CHAPTER 4

Models

Models can be a basis for experimental investigations at lower cost and in less time than trying changes in actual systems. Social science models need to be models of systems, not merely of isolated components of an information-feedback system. Our descriptive knowledge provides a wealth of material from which to formulate dynamic models.

MODELS have become widely accepted as a means for studying complex phenomena. A model is a substitute for some real equipment or system. The value of a model arises from its improving our understanding of obscure behavior characteristics more effectively than could be done by observing the real system. A model, compared to the real system it represents, can yield information at lower cost. Knowledge can be obtained more quickly and for conditions not observable in real life.

4.1 Classification of Models

Models might be classified in many ways. Figure 4-1 shows models subdivided into the categories of interest here.

Physical or Abstract. First, models can be distinguished as being either physical models or abstract models.

Physical models are the most easily understood. They are usually physical replicas, often on a reduced scale, of objects under study. Static physical models, such as architectural models, help us to visualize floor plans and space relationships. Dynamic physical models are used as in wind tunnels to show the aerodynamic characteristics of proposed aircraft designs.

An abstract model is one in which symbols, rather than physical devices, constitute the model. The abstract model is much more common than the physical model but is less often recognized for what it is. The symbolism used

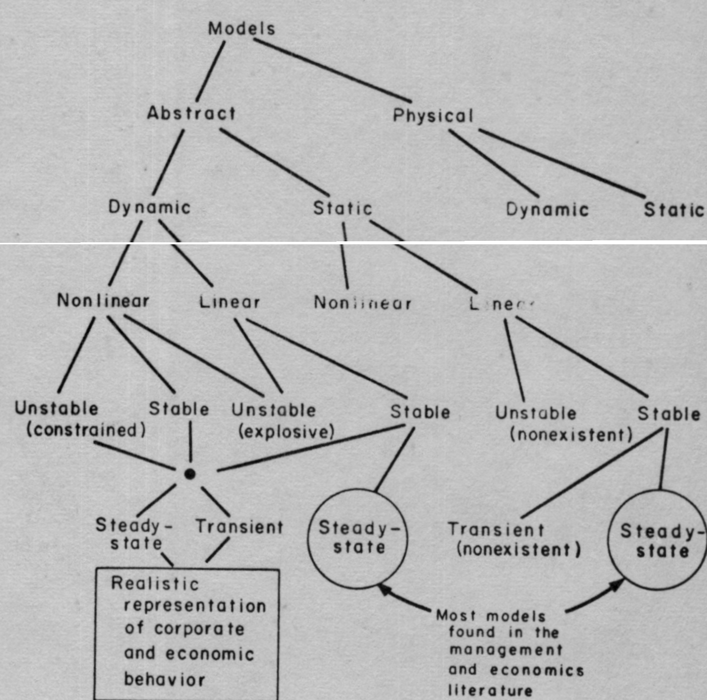

Figure 4-1 Classification of models.

can be a written language or a thought process.

A mental image or a verbal description in English can form a model of corporate organization and its processes. The manager deals continuously with these mental and verbal models of the corporation. They are not the real corporation. They are not necessarily correct. They are models to substitute in our thinking for the real system that is being represented.

A mathematical model is a special subdivision of abstract models. The mathematical model is written in the "language" of mathematical symbols. A mathematical model, like other abstract models, is a *description* of the system it represents. Mathematical models are in common use but are less easy to comprehend than physical models and are less frequent in everyday life than verbal models. An equation relating the lengths and weights on each side of a playground seesaw is a static mathematical model. The equations for stress in a structure make up a static mathematical model of the girders and supports. The equations of motion of the planets around the sun form a dynamic mathematical model of the solar system.

Mathematical notation is a more specific language than English. It is less ambiguous. A mathematical model is therefore a description having greater clarity than most verbal models. In model building, we start with a verbal model and then refine it until it can be translated into mathematical language. The translation is not inherently difficult. The problems in going from the verbal to mathematical statements arise when the initial verbal model is not an adequate description, and the shortcomings of the verbal model are revealed in the attempt to translate.

The mathematical model is valuable because it can be manipulated more easily than verbal or physical models. Its logical structure is more explicit. It can be more readily used to trace assumptions to their resulting consequences.

Static or Dynamic. Models may or may not represent situations that change with time. A static model describes a relationship that does not vary with time. A dynamic model deals with time-varying interactions.

Linear or Nonlinear. Systems represented by a model may be "linear" or "nonlinear," and the models can be similarly classified.

In a linear system, external effects on the system are purely additive.[1] A linear representation of a factory would be one in which a doubling of the incoming-order rate would, at every future moment of time, produce exactly ten times the changes that would come from a 10% increase in orders. In such a factory model, production capacity limits would not be permissible; man-hour productivity would not decrease as employment began to crowd the available equipment; large changes in capacity would take no longer to accomplish than small changes. Labor, equipment, and materials would each make its own contribution to production rate entirely independently of the state of the other two, implying, for example, that labor and equipment could produce a product even if materials were zero. Linear models are adequate in much of the work in the physical sciences but fail to represent essential characteristics of industrial and social processes.

In obtaining explicit mathematical solutions, linear models are much simpler than nonlinear. With negligible exceptions, mathematical analysis is unable to deal with the general solutions to nonlinear systems. As a consequence, linear models have often been used to approximate phenomena that are admittedly nonlinear.

[1]A linear model is one in which the concept of "superposition" holds. In a linear system the response to every disturbance runs its course independently of preceding or succeeding inputs to the system; the total result is no more nor less than the sum of the separate components of system response. The response to an input is independent of when the input occurs in the case of a linear system with constant coefficients (not for a linear system having time-varying coefficients). Only damped or sustained oscillations can exist in an actual linear system; an oscillation that grows is not bounded and must become explosively larger. These are not descriptions of real industrial and economic systems. Nonlinear phenomena are the causes of much of the system behavior that we shall wish to study.

As a result, the nonlinear characteristics have been lost.[2]

When we no longer insist that we must obtain a general solution that describes, in one neat package, all possible behavior characteristics of the system, the difference in difficulty between linear and nonlinear systems vanishes. Simulation methods that obtain only a particular solution to each separately specified set of circumstances can deal as readily with nonlinear as with linear systems.

Stable or Unstable. Dynamic models, in which conditions change with time, can be subdivided into stable and unstable models. Likewise, the actual systems they represent are characterized as being stable or unstable.

A stable system is one that tends to return to its initial condition after being disturbed. It may overshoot and oscillate (like a simple pendulum that is set in motion), but the disturbances decline and die out.

In an unstable system that starts at rest, an initial disturbance is amplified, leading to growth or to oscillations whose amplitude increases. A nonlinear system that is unstable under normal conditions can exhibit fluctuations that grow until restrained by the appearance of nonlinear influences (labor shortage, production capacity, declining availability of materials). The sustained fluctuation might then be thought of as having reached a stable amplitude of peak-and-valley excursion. Clearly, in economic systems, upper levels of activity are limited by resources, and the lower levels are at least bounded by zero activity.

The indications are that the industrial and economic systems of greatest interest will often be of this type wherein small disturbances grow in an unstable manner until restrained by nonlinearities.

Steady-State or Transient. Models (and systems) can be further subdivided according to whether their behavior is primarily steady-state or transient.

A steady-state pattern is one that is repetitive with time and in which the behavior in one time period is of the same nature as any other period. (For some purposes, a model of a nongrowing national economy that shows business-cycle patterns could be considered a steady-state fluctuation, even though never repeating identically any particular sequence of events. Likewise, the long, mature portion of a product life cycle, as now illustrated by automobiles, might be considered a steady-state dynamic model for the answering of certain questions.) In business systems, steady-state behavior is a restricted, special case. (The system discussed in Chapter 2 is a steady-state, dynamic model.)

Transient behavior describes those changes where the *character* of the system changes with time. A system that exhibits growth would show transient behavior. Transient responses are "one-time" phenomena that cannot repeat. Many of the important management problems are transient in character — company growth, new plant construction, and market development.

Open or Closed. In addition to the classification of Figure 4-1, models may be "open" or "closed." The distinction is not as sharp as the words would indicate. Different degrees of "openness" can exist.

The closed dynamic model is one that functions without connection to externally supplied (exogenous) variables that are generated outside the model. A closed model is one that internally generates the values of variables through time by the interaction of the variables, one on another. The closed model can exhibit interesting and informative behavior without receiving an input variable from an external source.[3]

Information-feedback systems are essentially

[2] For an interesting, descriptive, nonmathematical discussion of nonlinearity, see Reference 8.

[3] See Chapter 12 on exogenous inputs to models.

closed systems. They are self-regulating, and the characteristics of principal interest are those that arise from the internal structure and interactions rather than those responses that reflect merely the externally supplied inputs.

The models of interest to us here can be operated as closed systems. The internal dynamic interactions are of primary interest. We shall not always choose to study such models in completely closed form. It is often informative to depart from strictly closed operation enough to permit a test input that serves as excitation of the internal responses of the system. Impulses, steps, sinusoids, trends, and noise (random disturbances) are common test inputs. Such external (exogenous) inputs are valid only under conditions where we are willing to assume that the external inputs are themselves entirely independent of the resulting response within the system.

Models of Industrial Systems. Most of the mathematical models found thus far in the management and economics literature belong in one of the two circles in the figure. Nearly all are steady-state, stable, and linear. Some are static and some dynamic. The practical utility of these models in dealing with economic systems has not been notable. The models of industrial situations in the field of operations research have often repaid their cost manyfold, but even so they have not dealt with the major problems of corporate top management.

To deal with practical management and economic problems of pressing importance, a mathematical model must be able to include all of the categories leading to the square in Figure 4-1. Corporate management must cope with the transients of growth and the steady state of normal business fluctuation and uncertainty. Stable industrial systems may exist in mature product lines. Systems that are unstable and are restrained only by their nonlinearities are to be expected in capital goods industries, commodities, and probably in our economic system as a whole. The nonlinearities of maximum factory capacity, labor and credit shortage, and the dependence of decisions on complex relationships between variables, all compellingly insist on being included in a usefully realistic model of the industrial enterprise. Since time and changes with time are the essence of the manager's task, a useful model must be dynamic and capable of adequately generating its own evolution through time.

Consequently, we are speaking here of mathematical models that can be used to simulate the time-sequential operation of *dynamic* systems, *linear* or *nonlinear, stable* or *unstable, steady-state* or *transient*. The model must be able to accept our descriptions of *organizational form, policy,* and the *tangible* and *intangible* factors that determine how the system evolves with time. Such models will be far too complex (tens, hundreds, or thousands of variables) to yield analytical solutions. In fact, for nonlinear systems modern mathematics can achieve analytical solutions to only the most trivial of problems. The models considered here are instead to be used to simulate (that is, to trace through time) a particular course of action that results from a specific set of starting conditions coupled with one specific combination of noise and other inputs which are introduced. This is an experimental, empirical approach in search of better knowledge, and thereby better results, but not promising "optimum" solutions to any question.

In the management science and economics literature, the term "mathematical model" has customarily been used to mean any mathematical relationship between the inputs and the output of a part of a system. In the terminology of engineering systems, this output reaction of a system component to one or more inputs is commonly called a "transfer function." The transfer function specifies how conditions at the input will be transferred to the output. In this text, a simple mathematical relationship describing the response of a component of the system to its immediate environment will not be called a "model" but instead will be referred to synonymously as "transfer function," "functional relation," "decision equation," or "rate equation." In contrast, a "model" defines a system consisting of an interacting set of "decision equations."

4.2 Models in the Physical Sciences, Engineering, and the Social Sciences

Mathematical models in the social sciences have often been compared with the simple models in the physical and biological sciences. This may have been misleading.

Useful models of the solar system, the atom, Newton's laws of motion, and heredity are much simpler than models that will be helpful in industrial and economic systems. Linear analysis is much more widely applicable in such physical science systems. Most physical science systems that have been represented by successful models have contained much smaller amounts of noise (uncertainty) than in our social systems. Physical science models have been deduced to explain phenomena that can be observed but usually not altered. Statistical inference methods that succeed in relating unidirectional cause and effect in biological heredity are not necessarily sound in studying social systems where effect reacts on cause.

The attitudes toward the source and purpose of physical science and social science models have been similar, to the detriment of progress in models of social systems.

Models in the engineering and military worlds are so different in degree from the physical science models that we can fairly say they differ in principle. They arise in a different way, to be used for a different purpose.

Models in engineering and military usage provide a much better precedent for the social sciences than do physical science and biology models. Economics and management, like engineering, deal with aggregate systems above the level of the individual elementary events that are the subject of many physical science models. Unlike systems that are commonly modeled in the physical sciences, engineering systems have complexity approaching the complexity of social systems. Both engineering and social systems have a continuous gradation (from the obviously important, through the doubtful, into the negligible) of influences that affect each action and decision; by contrast, the physical science systems have often been different, with a substantial gap in importance between the few factors that must be included in a model and nearly insignificant ones that can be omitted. Social systems are strongly characterized by their closed-loop (information-feedback) structure, like many engineering systems that have been modeled but unlike most models in the basic physical sciences. In models of social systems, as in engineering but unlike simple physical science models, we must be interested in transient, noncyclic, nonrepeating phenomena.

Dynamic models have proved indispensable in designing physical systems. They are used in aircraft engineering, the planning of military command systems, and in studying communications networks. They have included both equipment and people; therefore, they take on aspects of social systems. Today's advanced technology would be impossible without the knowledge that has resulted from mathematical models.

The same cannot be said for the impact of mathematical models on business and economic decisions. Economic models have enjoyed a long history of research but little general acceptance as a tool to aid top management of a company or a country.

Many of the past failures in economic model building can be traced to unsound methods and to attempts to reach unachievable objectives. We need new attitudes toward the construction and use of models of social systems.

Objectives. The past contrast in usefulness between engineering and economic dynamic models can be partly traced to the way the tools of model building have been employed. The difference between the two uses of models seems to arise from a different emphasis on end objective. In engineering, models have been used for *designing* new systems; in economics, a common use is to *explain* existing systems. A model that is useful for design must also explain. But it appears that models that have been undertaken only for explanation have often had their goals set so low that they fail not only for design but also for their explanatory purposes.

Basis for a Model. In engineering systems, models have been built upward from available knowledge about the separate components. Designing a system model upward from identifiable and observable pieces is a sound procedure with a history of success.

In economics, models have often been constructed working backward from observed total-system results. Even as a theoretical goal, there is no evident reason to believe that the inverse process of going from total-system behavior to the characteristics of the parts is possible in the kinds of complicated, noisy systems that are encountered in business and economics.

The attempt merely to reproduce an existing economic system in a model has led to models that are statistically derived from observed time series of past behavior. It is most unlikely that the internal causal mechanisms of a complex, nonlinear information-feedback system can be derived from a sequence of external observations of its normal performance. By contrast, the use of models for the *design* of physical systems has emphasized models of systems that do not yet exist, models that could not possibly be constructed backward from observed results. A wind-tunnel model of an airplane is not constructed to reproduce merely observable overall behavior of a known airplane; it is not designed merely to match the aggregate average of all airplanes designed in the past. It is designed part by part to represent a proposed new aircraft so that the interaction of the parts and the performance of the airplane as a whole can be studied.

In formulating a model of a system, we should rely less exclusively on statistics and formal data and make better use of our vast store of descriptive information.

Validity of a Model. The test of the *adequacy* of a model also differs between engineering and economic usage. In technical and military circles, models have been judged by their ability to exhibit the dynamic characteristics of systems such as amplification, bandwidth,[4] and transient response. In economics, models have often been judged by their ability to predict the *specific state* of the system at some future time; and the models have customarily failed to pass this prediction test.

In using a model, we should look less for prediction of *specific actions* in the future and more for enhancing our understanding of the inherent *characteristics* of the system. There seem to be good reasons why models cannot be expected to predict specific system condition far enough into the future to be particularly significant. If so, prediction of a specific sequence of actions is not a useful test of a model.[5] Instead a model should be judged by its ability to reproduce or to predict the *behavior characteristics* of the system — stability, oscillation, growth, average periods between peaks, general time relationships between changing variables, and tendency to amplify or attenuate externally imposed disturbances.

Similarity of Model and System. In engineering, mathematical models have shown a greater correspondence to the structural and operational details of the real systems they represent than appears in the classical economic models. The communications barrier has been nearly impenetrable between the mathematical models in the social sciences, and the industrial and governmental executives. This is accentuated because models of social systems, unlike models of physical systems, have not been cast in the terms commonly employed by the active prac-

[4] An indication of the resistance to disturbance of any existing trends and cycles.

[5] See Chapter 13 on model validity and also Appendix K.

titioners of the art. The difference in terminology may arise from the differing initial viewpoint. The manager deals with the components of his organization just as the engineer does with the components of his airplane; the manager does not use abstract coefficients that cannot be tied to specific sources in the real system. The modelmaker, who derives relationships from statistical analysis, is apt to leave his coefficients as abstract, empirical results that are not identified with particular features of the real system.

In the chapters that follow, we shall attempt to make every variable and every constant have individual significance in the context of everyday managerial practice. It should be possible to discuss the individual plausibility of the value of any constant because that constant will, in its own right, have physical or conceptual meaning.

4.3 Models for Controlled Experiments

The mathematical model makes controlled experiments possible. The effects of different assumptions and environmental factors can be tested. In the model system, unlike real systems, the effect of changing one factor can be observed while all other factors are held unchanged. Such experimentation will yield new insights into the characteristics of the system that the model represents. By using a model of a complex system, more can be learned about internal interactions than would ever be possible through manipulation of the real system. Internally, the model provides complete control of the system organizational structure, its policies, and its sensitivities to various events. Externally, a wider range of circumstances can be generated than are apt to be observable in real life.

In the model, observations can be made of variables that are unmeasurable in the real system. An adequate model must include any "intangibles" that we believe contribute importantly to the behavior being studied. In the model, the intangibles, and our assumptions about them, become tangible and observable. We then have a means for tracing the implications of our assumptions.

4.4 Mechanizing the Model

A dynamic mathematical model is a description of how to generate the actions that are to be taken progressively through time. To be useful, the model must be mechanized by providing some way of carrying out the specified actions.

The actions called for by the model could be executed by a group of people playing the separate parts of the real system that is being simulated. Decisions and actions would generate results that would in turn become the inputs for the decisions and actions that follow. Such simulation, using groups of people, has been employed in studies of real systems. It is a good technique for classroom demonstration of basic principles. For the study of large systems it is burdensome and expensive.

A digital computer can be instructed to execute the same procedures that would be followed by the group. The cost is less than one-thousandth of the cost of the same clerical operations executed by a group of persons. The task is ideally suited to the unique characteristics of the electronic digital computer.

4.5 Scope of Models

In recent years it has become possible to formulate dynamic models of industrial behavior with sufficient reality to cope with the interactions of production, distribution, advertising, research, investment, and the consumer market. Within such a formulation, both physical and psychological factors can be included. Model-building technique and computational cost no longer limit the systems that can be studied. Instead, progress will be set by the rate at which our knowledge of the industrial world can be sifted, refined, and reorganized into an explicit form.

The immediate goal is to take our literature and knowledge of "descriptive management" and "descriptive economics" and formalize what we believe about the separate parts. It then will become possible to improve our understanding of how these parts interact. In discussing the formulation of dynamic models, no distinction is made in this book between corporations, industries, and complete economies. There should be no difference in approach or arbitrary distinction between microeconomics and macroeconomics. The same principles control. The same theoretical considerations will guide the way in which aggregation can be accomplished. The opportunities for improving our understanding are similar, with the same restrictions on achievable objectives. The comments in this book are intended to apply equally at all levels, from dynamic behavior of the individual firm to international economics.

4.6 Objectives in Using Mathematical Models

A mathematical model of an industrial enterprise should aid in understanding that enterprise. It should be a useful guide to judgment and intuitive decisions. It should help establish desirable policies. Using a model implies the following:

- We have some knowledge about the detailed characteristics of the system.
- These known and assumed facts interact to influence the way in which the system will evolve with time.
- Our intuitive ability to visualize the interaction of the parts is less reliable than our knowledge of the parts individually.
- By constructing the model and watching the interplay of the factors within it, we shall come to a better understanding of the system with which we are dealing.

These assumptions form the same basis on which we construct models of floor plans and of equipment. The model of a company is justified to the extent that it will allow us to manage the company better. There is no implication that the results need be perfect to be beneficial. A model can be useful in determining the degree to which the industrial system is sensitive to changes in a policy or in system structure. It can help determine the relative value of information of differing kind, accuracy, and timeliness. It can show the extent to which the system amplifies or attenuates disturbances impressed by the outside environment. It is a tool for determining vulnerability to fluctuation, overexpansion, and collapse. A model can point the way to policies that yield more favorable performance. In short, mathematical models should serve as tools for "enterprise engineering," that is, for the design of an industrial organization to meet better the desired objectives.

The preceding comments imply that a useful model of a real system should be able to represent the *nature* of the system; it should show how changes in policies or structure will produce better or worse behavior. It should show the kinds of external disturbance to which the system is vulnerable. It is a guide to improving management effectiveness.

But note especially that quantitative prediction of *specific events* at *particular future times* has not been included in the objectives of a model. It has often been erroneously taken as self-evident that a useful dynamic model must forecast the specific condition of the system at some future time.[6] This may be desirable, but the usefulness of models need not rest on their ability to predict a specific path in the future. This is fortunate because there is ample reason to believe that such a prediction will not be achieved in the foreseeable future.[7]

[6] Least-squares tests of the period-by-period differences between model variables and real-system variables imply such an expectation that the model should predict the specific future configuration of the system. See Chapter 13 on model validity.

[7] See Appendix K for an example of system *nature* versus future system *condition* prediction.

4.7 Sources of Information for Constructing Models

Many persons discount the potential utility of models of industrial operations on the assumption that we lack adequate data on which to base a model. They believe that the first step must be extensive collecting of statistical data. Exactly the reverse is true.

We usually start already equipped with enough descriptive information to begin the construction of a highly useful model. A model should come first. And one of the first uses of the model should be to determine what formal data need to be collected. We see all around us the laborious collection of data whose value does not equal the cost. At the same time highly crucial and easily available information is neither sought nor used.

The routine, clerical collection of numerical data is unlikely to expose new concepts or previously unknown but significant variables. Extensive data collecting is not apt to shed new light on the *general nature* of the variables. Some of the most important sources for a realistic dynamic model do not exist as "data" in the usual sense of tabulated statistical information.

What is the relative importance of the many different variables? How accurately is the information needed? What will be the consequences of incorrect data? These questions should be answered before much time or money is expended in data gathering.

Actually we use models of corporate and economic systems continuously with only the data that we have at hand. A word picture or description is a model; our mental picture of how the organization functions is a model. A verbal model and a mathematical model are close kin. Both are abstract descriptions of the real system. The mathematical model is the more orderly; it tends to dispel the hazy inconsistencies that can exist in a verbal description. The mathematical model is more "precise." By precise is meant "specific," "sharply defined," and "not vague." The mathematical model is not necessarily more "accurate" than the verbal model, where by accuracy we mean the degree of correspondence to the real world. A mathematical model could "precisely" represent our verbal description and yet be totally "inaccurate."

Much of the value of the mathematical model comes from its "precision" and not from its "accuracy." The act of constructing a mathematical model enforces precision. It requires a specific statement of what we mean. Constructing a model implies nothing one way or the other about the accuracy of what is being precisely stated.

There seems to be a general misunderstanding to the effect that a mathematical model cannot be undertaken until every constant and functional relationship is known to high accuracy. This often leads to the omission of admittedly highly significant factors (most of the "intangible" influences on decisions) because these are unmeasured or unmeasurable. To omit such variables is equivalent to saying they have zero effect — probably the only value that is known to be wrong!

Different attitudes toward data and their accuracy can be traced to the different goals and objectives of models already discussed.

If the only useful and acceptable model is one that fully explains the real system and predicts its specific future condition, then precision is not sufficient; it must also be accurate. Lacking such accuracy, the endeavor flounders.

If, on the other hand, our objective is to enhance understanding and to clarify our thinking about the system, a model can be useful if it represents only what we *believe* to be the nature of the system under study. Such a model will impart precision to our thinking; vagueness must be eliminated in the process of constructing a mathematical model; we are forced to commit ourselves on what we believe is the relative importance of various factors. We shall discover inconsistencies in our basic assumptions. We shall often find that our assumptions about the separate components cannot lead to our expected consequences. Our verbal model, when converted to precise mathematical form, may be inconsistent with the *qualitative* nature of the real world we observe around us. We may find that cherished prejudicies cannot, by any plausible combination of assumptions, be shown to have validity. Through any of these we learn.

In these ways we use a model as does the engineer or military strategist. What would the situation be like if the real system corresponds to our basic assumptions? What would a *proposed* system be like if we designed it to agree with the model? What changes in the model would give it more nearly the characteristics of the existing system that it presumably represents? These are questions that can be asked of a closed, or closable, model and are significant when the system is so complex that the correct answers are not evident by inspection.

A model must start with a "structure," meaning the general nature of the interrelationships within it. Assumptions about structure must be made before we can collect data from the real system. Having a reasonable structure that fits our descriptive knowledge of the system, we can take the next step and assign plausible numerical values to coefficients, since the coefficients should represent identifiable and describable characteristics of the real system. We can then proceed to alter the model and the real system to eliminate disagreement and move both toward a more desirable level of performance.

This is the attitude of the manager toward the verbal image that he uses as a model of the company he directs. He strives to grasp the implications of the separate factors he observes about him. He attempts to relate individual policies and characteristics of the system to the consequences that they imply. He tries to estimate the result of changing those parts of the system over which he has control.

As a model is detailed toward an approximation of a real or proposed system, we can use the model itself to study the significance of various assumptions that have gone into it. With respect to every numerical value that we have been forced to estimate arbitrarily, there is some range within which we are practically certain that the "true" value must fall. It will often happen that the model is relatively insensitive to changes in value within this range; refining our estimate would then be unjustified.[8]

On the other hand, the entire qualitative behavior of the system may depend significantly on some different numerical value that has been assumed.[9] We are then alerted to the critical nature of this assumption. When the vulnerability to an error in numerical value is demonstrated, we must then choose between

- Measuring the value with adequate accuracy
- Controlling the value to a desired range
- Redesigning the system and the model to make the value less important

A mathematical model should be based on the best information that is readily available, but the design of a model should not be postponed until all pertinent parameters have been accurately measured. That day will never come. Values should be estimated where necessary, so that we can get on with the many things that can be learned while data gathering is proceeding. In general sufficient information exists in the descriptive knowledge possessed by the active practitioners of the management and economics arts to serve the model builder in all his initial efforts. He will find that he is more in danger from being insensitive to and unperceiving of important variables than from lack of information, once the variables have been exposed and defined. Searching questions, asked at points throughout the organization under study by one skilled in knowing what is critical in system

[8] See Figure 2-6 on the system insensitivity to clerical delays.

[9] See Figure 2-8 showing sensitivity to rapidity of inventory adjustment.

dynamics, can divulge far more useful information than is apt to exist in recorded data.

These comments are not to discourage the proper use of the data that are available nor the making of measurements that are shown to be justified; they are to challenge the common opinion that measurement comes first and foremost. Lord Kelvin's famed quotation, that we do not really understand until we can measure, still stands. But before we measure, we should name the quantity, select a scale of measurement, and in the interests of efficiency we should have a reason for wanting to know. Even in the context of basic research that is presumed to seek information for its own sake, the world has limited resources, and the researcher should have conviction that his investigation promises a high probability of important results.

To some, this attitude toward the data on which to base a model will seem highhanded and will be repugnant. To others, it will seem the practical and necessary avenue along which to attack a difficult problem.

One important use for a model is to explore system behavior outside the normal and historical ranges of operation. These ranges will be outside the region of any data that could have been collected in the past. We are dependent on our insight into the separate parts of the system to establish how they would respond to new circumstances. Fortunately, this is usually possible. In fact, we may be more certain about the extreme limiting circumstances of human behavior, the likely decisions, and the technological nature of production and inventories than we are about the "normal" range. These limiting conditions are part of our body of descriptive knowledge. Incorporating the full possible range of functional relationships in a model makes it feasible to study wider ranges of system operation. It also improves the accuracy of model representation over normal ranges because incorporating the known extreme values helps to bound and determine many characteristics in the normal ranges.

Useful results can be expected from models constructed as herein discussed — by building upward from the characteristics of the separate components and by incorporating and estimating the values of all factors that our descriptive familiarity with the system tells us are important. Such models will communicate easily with the practicing manager because they arise from the same sources and in the same terminology as his own experience.