D. CLASSIFICATION OF MODELS

There are two fundamental features which characterize all models: form and content. Models can be classified according to many different forms. Some of these forms are as follows:

(1) *Verbal or qualitative models*: Here the model is limited to only qualitative statements. For example, such a model for the number of sales of an item could be: sales go up as the number of salesmen is increased, and the item is sold even if there is no salesman.

(2) *Mathematical models*: Here one tries to quantify the qualitative model through mathematical relationships. In the example of sales of an item, the mathematical model could be expressed as: $y = ax + b$, where y is the number of sales, x is the number of salesmen, b is the number of sales without any salesman, and a is the parameter which quantifies the increase in sales if the number of salesmen is increased by one.

(3) *Analog models*: Here, instead of modeling the specific phenomenon or system, one models 'analog' phenomena or systems. The word analog is derived from the Greek word 'analogia', which means proportion. Such models are extremely powerful and prevalent in many branches of the social, physical, and biological sciences and in engineering. For example, excellent electrical circuit models (involving resistors, inductors, and capacitors) exist for hydraulic and mechanical systems and even for the human ear. There is a whole branch of solid-state physics, the theory of lattice vibration, which is based on approximating solids with a set of coupled oscillators arrayed in a lattice structure. Automobile traffic flow has also been modeled as a system of coupled oscillators with the added rule that there is a delay in the response of one oscillator when the state of another oscillator is changed (Haberman, 1977). This delay is required to mimic the delayed reaction of a driver to the movement of the vehicle ahead of him. Attempts have also been made to model the brain as a computer.

(4) *Physical models vs. abstract models*: The model of a system or phenomenon can be an abstract or a physical model (involving hardware). An example of an abstract model is the map of a country, which can be very effective in determining the distance and time for travel between any two cities. An

example of a physical model is a small-scale model of an airplane in a wind tunnel. Such models are routinely used by the aerospace corporations, such as Boeing and McDonnell-Douglas, in developing aircraft.

(5) *Descriptive vs. functional models*: A set of drawings or blueprint of a train is a descriptive model; a small model train is a functional model of how the train runs.

(6) *Causal vs. correlative models*: Causal models reflect cause and effect, while correlative models may simply reflect a statistical correlation. Suppose the amount of paint sold by a paint manufacturing company is observed to increase year after year. One could take these data and develop a correlative model (using regression analysis) relating sales to time since the death of Christ and use it to predict the sales in a future year. This prediction will be independent of any other event — an incorrect conclusion. On the other hand one might develop a causal model relating paint sales to the sales of automobiles and homes in a given year. Such a model will reflect the fact that paint is needed for automobiles and houses, and that if their sales go up, so will paint sales. The predictions of this latter model will obviously be more correct and representative of the real situation than those of the former model.

(7) *Deterministic vs. stochastic models*: The behavior of a deterministic model, for a given set of values of the parameters, at any given time, is determined or well-defined. Such models are used for systems where the 'environment' is certain and well-defined. Stochastic models, on the other hand, deal with uncertainty, and the behavior of such models cannot be precisely predicted. Many natural systems, including biological systems, have stochastic elements which influence their behavior. Therefore, stochastic models are more appropriate for such systems (Goel and Richter-Dyn, 1974). These models deal with the probabilities that the parameters specifying the system will take on certain values.

(8) *Isomorphic vs. homomorphic models*: In isomorphic models there is a one-to-one correspondence between elements of the system being modeled and those of the models. In homomorphic models many elements of the system being modeled are integrated into one to make the model simpler and more amenable to detailed investigation.

(9) *Static vs. dynamic models*: Static models represent the behavior of the system at a given time, whereas dynamic models represent the trajectory followed by the system as a function of time. A model which gives the folded structure of a globular protein from its primary sequence is a static model, while one which gives the path followed by the protein in going from an unfolded structure to the final folded structure is a dynamic model. Models of both types exist for determining the aggregate structure of embryonic cells from several tissues (see Chapter 9).

(10) *Decision models*: These models provide the users with if–then scenarios, and are used in policy analysis and subsequent management decisions. For the various values of key parameters they generate outcomes which are reflections

of corresponding policy decisions.

(11) *Simulation models*: These models involve the creation of an artificial system which displays either the same behavior as the one being modeled or behavior related to it in some simple way. Simulation is a technique that involves building a model and then performing experiments on it in order to infer properties of the real system.

It is this last form, specifically using computers, on which we will focus. Computer simulation is a way of using a computer to produce a reasonable model of a system under study. This model takes the form of a computer program that contains entities representing the elements of the real system. In executing the program, the computer emulates the behavior of the system. It produces an output from which the behavior of the system can be deduced. It can also keep track of what happens at various points in the system and can accumulate statistics as the run progresses, if this is so desired. Also because of the speed of present-day computers, computer simulations are more capable of representing complex systems than many other types of models.

Because of easy access to computers, computer-based simulation models have become extremely popular. Simulation models (as embedded in a flight simulator) are invaluable tools for training pilots and astronauts. Simulation games are regularly used in schools of management to teach the intricacies of running a corporation in a competitive environment. To appreciate the power of this type of model, let us consider its use in the management of a corporation. Suppose a manager wants to adopt a new plan for manufacturing. One approach is to adopt an actual plan, implement it, evaluate it, adjust it if necessary, re-evaluate it and adjust it again, and so on. Another approach is to examine a close approximation of the plan. Here one could make a model of the manufacturing process, study the impacts of various plans and decisions, and then select and implement the plan with maximum benefits and minimal drawbacks. This latter approach is, of course, the simulation approach. Some of the advantages of this approach are as follows:

(1) It allows *controlled experimentation*, in which many factors can be considered, many units can be manipulated, alternative policies can be analyzed, and all of this with little or no disturbance of the actual system.

(2) It allows *compression of real future time* into present time.

(3) It is an effective and inexpensive *training tool*.

(4) It provides *operational insights*, may *dispel operational myths*, and make *management more effective*.

There are similar advantages to computer simulation of biological systems. Here analysis of alternative policies is replaced by analysis of alternative designs. Such models complement experiments. A model for the simulation of protein