

CHAPTER 4

Purposes of Environmental Modelling

Environmental modelling can be used for a number of overlapping but different purposes. Because this report samples a wide spectrum of present and potential applications of modelling techniques, it may be useful to clarify the various objectives of modelling studies, and to sketch in broad outline the features of each.

4.1 MODELLING AS AN EXTENSION OF INFORMATION SYSTEMS

As a background to any environmental problem, there already exists a considerable body of information. In order that a problem be defined and analysed, and a suitable solution sought, it is desirable that existing, relevant information be utilized as far as possible. This knowledge should include a full description of the systems in question, descriptions of the behaviour of analogous systems in the past, and of the factors affecting those systems; descriptions of the mechanisms involved in the dynamics of the systems; and the best information obtainable to permit forecasting of future changes in relevant external factors.

In many cases, much of this information may have been accumulated in some organized manner – either in a form readable by the human eye, or one directly accessible to the computer. The information is likely to include raw data – the results of actual observations and surveys made of this and similar systems in the past; and statistical summaries of various sorts, such as means, totals, and tabulations. It will also include the results of statistical analyses, some of which may be performed only when the specific needs of the present environmental problem become clear.

The simulation model itself can be regarded as a part of the background data on the system, condensing existing knowledge of the structure and dynamics of processes in an organized and precise form. The results obtained by use of the model are also as much a part of the data system as the original observed data on which the model is based, or any quantities derived from them by statistical analysis.

4.2 MODELLING IN ENVIRONMENTAL MANAGEMENT AND DECISION-MAKING

Environmental decisions are made at various levels. These begin with the individual who, on the spur of the moment, may decide to throw his cigarette butt out of the car window instead of putting it in the ash-tray – a decision which may even result in the destruction of a large area of forest. At other levels, the industrialist deciding to install a precipitator in his smoke-stack, the regional

council deciding to realign a road, the government deciding to permit flights by supersonic aircraft, or the inter-governmental body deciding to impose limits on whale catches – all are making decisions which will have some effect on the environment.

Any decision involves a choice between at least two possible courses of action – even if one of them may be to take *no* action, which is itself a decision. The consequences of *each* of the possible courses of action need to be foreseen in order that the most appropriate choice be made. If the decision-maker's objectives involve any features of the environment – to improve them, to maintain them, or not to permit them to deteriorate beyond tolerable limits – he accordingly needs to be able to foresee the possible environmental effects of the various courses of action open to him. He must also be aware of any other effects (economic, social, political, etc.) which may be relevant to his objectives.

Environmental effects are often less well-defined and usually much more difficult to foresee than the immediate economic consequences of proposed courses of action. This makes it particularly difficult for the decision-maker, even when fully aware of the possible importance of environmental effects, to take them into account adequately. A first step towards giving environmental effects appropriate weight with other consequences of the decisions taken is to define, as accurately as possible, those potential effects which would be regarded as relevant. This is an essential step in the application of systems analysis, and an important preliminary to the use of simulation modelling.

A choice between the various possible decisions must be based on predictions of the likely course of events following each. Given these predictions, the decision-maker compares, for a number of variables in the system, the values which are likely to result if he makes this or that choice. Very often, prediction of the results of different management strategies is purely intuitive – the decision-maker himself makes a guess, in which his general previous experience in similar situations plays a role, often largely subconscious. If a simulation model is used, however, the predictive processes on which decisions are based can be made explicit, all the most relevant knowledge of the system can be incorporated, and thus the predictions become much more objective than purely intuitive guesses.

A simulation model used in this way constitutes a condensation of existing knowledge, providing the decision-maker with predictions which can help him to make an intelligent choice between different strategies, and which he can use to modify his own intuitive thought processes. Where background knowledge is scanty, however, experience and intuition may sometimes be as dependable, and a formal simulation model may provide a false and possibly harmful feeling of security.

In the real world, decisions are always made in the face of uncertainty – uncertainty about the future course of uncontrollable events, and uncertainty in one's knowledge of the system as it now exists. Thus, predictions are most useful to the decision-maker if they take this uncertainty into account – for instance, by the output taking the form of a probability distribution for each variable rather than a single expected value. The decision-maker can then weight the possible outcome – good and bad – of each decision he might make with its probability. Thus, the most useful models for decision-making are likely to incorporate stochastic elements, and should provide with each prediction an indication of its uncertainty.

Simulations are most likely to be useful to, and used by, the decision-maker if he himself has been involved in the model-building process, at least to the point of indicating the variables he wishes to be taken into account. If, further, he can in advance be rather specific about his value system – not only name the variables, but indicate their relative importance – the model can be more precisely adapted to his needs, and built more economically for his purposes.

As a variant of simulation modelling for decision making, one may consider a gaming approach. Here, a human participant interacts with the model, and makes decisions between the time steps as the simulation proceeds. The effects of the sequence of decisions he makes on the ultimate outcome may then be studied. This constitutes an extension of simulation modelling by allowing the user of simulation techniques to introduce the decision-maker's behaviour into the simulation process. The user becomes more aware of the complex of factors that should be observed before resources are allocated. He performs these allocations and then lets the in-built dynamics of the underlying simulation model carry him to the next time step. Where several players are involved separately, each representing different interests, the adjustments and compromises which result make it possible to see political, social, economic, technological, ecological, and psychological constraints that might otherwise escape attention. A good example of gaming as an aid to decision-making is the nutritional game described in Section 9.6.

In principle, the use of simulation modelling and gaming in solving environmental problems is as appropriate to developing countries as to those in an advanced stage of development. The value systems used in the two cases may, of course, differ. The decision-maker in the developing country is likely to attach more weight to economic growth and to food supply, and less to pollution and environmental amenities, for instance. However, there is no reason why simulation modelling cannot facilitate the decision process there as much as in a fully industrialized country.

4.3 MODELLING AS A RESEARCH TOOL

Generally speaking, a model provides a research tool for exploring the deductive consequences of any set of assumptions regarding the dynamics of a system. This exploration is often the best way of testing the assumptions. Their consequences may be much easier to test against actual observations than the assumptions themselves. In a complex system it may be impossible to deduce the consequences without a simulation model.

The complex systems involved in environmental problems often require an interdisciplinary approach. Most decision processes relating to the environment involve complex considerations of man and the structure of society, on the one hand, and of the surrounding world, on the other. Traditionally, however, these two sides of the problem have been studied as different groups of disciplines, and appear to be governed by different types of laws. Little attention has been devoted to the interface between them.

Improved understanding of processes at the interface – the links between physical and biological processes in the environment on the one hand, and the response of man and human society to these processes on the other – will certainly improve man's ability to control the environment. Effective study of this interface

system calls, of course, for the commitment of interdisciplinary teams. A purely observational approach to the interactions between human society and the environment, however, may not lead very far, because the observable combinations of factors are a limited and biased sample of those which one wishes to study. And to extend observation by experiment is often hardly practicable where human society is involved.

Where experiments under controlled conditions are impossible in the real world, a simulation model may form a useful substitute in so far as it can be regarded as an adequate representation of reality. It is much more practicable, for instance, to study the internal stability of model systems than that of the real world represented by these systems. It is also easier to study the sensitivity of systems to external influences if the systems can be represented by well-validated models.

The possibility of experimentation on environmental problems in the real world are often limited by ethical considerations; for instance, atomic explosions can hardly be initiated purely as an experiment. Simulated experiments in a computer are subject to no such limitations – they are restricted only by the computer capacity and time available. Thus, experimentation using simulation models seems a promising way of tackling problems at the interface between human society and the environment. If models of the physical and biological systems and of the social and economic systems are already available, and they have been adequately tested separately*, then uncertainty is limited to the interaction of these models. Different ways of handling the processes involved may be tried out, and the behaviour of the model compared with the known behaviour of real-life systems. In this way, by trial and error, a satisfactory representation of the interactions may be attained, and understanding of the processes involved increased. Thus, simulation models can serve as research tools, on the one hand to test hypotheses which have been developed by other means, and, on the other, to formulate hypotheses about system behaviour which might otherwise not have been conceived.

4.4 MODELLING FOR ALLOCATION OF RESEARCH RESOURCES

When a large research project involves a number of disparate elements, each making a separate and definable contribution to an accepted common goal, it is often difficult for the research director to judge the appropriate allocation of funds and personnel among them. If, however, a simulation model of the system under study is built, and incorporates the best existing knowledge (or informed guesses), then the objective of the project can be defined in terms of improved knowledge of the behaviour of a given set of variables.

Within this approach, each research element in the project is expected to reduce existing uncertainty about the part of the system to which it is addressing itself; this is, in fact, the justification for its inclusion. One may ask, for each of the areas addressed, what is the present degree of uncertainty and to what extent is this

*Various problems of estimation may occur if the system is affected by feedback problems and interaction between the component sub-systems. This represents a difficult theoretical problem which is not yet fully understood nor generally appreciated; but it indicates that great care should be taken when decomposing a system into sub-systems and validating them separately.

uncertainty likely to be reduced as a result of the research proposed. One may then use the model to test what improvement in the predictions could be expected if the project were successfully completed. Such tests constitute a form of *sensitivity analysis*, and research priorities can then be allotted in accordance with the sensitivity of prediction to the expected results of the alternative lines of research envisaged. Such sensitivity tests can also help in improving the model itself, by determining which parts of it are critical, and where further effort in developing the model is likely to be most fruitful.

Modelling can also serve research by indicating where, when, and how observations for a particular purpose can best be made. Astronomical observation, for instance, depends on the distribution of cloud and particulate material in the atmosphere; simulation modelling of atmospheric conditions can help in determining optimum locations for observations. Programmes for environmental monitoring – selection of types of observation, as well as the times and places at which they should be made – can likewise receive useful guidance from simulation modelling.

4.5 MODELLING IN EDUCATION

Simulation modelling can also play a useful role in courses in the environmental sciences in universities and technical colleges. If the instructor wishes to show the students how some particular course of action will impinge on the environment, a computer simulation programme may carry the message better than any purely verbal account, even if illustrated with diagrams and graphs. This is especially true if the model programme can be set up in such a way that the student can himself modify the inputs and controls and see the results in the form of moving graphs of the variables with time. Gaming approaches – sometimes making use of a computer, sometimes not – are already used extensively in the classroom to help students understand the interaction of variables in environmental problems, and the ways in which they can be influenced by management.

For the somewhat more advanced student, the actual building of models can provide valuable training. The computer makes great demands on its users for clarity and logical thought, and any deficiency in this regard is mercilessly revealed. Furthermore, in programming a model of an environmental system, the student will be forced to express clearly all the relationships in the system, to make explicit assumptions where knowledge is inadequate, and to avoid all comforting vaguenesses.

The educational value of simulation modelling can extend well outside the classroom. In recent years, a fierce public debate has arisen over ideas induced by the publication of the results of 'world models' by the Club of Rome (Meadows et al., 1972) and other groups. Even though some of these models have been subject to much criticism, they caused people to think about the likely course of change in the environment, given present trends. The models did this to an extent which purely verbal arguments might not have accomplished. The Club of Rome study just referred to, however, has also demonstrated that, if models are used in public education, some instruction should be included on the limitations of modelling and the dangers of uncritical acceptance of the results of extrapolation.

4.6 MODELLING IN PUBLIC INFORMATION

A relatively new use of simulation modelling which could gain wider prominence in the future is involved with education and information exchange in the public arena. For instance, citizens are coming to expect environmental impact statements regarding major works or changes in policy. Where, however, the environmental impact statement becomes the subject of litigation, there may be difficulties in demonstrating the relevance of modelling results within the framework of legal procedures (Loucks, 1974; Chapter 5 of SCOPE, 1975a), and the results may be liable to distortion and misrepresentation.

Simulation modelling can also play a part in improving the competence of special groups of decision-makers. A model can show them the results of action in situations similar to those which they themselves have to confront, and can show some of the ways in which the various parts of the system interact and interlock. Models can thus enhance their appreciation of the dynamics of the system, even where they may not themselves be in a position to apply a simulation-modelling approach directly.

One approach to this use of models has been through the use of the technique of gaming/simulation. An example is 'The Pastoralist Game' developed in Australia (Bennett et al., 1973; Tronson et al., 1974). The 'player' takes the role of a pastoralist breeding livestock in semi-arid country, deciding on his stocking rates, selling and buying livestock, and gaining or losing money as a result of his decisions. The financial effects, however, are not the only ones; he also sees the pastures deteriorating or improving as a result of the stocking rates he imposes in seasons of varying rainfall, and thus he can accumulate experience in pastoral management under varying conditions which might normally take him many years to acquire. The game was developed in the form of a computer programme where the player sits at a terminal and interacts with the computer as the game proceeds; but it is also available as a table game with cards and counters.

Gaming/simulation can certainly help the player to understand how various factors may be interrelated within a very complex system; but there is always the risk that excessive confidence may be placed in the results of gaming exercises, as in other simulation approaches. Apart from the simplifications inevitably introduced, the behaviour of the player may differ from that of the same person in a real-life situation. The time-scale is different and his motivations are different.