimal cost, a computer simulation approach seems to make even more sense in management science.

1.2 MODELS IN MANAGEMENT SCIENCE

Models of various types are often used in management science. They are representations of the system of interest and are used to investigate possible improvements in the real system or to discover the effect of different policies on that system. This is not the place for a detailed exposition of modelling; for this the reader should consult Rivett (1972), White (1975) or Ackoff and Sasieni (1968). However some mention of the topic is necessary.

The simplest type of model employed in management is probably a scale model, possibly of a building. By using scale models it is possible to plan sensible layouts of warehouses, factories, offices, etc. In a scale model, physical properties are simply changed in scale and the relationship of the model to the full-scale system is usually obvious. However, such simple scale models do have significant disadvantages.

First, a scale model is concrete in form and highly specific. No one would contemplate using the same scale model for a chemical factory and a school — the two require distinctly different buildings. More subtly, to experiment with a scale model always requires physical alteration of the model. This can be tiresome and expensive.

Second, scale models are static. That is, they cannot show how the various factors interact dynamically. For example, suppose that a warehouse is being designed. One issue that must be considered is the relationship between the internal capacity of the building and the number of loading or unloading bays provided for vehicles. Though it is easy to design a warehouse which always has enough internal space — simply make it too big — this is clearly a waste of money. Given that both the demand for the products and the production level will vary, the art is to design a building which balances the cost of shortages with the cost of over-capacity. Such a balance will vary over time, particularly for seasonal products. No scale model could consider this.

Management scientists tend to employ mathematical and logical models rather than scale models. These represent the important factors of a system by a series of equations which may sometimes be solved to produce an optimal solution. Many of the commonly employed techniques described in management science textbooks are of this form. For example, mathematical programming, game theory etc. For computer simulation, logical models are usually required — though in the case of system dynamics (see Chapters 9–11) these are expressed in a mathematical form. The simplest way of thinking about logical models is to consider flow diagrams of various kinds. Industrial engineers often employ flow process charts in method study (Hicks, 1977) to display the various processes through which products pass in their manufacture and assembly. That is, the charts display the logic of the production process. Such a chart might show that a car body needs to be thoroughly degreased before any painting can begin. Instead of drawing a chart it is possible to represent the logic as a set of instructions. If these directions are clear and unambiguous, then they could be used to show someone how to do the job.

Any sequence of unambiguous instructions can form the basis of a computer program. Hence programs can be written which embody the logical processes which make up the system of interest. Whilst many programming languages are not designed to ease this task of logical expression, there are simulation programming languages such as SIMSCRIPT (Markowitz *et al.*, 1963) and ECSL (Clementson, 1982) which do so. Once the model is programmed, it may be easily modified, for example to introduce more loading bays in a warehouse model, by editing the program.

Flow diagrams as such do have their uses in computer simulation. In particular, they are often used in the early stages of a computer simulation project. One type of flow diagram will be introduced in Chapter 3.

1.3 SIMULATION AS EXPERIMENTATION

Computer simulation involves experimentation on a computer-based model of some system. The model is used as a vehicle for experimentation, often in a 'trial and error' way to demonstrate the likely effects of various policies. Thus,

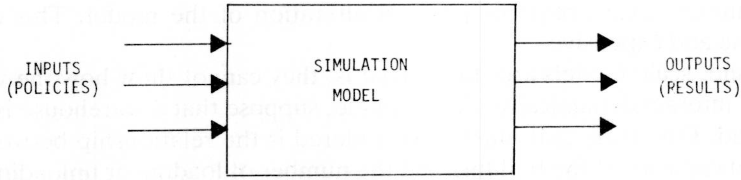

Figure 1.1 Simulation as experimentation

those which produce the best results in the model would be implemented in the real system. Figure 1.1 shows the basic idea.

Sometimes these experiments may be quite sophisticated, involving the use of statistical design techniques. Such sophistication is necessary if there is a set of different effects which may be produced in the results by several interacting policies. At the other extreme, the experimentation may be very simple, taking the form of 'what if?' questions. Thus, if the simulation model represents the financial flows in an organization over the next 12 months, typical questions might be:

'What if interest rates rise by 3%?'
'What if the market grows by 5% this year?'

To answer these questions, the simulation is carried out with the appropriate variables of the program set to these values.

An example of a more sophisticated approach can be found in the study described by McCurdy (1977). This was carried out for a motor manufacturer who wished to design a three-storey paintshop for a completely new car. Ideally, such a new paintshop would be all on the same level, but a shortage of land meant that three storeys were necessary. The floors of the paintshop were to be connected by automatic lifts in which the bodies would be carried. The nature of the processes meant that some of them had to be kept physically separate. For example, some of the preparation processes could not be sited next to the ovens because volatile solvents were to be used. Thus, as shown in Figure 1.2, the ground floor was to be two storage areas, one for the unpainted bodies arriving from the bodyshop and the other for painted bodies which had been through the paintshop. These painted bodies would later be required in the assembly area and it was important that they should arrive there in the correct colour sequence. The first floor was to contain all the processes necessary for preparing and painting the bodies and the second floor would house all the ovens through which the bodies passed after each coat of paint.

This outline design meant that each body would undergo a great many vertical and horizontal transfers. Indeed each body would require 14 transfers between floors via the automatic lifts. As most people know from their own experience, lifts do break down sometimes. This, combined with the possibility of stoppages in the main process, meant that some buffer storage would be needed — otherwise a breakdown or stoppage anywhere would bring the paintshop to an immediate halt. However, monocoque car bodies take up a