CHAPTER 8

Problems of Modelling for Decision-Making

When models are used to aid decision-making, rather than to advance scientific research, problems arise in providing the modellers with a suitable working environment, as well as in different aspects of modelling methodology. There may also be difficulties in ensuring that modellers communicate effectively with the decision-makers and with each other. In this chapter we try to identify the main problems in these various fields, and draw particular attention to special problems of developing countries.

8.1 PROBLEMS IN MODEL-BUILDING METHODOLOGY

We have briefly considered the various approaches to the problem of building environmental simulation models (see Section 7.3). It should be emphasized, however, that environmental simulation is a relatively new and expanding field of research and, while the existing approaches provide systematic ways of developing these models, they are not free from limitations. In this section, we will discuss some of the more important of these limitations and the kind of pitfalls open to the unwary model builder.

8.1.1 Data Requirements*

One of the most difficult problems facing the environmental modeller is the availability of appropriate data. The first step in his investigation should always be an evaluation of existing relevant information on the system, in all its forms. Some collection of preliminary data may be necessary; however, it is important to note that extensive data should be collected only after the problem and its modelling requirements have been evaluated. In fact, the processes of model building and data collection should interact iteratively. Thus, a preliminary model may be built using existing data, and defining the new data which would be required to permit an improved model to be built. This would in turn define further data requirements, and the process would be repeated until further refinements appear unjustified. As we have seen in Chapter 7, it is not usually possible to perform planned experiments on the real-life system, and the most that can normally be hoped for is the collection of data during its normal operation; but, even if this is possible, it

*A more detailed treatment of this subject is given in Appendix 1 of the SCOPE Report on Environmental Impact Assessment (SCOPE, 1975a).

will usually be difficult. Thus, to collect daily data on even the major indicators of water quality in a river system for an extended period of time can be time-consuming and costly. The data must also, of course, be relevant to the specific modelling problem; nothing is more frustrating than to be presented with an excessive amount of data, only to find that most of it has little relevance to the problem at hand.

The problems of data collection, including the lack of adequate measurement techniques and sensors, can make it difficult to supply all the required data. For example, biochemical oxygen demand (BOD) takes four days to measure and thus can introduce obvious problems if a daily model for water quality is required. In such a situation, modellers may be tempted to proceed without adequate data or procedures; this can lead to inadequate models and a tendency to regard the model as the system itself, rather than as an approximate mathematical representation subject to uncertainty.

8.1.2 Scale: Temporal and Spatial

In many environmental simulation models, most of the system variables vary in space over the geographic area under consideration. A choice of scale often has to be made and there may be little information available to guide this choice. It is possible that an overall collection of particulars into one aggregate would lead to vital points being missed, while too detailed information could make the model impractical, in terms both of modelling and of data collection.

Depending on the nature of the simulation modelling objectives, the model may require different time scales. For example, the process of constructing an industrial complex could cause immediate damage to the local environment, whereas the effects of pollution from this complex may take several years before they become significant. Again, the long-term average levels of water pollution may be satisfactory for potable water supply, but this is not much comfort to the fish (or the fisherman), for example, since short-term violations of water quality can cause extensive fish kills. These kinds of problems can be exacerbated by failing to define sufficiently well the objectives of the study at the outset.

Another problem arising out of this need to define the time scale carefully lies in the construction of models that may contain a mixture of behavioural oscillations with widely differing natural frequencies. Models constructed in this manner can be subject to computational problems: for instance, the integration of the set of differential equations (often termed 'stiff' differential equations) describing such a system can raise many difficulties. A practical example of this latter problem occurs in the solution of numerical models of the atmosphere, where special procedures are required to eliminate gravity waves.

8.1.3 Aggregation

When dealing with large environmental systems it is necessary to see whether the modelling objectives require an aggregate *macro* simulation of the system or whether more detailed *micro* information is desired. In the first case, it is necessary to define the model in terms of aggregative variables. This exercise can sometimes be obvious, as when biochemical oxygen demand is used as a macro-measure of the oxygen-absorbing potential in a stream. However, it may be difficult, as when one attempts to define an overall water-quality index which includes not only oxygen-absorbing potential, but also the presence of nutrients and toxic substances. This difficulty arises because in this situation it is necessary to define the relative weightings of the different variables in the index.

In the second case, it may be difficult to produce a large model with many state variables as a complete entity. In such a situation it is often advisable to develop the model by decomposing it into a collection of interconnected sub-models, each of which is simpler to handle than the overall model and can be fairly simply connected with the other sub-models through easily definable interfaces with compatible inputs and outputs. Such model decomposition can often be accomplished by reference to the physical nature of the system, which may itself be similarly considered in sub-system terms. Alternatively, there have been attempts at systematic methods of system decomposition; but these do not seem to have been particularly successful in practice, and there is an urgent need for further research in this area. Finally, it can be helpful and instructive for decision-makers to consider the disaggregated sub-models in terms of a hierarchy of different levels, with the upper levels linking with the lower levels, and with possible links or coordination between sub-systems at the same level.

8.1.4 Interfaces between Sub-Models

If sub-models are constructed in a similar manner, then there are often only minor problems of interfacing them. If, on the other hand, the programmes are different in some sense, many problems can arise – certainly too many to discuss here. The problem can be minimized, however, by maintaining constant communication between the model builders considering the sub-systems (should there be more than one participant in the modelling exercise), and ensuring that the variables passing through the interface are well matched. For example, if time-series at one time scale are generated in one sub-system, the output of that sub-system into another using a different time scale should be made compatible.

8.1.5 Validation of Models

The validation of the model – i.e., the matching of the model with the real system – is particularly difficult in environmental studies. In structuring an appropriate model, it is of great importance to incorporate the best possible understanding of the environmental phenomena. Validation is then the next step. It is always necessary to ensure that relevant data are collected and used for the purposes of validation, although it may be difficult to define which parts of the model require better validation. One popular approach to this problem is to use sensitivity analysis to indicate those portions of the model which have a marked effect on the system response and thus should be particularly carefully validated. If it proves impossible to collect the required data defined in this manner, the resulting uncertainties should always be noted carefully in the presentation of any results to the decision-maker.

A model of an environmental system can be validated only within some prescribed limits of uncertainty, which in turn will limit the accuracy with which decisions based on the model may be made. As we have seen in Chapter 7, this difficulty arises, in part, because environmental systems are sometimes rather ill-defined and, at the same time, can be extremely complex. Similar problems have worried the economic model builder for many years. There is clearly, however, an urgent need for more theoretical work on the estimation and validation of models for large complex systems, and the further involvement of mathematical statisticians with an understanding of and sympathy for systems science. This requirement cannot be over-stressed; the deficiencies of current simulation modelling in this respect are considerable and corrective action is urgently required if simulation modelling of mixed physical-biological-socio-economic systems is to retain its credibility.

8.1.6 Transferability of Models

Simulation models may be transferred between people or organizations in a number of ways and this can lead to various problems. First, if the model is to be used by the recipient for application to the same system, then the major problem is to ensure that the language (either mathematical or computer) is understandable. Second, under these same circumstances, it is clearly necessary to ensure that, if the model is in the form of a computer programme, then it is compatible with the computer system used by the recipient or that adequate translation facilities are available. Third, it is most important that the recipient understands the inner functioning of the model or programme: in other words, how it works. Finally, the model may be transferred in the manner already discussed but for use in connection with a geographically different but analogous type of system – e.g., between ecosystems of different types (the U.S. Desert Biome model was applied to Norwegian tundra by Wielgolaski et al. [1975]). In this case, there are, of course, many pitfalls. In addition to the communication difficulties there is also a need to ensure that the model is revalidated in the new context, although the extent of revalidation will differ depending upon the circumstances. It is unlikely, in other words, that a truly transferable model will ever be developed except under very special circumstances.

Another important point regarding transferability relates to the degree of generalization. The model builder should attempt a compromise between a model which is too general and therefore too complex, and one which is too specific and whose application potential cannot, therefore, be fully realized.

One of the most widespread communication problems is the lack of adequate documentation of models. Inadequate documentation of the conceptual basis, assumptions, limitations, and operating features of models prevents proper use by decision-makers and successful transfer of models to new situations.

8.2 PROBLEMS OF PROVIDING A SUITABLE ENVIRONMENT FOR MODEL BUILDERS

Within his working environment, one of the most important difficulties confronting a model builder may be pressures from interested parties. If model results are unfavourable to the current policies of his country or employer, he may be pressed to modify the model and may find it difficult to offer the resistance that professional integrity would dictate. In this connexion, the modeller needs the support of an external and impartial body with sufficient prestige to act as an arbiter.

One can see the need for an international academic body, adequately staffed and equipped, whose prime function is to coordinate the long-term planning of modelling in the field of science and technology. Such a body might include among its functions those of adjudging the value, reliability and appropriateness of models submitted to it by prospective users, and acting as a court of appeal where differences arose between modeller and model user.

8.3 PROBLEMS ARISING BETWEEN MODELLERS AND CLASSICAL SCIENTISTS

It cannot be denied that at the present time some scientists remain unconvinced of the true worth of systems-modelling techniques. This attitude has been encouraged by examples of bad modelling and model application, and by misrepresentation of what models can effectively accomplish. Furthermore, there have been instances in which models were developed based on empirical data or outdated theories where much better theoretical background was available. As a result, difficulties may be encountered in obtaining the whole-hearted cooperation of particular groups of scientists whose specialized knowledge may be most valuable for inclusion in a model. Even when cooperation is forthcoming, difficulties can still arise when scientists tend to insist upon providing more detail than is required for the limited purposes of the model.

8.4 COMMUNICATION PROBLEMS BETWEEN DISCIPLINES

In this era of increasingly narrow specialization, there can be difficulties in establishing effective cooperation and communication between experts from different disciplines who have different concepts, language, and levels of sophistication. Environmental problems, however, know no disciplinary boundaries and, as the insights provided by systems science make clear, the different disciplinary aspects interact and cannot easily be isolated from each other. Thus, environmental simulation modelling will usually demand very close cooperation and communication between a variety of experts in different disciplines.

The problem of communication is particularly severe between those in the physical sciences, at the one extreme, and those in the social sciences at the other (Biswas, 1975b). Many social scientists are not accustomed to expressing their hypotheses in quantitative form. Indeed, some may even be antagonistic towards quantitative methods of any kind, feeling that human behaviour, for example, is by its very nature not quantifiable and difficult to predict. To some extent their objections are based on misunderstanding of the reasons for modelling.

Because of the difficulties in obtaining the whole-hearted involvement of all the specialists required, or of obtaining it when required, professional modellers may sometimes be tempted to seek out the necessary knowledge for themselves. This is regrettable, even though the modellers' understanding of systems and familiarity with the rest of the model may be greater than that of the specialists. The modellers should not proceed too far without the proper participation of all the relevant specialists, if an appropriate standard of simulation modelling is to be achieved.

8.5 COMMUNICATION PROBLEMS BETWEEN MODELLERS AND DECISION-MAKERS

The last and most serious problem area in modelling for decision-making lies in the interaction between scientists/modellers and managers/decision-makers. The often disparate training, perspectives, goals, and reward systems of these two groups, as described in Chapters 5 and 6, may present barriers to communication and mutual understanding, and thereby limit the success of model application. Communication problems are manifest at several points in the process of model application.

In many instances, decision-makers may not be aware of the potential of simulation modelling to aid the analysis and synthesis of policy alternatives. Many decision-makers are accustomed to traditional problem-solving techniques and may resist or mistrust new techniques such as simulation modelling. This is particularly true in less developed countries.

At another level, it is important that both modellers and decision-makers share a common definition of the environmental problem at hand if a model is to be useful in the decision process. Failure to interact adequately from the beginning of model development can result in a model that excludes factors which are of critical importance to policy-making or provide results which are only of interest to the Scientific researcher, but inappropriate or irrelevant to the decision-making situation. It is also important that modellers be aware of the decision-makers' goals and objectives, in order to ensure maximum utility of the model output. Decision-making objectives should be stated as well as possible at the beginning, with the realization that formulation of objectives is an iterative process. It should be recognized that the definition of societal objectives in the decision process is difficult. In fact, goals and objectives evolve slowly in response to changes in attitude and perception of the general public.

In addition to the problems associated with the definition of model objectives, different types of models may be suitable to specific decision-making situations. This is true when a new modelling project is being commissioned for a specific problem, as well as when an existing model is being chosen for application. Factors such as constraints on time, money, and personnel, as well as the informational needs of the decision-maker, will all affect which model structure or approach is the most appropriate. This choice can be successful only after effective communication between modellers and decision-makers has taken place.

Failure of modellers to communicate to decision-makers the limitations and simplifying assumptions of the model can result in misleading interpretations of results, inflated expectations of the model, and, ultimately, loss of credibility for the model and simulation modelling in general. The assumptions on which the model is based must, of course, be clearly emphasized and re-emphasized, and the consequences of an incorrect interpretation of the results when the assumptions are invalid should be stated. Moreover, model output must be in a form that is understandable and useful to the decision-maker. In some cases, this may take the form of a third language which is common to both modellers and decision-makers, such as graphic displays or gaming-simulations.

The general problem of establishing the decision-makers' confidence in the model is ultimately most crucial, because without this confidence the model's results will never be incorporated into the policy-making process. A decision-maker's confidence will be directly affected by the extent to which all of the above-mentioned problems are satisfactorily solved. However, it is likely that he will be particularly concerned that the model is as well validated as possible and that the extent of this validation – and the resulting confidence he may, therefore, associate with the model forecasts – is always reported clearly and unambiguously.

8.6 SPECIAL PROBLEMS OF DEVELOPING COUNTRIES

At the present time, certain identifiable problems exist which restrict the use of simulation modelling in developing countries. The first of these is a shortage of expertise and technical personnel capable of developing and implementing modelling projects. A second problem is that computer facilities may be inadequate. Some types of modelling project require quite large computer installations such as are rarely available in developing countries. Admittedly, it is often possible to develop and run a model at a distance; but this has drawbacks, for interaction between modeller and decision-maker during the model-building is very desirable – a better model, and one answering the decision-maker's needs more precisely, is likely to result, and the decision-maker is also likely to have more confidence in it. When the predictions start to be produced, the decision-maker may want to modify his proposed course of action and will call for predictions under changed assumptions. Consequently, there are considerable advantages in having the model prepared locally. In fact, modelling projects which rely on a bigger and better computer out of the country are likely to fail. Clearly, realism and detail may suffer from limited local facilities, but there is now a useful body of experience with simulation models for small computers to be drawn upon.

The use of ready-made models, rather than ones built to order, may be particularly advantageous for developing countries. So long as a model is reasonably general, it may be adapted to fit a different type of system, although the effort which may be required should not be underestimated. One example of such a model transfer is an ecosystem model developed by the U.S./IBP Desert Biome programme, which was adapted to model the coastal desert of Egypt (Ayyad, 1976) – and, also, with a moderate degree of simplification, to run on a quite different and much smaller computer available in Cairo (see Section 9.4). In such a case, the most important thing is to ensure that all the variables relevant to decisions in the developing country are, in fact, embodied in the model being transferred – or, if they are not already there, that they can be inserted without difficulty. At present, there are rather few examples of model transfer like this, and even in this case there are still a number of problems to be overcome.

Quite a different type of difficulty in the use of simulation modelling in developing countries arises from shortages of data. To be sure, data on the behaviour of the complex systems involved in environmental problems are inadequate even in developed societies, but this problem is increased in developing countries, because of the much shorter period for which scientific studies have been in progress. It should be emphasized, however, that lack of data is not a sound reason for postponing the development and application of simulation models*.

*Thus, in the first application of mathematical modelling to urban pollution (Frenkiel 1957, 1959) some informative results were obtained, although only limited data were available at that time.

Even where data are sparse and largely qualitative, a simulation model may make better use of existing information than the usual intuitive approach – although this cannot be guaranteed, and care must be taken to avoid misplaced confidence. For modelling purposes, the data will need to be made definite, perhaps even quantitative; but this very process of converting the vague and qualitative into the precise and quantitative will be valuable in directing attention to the gaps and inadequacies in existing information. The model can then be expected to provide the best predictions available, given the present state of uncertainty, and at the same time to rationalize subsequent data collection.