Part I

Fundamentals of Computer Simulation in Management Science

1

The Computer Simulation Approach

1.1 MODELS, EXPERIMENTS AND COMPUTERS

Management scientists are not easily separated from their computers and for 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 with excellent graphics 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 that 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 and, are unloaded and transferred onto storage racks by forklift 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. For example, they could:

(1) Increase the number of loading or unloading bays.
(2) Increase the number of forklift trucks.
(3) 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 (e.g., 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 people would wish to do so. Now that computers offer significant power for a minimal cost, a computer simulation approach seems to make even more sense in management science.

1.2 SOME APPLICATIONS OF COMPUTER SIMULATION

Though it is impossible to be sure which techniques are most commonly used in management science, the occasional surveys of practitioners usually report simulation methods in the top three. This section briefly reviews some of the main application areas.

1.2.1 Manufacturing

As markets for manufactured goods have become globalized, manufacturers have increasingly attempted to mass customize their products. That is, they have sought economies of scale by developing products that will have global appeal and should sell in many countries. At the same time they have had to ensure that the products themselves are suited to local preferences, which means they have had to produce local variants of the global designs. This mass customization, sometimes known as glocalization, has placed great pressure on manufacturers to develop and install manufacturing systems that can deliver high volumes of high-quality goods at low cost to meet local needs. This has led to huge investments in manufacturing plant and associated control systems. It is important to ensure that such systems operate as intended, and therefore computer simulation methods have found an important place in the process of designing and implementing these manufacturing plant and systems.

Examples of this use of computer simulation occur across most manufacturing sectors and include food manufacturing (Pidd, 1987), semiconductor wafer fabrication (De Jong, 2001), beverages (Harrell, 1993), automobile manufacture (Ladbrook and Januszczak, 2001), aerospace (Lu and Sundaram, 2002), shipbuilding (Williams *et al.*, 2001) and materials handling (Burnett and LeBaron, 2001). Simulation allows the comparison of alternative designs and control policies on the model before starting to build the physical plant. It helps to reduce the cost and risk of large-scale errors. Simulation approaches are also used on existing plant to find better ways to operate, and these studies might be one-off exercises or may be part of a periodic check on the running of the system.

1.2.2 Health care

As with manufacturing, there is also a need to make effective use of limited resources when providing and delivering health care. Thus, simulation approaches have found widespread application in health care systems around the world. Hupert *et al.* (2002) discuss the distribution of antibiotics and vaccines to dispensing centres in the event of a terrorist attack. Ceric (1990) describes how the methods were used to plan a system to move goods and equipment around a large new hospital in an effective and efficient manner. McGuire (1994) reports on the use of simulation for the planning of effective emergency departments. In all such simulations, the idea was to test different policies without putting patients to inconvenience or placing them at risk. Simulation is also used to assess the effect of different treatment programmes. For example, Davies *et al.* (2002) used simulation to investigate ways in which the eyesight of diabetic patients can be more effectively preserved and Jacobsen *et al.* (2001) used it to assess the value of paediatric immunization programmes.

1.2.3 Business process re-engineering

Recent years have seen an increasing concern by businesses to ensure that their core processes are operated effectively and efficiently, and this has been the aim of business process re-engineering (BPR). In BPR the idea is to take a fundamental look at the basic processes without which the business could not function and which contribute in a major way to both profit and cost. In some ways, the stress on BPR mirrors the shift in manufacturing from batch production towards flow-line manufacturing. An example of a BPR exercise might be an investigation of the various operations and activities involved in delivering goods to a customer, and in invoicing that customer and in receiving payment. In a traditional system, the paperwork and computer-based documentation might need to pass through several different departments. Taking a radical look at such processes might lead to great simplification and thus to reduced costs and to better service. The aim of BPR is to take an integrated view of such activities and to find ways to provide a better service at lower cost by more effective organization.

Dennis *et al.* (2000) summarize some applications in the telecomms industry. Bhaskar *et al.* (1994) identify computer simulation as one of the key approaches to understanding how business processes might be re-engineered to improve performance. Davies (1994) describes how simulation has been used in BPR in the UK financial services industry. Companies providing these financial services in the UK must meet legal time limits for their responses to customers and must also carry out a series of checks required by law—in addition to their own internal monitoring. Davies (1994) developed a simulation model known as SCOPE to enable organizations to organze their office processes so as to achieve target performance levels. SCOPE works by simulating the flow of documents through the organization.

1.2.4 Transport systems

Computer simulation is also used in a wide range of transportation systems. As with other applications, the idea is to ensure that the system operates as efficiently and as effectively as possible. In the aviation sector, simulation methods have, for example, been used to help plan large passenger terminals. Airport terminals include systems for moving baggage and for ensuring that passengers can get to the departure gates in time for their planes, and a number of simulations have been used to assess their performance (e.g., Joustra and Van Dijk, 2001). Also in the aviation sector, air traffic control systems are used to ensure that air space is used efficiently and safely. As part of this, the air traffic controllers must ensure that the movement of aircraft is planned in advance and then managed in real time. Simulation approaches have made a great contribution to safer and more cost-effective air traffic control (e.g., Lee *et al.*, 2001).

The shipping sector has also been a long-term user of computer methods. Indeed, one of the computer simulation programming languages (CSL; Buxton and Laski, 1962) was first developed by Esso (predecessor of Exxon) to support simulations of the movement of crude and refined oil around the world. Shipping applications continue to this day and an example is given in Heath (1993).

Salt (1991) reports how simulation methods were used to help plan the movement of traffic in the Channel Tunnel that links the UK and France. Though the introduction of this service was controversial, it is clear that one key to its future success is the reliability of the service that it offers. Unlike the ferries which also ply the route, bad weather should not prevent the operation of the tunnel service. It was therefore crucial that its operations were properly planned and managed. Salt (op cit) gives interesting examples of how this was supported by computer simulation approaches.

The road transport sector is also a major user of computer simulation methods both to plan individual companies' operations and to investigate road traffic systems in general. Traffic simulators are now a standard part of the armoury of road traffic planners (Pidd, 1995; Rathi and Santiago, 1990; Young *et al.*, 1989) since they permit possible road configurations and traffic management schemes to be refined before their physical implementation.

1.2.5 Defence

The defence sector is also a major user of simulation methods and the Proceedings of the Winter Simulation Conference usually include a range of papers discussing work in this area (e.g., see Robinson, 2001). Applications range from studies of logistics operations through to battle simulations, which investigate possible strategies and tactics to be used in defence or attack. Their appeal here is obvious; no battle commander wishes to be defeated and the chance to develop tactics beforehand and to prepare countermeasures is of some importance. Not surprisingly, the majority of defence simulations are not reported in the open literature.

1.3 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 Miser and Quade (1988), Pidd (2003), Rivett (1994), or White (1975). 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 that 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 that 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. Mathematical models represent the important factors of a system by a series of equations that may sometimes be solved to produce an optimal solution. Many of the commonly employed techniques described in management science textbooks are of this form (e.g., mathematical programming, game theory, etc.). For computer simulation, logical models are usually required—though in the case of system dynamics (see Chapters 13 to 15) 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 (Slack *et al.*, 1995) 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.

Modern digital computers are logical machines that obey a sequence of instructions, thus any sequence of instructions can form the basis of a computer program—which makes computer simulation possible. At some stage the simulation model, which may initially exist on scraps of paper, in agreed documents or in some formal set of flow diagrams, must be translated into a form that a computer can recognize and obey. Once in a computable form, the model may be easily modified so as to permit a wide range of options to be compared in simulation experiments.

1.4 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. Those that produce the best results in the model would be candidates for implementation 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 that 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

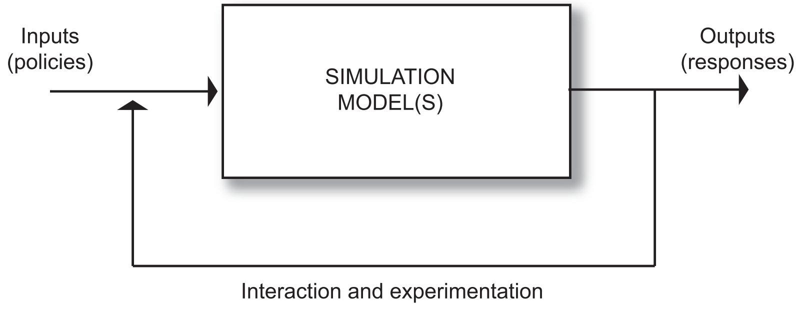

Figure 1.1 Simulation as experimentation

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.

1.5 WHY SIMULATE?

Certainly, computer simulation is no panacea. Realistic simulations may require long computer programs of some complexity. There are special purpose simulation languages and packaged systems available to ease this task, but it is still rarely simple. Consequently, producing useful results from a computer simulation can turn out to be a surprisingly time-consuming process. In one way, therefore, computer simulation should be regarded as a last resort—to be used if all else fails. However, there are certain advantages in employing a simulation approach in management science and it may be the only way of tackling some problems.

Assuming that a management scientist does not wish to make an instant ''seat of the pants'' judgement of a particular problem, various modes of approach are possible. First, it may be possible to conduct experiments directly on the real system. For example, the police may experiment with mock radar speed traps to see if this reduces the number and severity of accidents reported. Second, the analyst may be able to construct and use a mathematical model of the system of interest. For example, Thomas *et al.* (2001) describe how mathematical programming techniques are used in credit scoring and Wright (1994) describes how heuristics are used to timetable English cricket. A third possibility is to simulate the system.

1.5.1 Simulation versus direct experimentation

Then why simulate when it will be time consuming and there may be alternative approaches? Considered against real experimentation, simulation has the following advantages:

- *Cost*. Though simulation can be time consuming and therefore expensive in terms of skilled manpower, real experiments may also turn out to be expensive—particularly if something goes wrong!
- *Time*. Admittedly, it takes a significant amount of time to produce working computer programs for simulation models. However, once these are written then an attractive opportunity presents itself. Namely it is possible to simulate weeks, months or even years in seconds of computer time. Hence a whole range of policies may be properly compared.

- *Replication*. Unfortunately, the real world is rarely kind enough to allow precise replication of an experiment. One of the skills employed by physical scientists is the design of experiments that are repeatable by other scientists. This is rarely possible in management science. It seems unlikely that an organization's competitors will sit idly by as a whole variety of pricing policies are attempted in a bid to find the best. It is even less likely that a military adversary will allow a replay of a battle. Simulations are precisely repeatable.
- *Safety*. One of the objectives of a simulation study may be to estimate the effect of extreme conditions, and to do this in real life may be dangerous or even illegal. An airport authority may take some persuading to allow a doubling of the flights per day even if they do wish to know the capacity of the airport. Simulated aircraft cause little damage when they run out of fuel in the simulated sky.
- *Legality*. Even when not employed by the mafia there are times when an analyst may wish to investigate the effect of changes in legislation. For example, a company may wish to see what the effect would be on its delivery performance of changes in the laws that control drivers hours of work.

1.5.2 Simulation versus mathematical modelling

What, then, of the other possibility of building and using a mathematical model of the system? Here too there are problems. First, most mathematical models cannot satisfactorily cope with dynamic or transient effects and operate instead with average values. However, in any dynamic system, steady state values can be very misleading, particularly if there is statistical variation in demand. Even though average demand is met, this may not be true of peak demand. The challenge is to design such systems to meet reasonable demand without having idle resources ''just in case''. Thus, the model may need to take account of the statistical variation that is inherent in many systems. Second, though it is debatable (see Chapter 10) whether this is a good thing, it is possible to sample from non-standard probability distributions in a simulation model. However, queuing theory models permit only certain distributions and therefore cannot cope with many types of problem.

Computer simulation then may well be regarded as the last resort. Despite this, it is surprising how often such an approach is needed.

1.6 SUMMARY

Computer simulation methods allow experimentation on a computer-based model of some system. The model is built by carefully describing the ways in which the system changes state and the rules that govern its dynamic behaviour. Modelling is best planned on an incremental and parsimonious basis, with the expectation that the model will need to be enhanced as knowledge about the system develops. Once built, the model is used for experimentation, either interactive or classical or both.

EXERCISES

(1) Suppose that a public authority is considering various policies for checking whether goods vehicles are overweight as they arrive at ferry ports. Discuss whether it might be sensible to consider a simulation approach.
(2) In what types of situation would a simulation approach be unwise?
(3) Spreadsheet packages such as Microsoft Excel™ are widely used on personal computers. Discuss what type of simulation these packages allow.
(4) If you were the manager of a factory whose production operations were being simulated by a management scientist, why might you not be convinced that the simulation model was valid even if the production rates output from the simulation were the same as those of your factory?
(5) Consider the reasons why simulation approaches often form part of the process of designing new manufacturing systems.
(6) Computers are becoming easier to use by non-specialists. Should managers be encouraged to undertake computer simulations themselves or is there still a place for the specialist?

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