WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

TOWARD A BETTER UNDERSTANDING OF SOCIAL SYSTEMS

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June 1974 714-74

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INTRODUCTION

This paper attempts to outline a few improvements I feel we must make in the way we think about and attempt to manage our social systems. Social problems, defined broadly, are the problems of people acting in groups. Social problems occur at many different levels--from the interaction of members of a family or the management of a production line, to the behavior of our national economy or the evolution of our values, our culture and our civilization. Although the problems encountered at each level can be very different, the lack of insight and understanding we have had at all levels has been due in general to the same reasons. So although I here have time to discuss only a few of the myriad of possible social questions, much of what is said I think can be applied equally well to the analysis of most of our many other economic and social problems.

In general outline, this paper (1) summarizes a number of what are currently thought to be our most important national problems and policy issues; (2) explains why attempts to deal with such problems in the past have often met with failure; (3) outlines in general terms what it is we must do differently if we are to have any hope of explaining and dealing more adequately with such problems; and (4) discusses the importance and the role of models in the understanding of behavior and the design of social systems. I then illustrate many of the previous points with an example of a simple policy model, and attempt to show that it indeed is possible to model social problems in a way that achieves useful results. The paper concludes with a few philosophical comments on the role of models in the explanation of social behavior and the design of better social systems.

THE PROBLEMS

The goals and concerns of a nation change and develop over time. At its present stage in history, our nation seems to be turning its attention back from global problems to a greater relative emphasis on its own internal affairs. These internal concerns no longer are those of building a new nation based on democracy and individual freedom. Or of conquering the wilderness and building a mammoth economy to provide a wealth of goods, comforts, education, and leisure. Our concerns today are not so much those of attaining wealth and affluence as they are of retaining them, learning to live with them, and sharing them more equitably.

We now face a diminished competitive position in the world economy. Productivity is growing more slowly here than elsewhere. Domestic reserves of important resources are running short and we increasingly find it necessary to depend more and more on imports. Our industries face difficult competition in areas that until recently we dominated. Wages and prices continue to rise rapidly and we have had continuing deficits in our balance of payments.

Technology and economic growth in spite of all they have provided have not been universally beneficent. Our air, our streams, and even the oceans are becoming fouled with noxious wastes. Many forms of non-human life are becoming extinct. Rich farm land is being paved over for so-called development. Workers increasingly find their jobs boring and dissatisfying. Turnover and absenteeism have risen sharply. Suspicion and distrust warp and debilitate relations between labor and management, between government and the public and the news media. In general there is a growing distrust of all

authority and loss of faith in our institutions. Our lives have become isolated, impersonal, and lonely. Many groups feel oppressed and alienated, even those who traditionally have been thought of as privileged. Fraud, theft, drugs, and violent crime have come increasingly to dominate our lives. We have unprecedented wealth but much poverty. Agricultural efficiency and output are unparalleled, as small farmers go under and small towns die. Wages skyrocket while many can find no work. Ninety-nine percent of our children receive at least three years of education and eighty percent graduate from high school, but the welfare roles grow endlessly.

The present conditions of our society have been created by our own past actions. And the future also will be determined, within the constraints of natural forces, by our own present and future actions. And we know that the effectiveness of any action, as in trying to stop a fast moving train, will depend on how far in advance we are able to anticipate the need. But to achieve a more desirable future, or to prevent a worse one, what are the actions that we must now take? Can we save our air, water, wildlife, our forests and farmland, and our tranquility without retarding growth and causing massive unemployment? What would be the impact on energy supply, economic growth, environment and quality of life from possible changes in governmental policies--such as regulation of prices and rates of return, depletion allowance and other tax policies, import and export controls, antitrust policy, standards of environmental pollution abatement, and energy conservation policies? Will more education and job training help the poor to find satisfactory jobs? Can we create jobs without causing high rates of inflation? What are the proper fiscal and monetary controls for guiding the level of economic activity? Should we provide huge sub-

sidies for mass transit systems? Continue building high rise structures? Ban the automobile? Attempt to regulate urban sprawl? Are our present welfare programs reducing poverty or are they creating it? Should we be more strict at apprehending and punishing criminals? What can we do in the way of criminal rehabilitation? Will rehabilitation programs solve the crime problem?

These are a few of the many questions facing us as we attempt to decide what we should do to influence the future. The greatest difficulty we face is that most of these problems are not independent of one another so that a successful solution to one often has important side effects on others--some foreseen but many unfortunately not. This is the nightmare of the public decision maker. A program that looks good for one problem in isolation may, as second and third order effects percolate around the system, end up a disaster. Even in those rare areas where we correctly understand the individual influences and processes involved, interaction with other parts of the system can often produce results that are entirely unexpected. Many of our recent federal programs, for instance, such as foreign aid and the war on poverty, have not had the effects that were originally intended. Subsidised housing programs have been an unmitigated disaster. Recent federal air quality standards were set without full comprehension of the influence they would have on the consumption of scarce energy resources. The interstate highway program was conceived with little or no consideration of the ramifications it could have on residential and industrial location patterns and how this might effect the welfare and economic viability of cities. And no one adequately foresaw the impact that the automobile and increased mobility might have on social values and the breakdown of family and community cohesiveness.

So long as we are unaware of these important interrelations, we will continue to pursue independent and piecemeal policies and programs that will conflict, obviate the effects of one another, and more likely than not cause trouble somewhere else. We all pay lip service to the need for coordinated and comprehensive planning. But unfortunately the mere existence of planning does not guarantee success, and in fact can often lead to worse problems than we would have had without it. The complex interdependence of the many economic, social, and demographic processes at work in a society make it exceedingly difficult for any of us to determine which policies will best achieve our goals--or in many cases even to know whether a given policy would be beneficial, detrimental, or simply worthless.

At the present time, we have very little understanding of the behavior of most of our social systems. And in fact it seems likely that most of the "conventional wisdom" about the behavior of these social systems is incorrect or misleading. We have often been misled because we have failed to adequately account for the multiple interdependence between different parts of the system. In setting up a housing program, we have looked only at perceived housing needs. But have not accounted for the way these needs themselves depend on migration, which depends in turn on the amount of housing available. Or how available housing must depend on the number of jobs available, or so many of the other complex interdependencies that determine social and economic behavior.

Most of our ordinary experience with simple situations has led us to look for straightforward one-way cause-and-effect relationships, where the cause is both spacially and temporally proximate to its effects. In the complex structures that characterise our present social systems, however,

these primitive notions of cause-and-effect cease to be valid. Our social systems are complex structures composed of many mutual interdependencies, or feedback loops, where each element is both cause and effect. In interpersonal relations, my behavior toward you depends on how you have acted toward me, which depends on how I have responded to you, and so on. In business, more orders lead to higher backlogs, increased delivery delays, and eventually loss of customers to other suppliers, and hence to fewer orders. Or a company that is making high profits attracts competitors until the profit margin is forced down to the point where the industry is no more profitable than any other, and new competitors cease to enter. Other examples include the vicious cycles, such as the poverty-apathy cycle and the mutually supporting tendencies of inflation and inflationary expectations. And there are the self-enhancing processes such as economic growth, where increased production leads to increased income and investment, which still further increases production. It is this closed loop structure of mutual causal relations that provides the most interesting and important as well as the most difficult problems for our understanding of social and economic behavior. In such an interdependent system it obviously is impossible to point to any one quantity as the cause and to others as effects. They are all both cause and effect. It therefore must be the type of structure whereby these quantities are related, rather than the present value of any one of them, that has to be studied if we hope to make improvement.

By a "Social System", we mean the interacting people, technology, natural forces, laws, and ethical values that determine the evolution of a culture or civilization. The behavior of a social system depends on its structure and on the policies that govern decision making. By <u>structure</u>,

we mean both the interrelationships between the basic components of the system and the channels of information that are available to each decision-making point. By <u>policy</u>, we mean the criteria by which the information available to a decision point is filtered, selected, and used to determine the actions taken at that decision point. Policy includes all of the criteria and rationale that influence how decisions are reached--experience, prejudice, folklore, ethics, religious attitudes, integrity, generosity, loyalty, self-interest, and fear. In other words, all of both our explicit as well as our implicit value structures.

The information and policy structures that determine the behavior of our social systems have been created by man, and they can be changed. But how can we know which changes are the right ones, unless we first have correctly identified the policies that have caused the problems in the first place--and unless, secondly, we have been able to correctly trace the behavioral implications of the alternative policies that are being proposed? One can correctly address problems in a social system only if we first have identified the dynamic structures that are the true determinants of behavior. It is a serious mistake to attempt a solution without having first established what it is that has really caused the problem. This is more likely than not to lead to the treatment of symptoms--with results that are useless or even harmful. If we do not properly understand the structural causes, it can easily happen and often does that we can become entrapped in a vicious cycle, where we are faced with a problem and attempt the "obvious" solution. This obvious solution in fact makes the problem worse, but we do not know it. We think the deteriorating situation is in spite of our valiant efforts, whereas in fact it is because of them. Not knowing this, however, we re-

double our effort, applying the obvious solution with even more vigor, making the problem still worse, and so on.

Instead of first trying to relieve the most obvious symptoms, we must begin by establishing a model of the structure and relationships that interact to produce the problem in the first place. One must first replicate the system that generates the symptoms. Only then can we begin to have any confidence that we in fact understand the true causes. And it is only after we understand the real causes of behavior that we can be assured any degree of success in designing revised policies that have any hope of solving our many complex social and economic problems.

MODELS

The way we think about the world always involves some form of abstraction, simplification, mental structuring, and organization. Understanding must always involve abstraction and simplification. Our minds do not contain small exact reproductions or even images of the world, but rather concepts that filter, structure, and organize our thinking. These conceptual structures dictate how we perceive the world, and influence the way we act or react toward our physical and social environment. They are in some sense prior to and dictate our experience. Without some prior mental structure, our experience could be nothing but a booming buzzing confusion. We could never remember or learn from our experience. We could not interrelate facts and observations. We could never use the past to educate for the future.

Coherent conceptual schemes that are organized so that they seem to explain why such-and-such is or is not, or why such-and-such happens or does not, and which are communicated, discussed, and argued about publicly,

are called theories. Theories can be explicated or formalized in terms of what we call a model. A model is simply something that stands in place of something else. It is a surrogate used for some purpose to substitute for the real thing. In this sense all of our mental structures and theories are what we would call models. They stand for, or at least purport to stand for or in place of, certain aspects of things we are trying to understand. There are many different kinds of models. Model ships and model airplanes. Dolls and most children's toys are models. Architects build models to help them visualize the spacial relationships of a building. A city map is a more abstract spacial model that allows us to compare alternate routes without actually traveling them. Science has always used models extensively--models for instance of the atom and of the solar system. Engineers build models to help plan the design of bridges, airplanes, chemical plants and so many other of the important artifacts of our civilization.

A model is never an exact duplicate of the thing it represents. A model airplane or an architect's model may have the same shape and proportions as the real airplane or building. But it is much smaller, does not have the same weight, and is not constructed from the same materials. The model is always similar in some respects to the thing it represents, but also different in others. These differences are what make the model useful. The model is much easier to build and carry around and change than is the real airplane or building. And being simpler, the model allows us to visualize more clearly particular features that may be of special significance. But this also means that the model, while very useful for understanding certain aspects of the real thing, is not at all useful for understanding others. The architect's model allows us to correctly visualize

the spacial relationships of a building. But it does not tell us if the building will sag, or sink, or be blown over in a high wind. To answer these questions, we need different models of the building--the mathematical stress models built and analysed by the construction engineer.

Models can take the form of physical representations or they may be symbolic and abstract. 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 often is not recognized for what it is. The symbolism used can be written language or a thought process. A mental structure or verbal description can describe a corporate organization. Such a description is a model of that organization. The manager deals continuously with these mental and verbal models. They are not the real corporation, and are not necessarily correct. They are models to substitute in his thinking for the real system they represent.

A mathematical model is a special type of abstract model, composed of mathematical rather than verbal symbols. Mathematical models are in common use but are less familiar and less easy to comprehend than physical models, and not so common to everyday life as are verbal models. An equation relating the lengths and weights on each side of a lever or a playground seesaw is a static mathematical model. The equations of stress in the girders and supports of a bridge constitute a static mathematical model for studying the strength of the structure. The equations of motion of the planets around the sun form a dynamic mathematical model of the solar system.

A mathematical model is more specific and less ambiguous than a verbal model. And it can be communicated and understood more clearly. A crucial advantage of the mathematical model is that its logical structure is much

more explicit. It allows us to see new relations we had not previously thought about, as well as gaps in the structure that we might otherwise have missed. But one cannot build a good mathematical model without first having a good verbal model to start from. We must always start with a verbal model and then refine it until it can be translated into mathematical symbolism. This translation is not itself inherently difficult. The difficulties that arise in going from a verbal to a mathematical model are due to the fact that the verbal model is itself usually not an adequate description. And the shortcomings of the verbal model are revealed in the attempt to translate it into a mathematical model. Thus the process of translating a verbal into a mathematical model forces a clarity and precision of thinking that we would not otherwise achieve. The mathematical model is more precise than a verbal model but not necessarily more accurate. It guarantees nothing one way or the other about the accuracy of what is being precisely stated. Beyond the increased precision and the explication of logical structure, the mathematical model also is valuable because it can be manipulated in ways that often can provide additional insight. And it can be more readily used to unambiguously trace assumptions to their resulting consequences.

In addition, a dynamic model can be experimented with in ways that can improve our understanding of obscure relationships and behavior characteristics more effectively than could ever be done by observing or experimenting with the real system. A well formulated dynamic model can make controlled experiments possible on systems with which it would be impossible or undesirable to experiment in real life. Simulation models for instance were used by Apollo engineers to test the behavior of guid-

ance systems before they were ever put to test in actual flight. Failures that otherwise would have caused the loss of multimillion-dollar rockets and spacecraft and the lives of crew were detected by simulation models and corrected. These same models also facilitated the evaluation of alternative strategies when unexpected failures during flight presented novel difficulties in situations where there was little or no margin for error.

Models allow the effect of different assumptions, designs, policies, and environmental factors to be tested. In the model system, unlike the real system, the effect of changing one factor can be observed while all others are held unchanged. Such experimentation can yield new insights into the characteristics of the system the model represents. By using a model, more can be learned about the internal interactions of a complex system than is possible by manipulation of the real system. Internally, the model provides complete control of the organizational structure, its policies, and its sensitivities to various events. Externally, a wider range of circumstances can be generated than could ever be observed in real life.

Dynamic models have proved indispensible for designing engineering systems. They have been essential to the design of communication and power transmission networks, of airplanes and spacecraft, of chemical plants, nuclear power plants, and many other of the important artifacts of our technological civilization. Today's advanced technology would not be possible without the knowledge that has resulted from mathematical models. But the same cannot be said for the impact of mathematical models on business, economic, or social problems. Economic models have enjoyed a long history of research but little general acceptance as a tool to aid the top management of a company or of the nation.

There are several reasons why this has been so. First of all, economic research has too often concentrated on the mere collection of data and not enough on the development of good theory. Past experience has too often only underscored the proposition that unless research is coupled with a theoretical framework, it tends to go nowhere and produces nothing more than ephemeral results.

Secondly, whatever models or theories there have been, have generally been externalist in orientation and have tended to make unrealistic *ceteris paribus* assumptions and to look only at one-way cause-and-effect relationships. The social sciences too often have looked for causes that are *external* to the social unit under study, rather than to internally generated modes of behavior that are inherent in the structure of the system itself. This externalist orientation may be described as a form of radical environmentalism in the explanation of human affairs. Environmentalism attempts to explain behavior solely in terms of environmental conditions that lie entirely outside the system. These environmental forces are assumed to create, control, modify, or destroy the unit studied, with the system itself conceived as merely a passive foil or focal point for the application of these forces, having no inherent causes of change within itself.

The externalist orientation is especially influential in the wide current of reform and reconstructive movements that look for the "roots of evil" and for the "patented cure" of any social or cultural problem solely in the outside environment. The wrong-doing and cure of a criminal are regarded as due to the milieu and not inherent in the person himself. The root of defectiveness in a social institution--be it the family, the political or economic organization, or the society itself--is again looked

for, not in the policies of the institution itself, but solely in its environmental conditions. Changing these conditions is expected automatically to produce the desired change of the system itself.

This viewpoint at the present time dominates all of the social sciences. Although there are important exceptions, some of which we will mention later, the overwhelming majority of all historical, sociological, economic and other writings that attempt to explain social change, do so solely in terms of factors that are completely external to the unit studied. Almost all quantitative and statistical studies, for example, assume the "independent variable" to be external, and not influenced by the dependent variable. Another prime example is behaviorism. The stimulus-response type of analysis attempts to explain all behavior in terms of stimuli from the environment, with the stimulus always assumed external to the organism. The organism itself is considered as capable only of response--never as being the prime determinant of its own behavior. This environmentalist viewpoint pervades the social sciences today and determines the essential character of most research. It shapes techniques and procedures. It influences the activities of its practitioners in their thinking, research, and even daily affairs.

The problem with environmentalism is that it never really explains anything in a way that would allow us to do something about it. The environmentalist is correct when he says that his car engine boiled over because of the hot day and the slow traffic. But the difficulty with his statement is that it gives no prescription for fixing the problem or for preventing it from occurring the next time. We can do that only if we know about the internal functionings and workings of the engine itself.

The hot day may indeed have caused the boilover. But it need not have if the engine had been better designed or if we had had the proper thermostat or the right type or amount of coolant, or whatever. And it is here, rather than to the weather, that we must look if we want to improve behavior. Looking at problems in this way will certainly be more effective and should produce far fewer unexpected and undesirable side effects than, for instance, trying to modify weather patterns so as to prevent the occurrance of hot days.

It is not wrong to say that the behavior of a person, a family, a social or economic organization, or a society is importantly influenced by its environment. Quite the contrary. But it is woefully and misleadingly incomplete, because the environmental influences acting on a person or social organization are in general not independent of its own actions and choices. Personal behavior certainly is affected by the social environment. But also, most people to a large degree do choose and influence their own environment. Or, in terms of the folk wisdom that we too often ignore, "Birds of a feather flock together". Another example is that the health of a business enterprise certainly does depend critically on influences from the environment, such as sales. But are a firm's sales totally independent of its own internal policies? Or do they not depend importantly on advertising, product quality and availability, and the many other influences that are determined by policies from within the firm itself. A behavioral system is not adequately defined by what lies strictly within the boundaries of that organism or formal organization itself, but must be broad enough to include the mutually interacting influences that operate in both directions to link the organism, organization, economy or society with the particularly relevant aspedts of its environment.

Prediction

There also has been far too much emphasis on attempting point prediction rather than on understanding the basic causes of behavior. Most recent economic modeling studies, for instance, have attempted to predict without first understanding the inherent causes of system behavior. And they have not been notable for their success. The attempt to engage in point forecasting has led to the construction of open boundary models that are statistically derived from time series of past behavior. But such models ignore the basic structural causes of behavior and add little to our insight and understanding. We should be principally concerned, not with extrapolating past data in an attempt to reach an unachievable point forecast, but rather with explaining the internally generated behavior of social systems, and of predicting the nature of the effect that possible changes in policy structure could have for improving system behavior.

We can no more predict the point-by-point behavior of a social system than the aircraft designer can predict at each moment the exact flight path of his airplane. What the aircraft designer does try to predict is not exact flight paths, but rather the type of flight paths the airplane is capable of flying and the types of behavior that alternative designs of that plane will exhibit under particular conditions of normal flying and of stress. Is the plane more stable flying right side up than upside down? How slow can the plane fly before it stalls? Will the wings break off when coming out of a strong downdraft? The aircraft designer is not in the business of predicting downdrafts. But he is in the business of predicting how well his plane will behave in the event that it is caught in a downdraft. This is what we ought to attempt to do with our social systems. We should not attempt

the impossible task of predicting each unique event. But we should attempt to predict how different policies within a social system affect the way the system behaves, and the way it responds to different circumstances. This type of prediction requires much more than just simple correlation or extrapolation of the past. It requires a basic understanding of the reasons for the system's internally generated behavior and for the way it responds to external influences. This understanding can be achieved only by knowing the structures that determine how components of the system interact to create observed behavior.

A good model or theory can never predict exactly what will happen, but it can and should predict what cannot happen. The theory of thermodynamics tells us that we cannot build a perpetual motion machine. The laws of mechanics, although they will not predict exact flight paths, tell us that we cannot instantaneously reverse the direction of a fast flying airplane and we therefore should not try. Attempting to do so could well lead to disaster. Most importantly, these theories not only tell us that we cannot, but they tell us why we cannot. In the same way a good model or theory of a social system ought to tell us what we realistically can or cannot force that system to do and why.

Keynes

Many of these points are particularly well illustrated by one of the most significant exceptions to the general sterility of most social science research. This is Keynes' General Theory of Employment, Interest, and Money--one of the few successfully applied theories we have had to date in the social sciences, and certainly one of the most important. Keynes laid particular stress on the fact that one cannot validly analyse economic behavior by

choosing some quantities as dependent variables and others as given or independent variables, and then deriving behavioral or policy conclusions based on _ceteris paribus_ or independence assumptions about the values of the so-called independent variables, when in fact these quantities are importantly affected by the values of the quantities whose behavior one is attempting to influence or analyse.

It was a mistake of this variety, Keynes argued, that led economists into error when investigating the causes of aggregate unemployment. Prior to Keynes, according to the then existing economic theory, there could be no such thing as involuntary unemployment. According to the standard theory of supply and demand relationships, if aggregate demand for output were to fall from a high value to some lower level, the price of labor (the wage rate) would have to fall. This would have two effects. With the lower cost of labor, employers would find it profitable to hire more. And on the other side of the market, at the lower wage there would be fewer people willing to work. Equilibrium would be reached at the point where the positive sloping supply curve intersects the negative sloping demand curve. At this new lower level of aggregate demand, there would be less employment since there are fewer people willing to work at the lower wage. But any such unemployment would be purely voluntary. Economists argued that if there were involuntary unemployment, it must be caused by an intransigence of labor which prevented money wages from falling, and that if wages were only more flexible there would be no unemployment (other than during short periods of transient change).

The harsh realities of the 1930's prompted a few people such as Keynes to reassess the validity of this theory. Keynes argued that more flexible wages, rather than reducing unemployment, could well lead to even greater

unemployment. The existing theory, Keynes said, might be true in the case of a single industry, where the demand for output from that industry does not depend importantly on factors such as employment and wages that are determined within that industry itself. But it is erroneous to generalize these relationships to apply to the entire aggregate economy, where the demand for output is not independent, but rather depends importantly on aggregate income, which in turn depends on the level of employment and the wage rate.

> The more significant change, of which we have to take account, is the effect of changes in demand... It is on the side of demand that we have to introduce quite new ideas when we are dealing with demand as a whole and no longer with the demand for a single product taken in isolation, with demand as a whole assumed to be unchanged.*

Thus, says Keynes, to explain unemployment we must account for the interdependence of feedback influences that determine aggregate demand. Aggregate demand is the total of expenditures for consumption and for investment. Consumption is a determinant fraction of the aggregate income which, under conditions of constant wages and prices, is proportional to employment. And employment is determined by the amount of expected demand. Thus the consumption component of aggregate demand is determined within a positive feedback structure. Investment, the other component of aggregate demand, is a function of the value of the marginal efficiency of capital relative to the interest rate. And the marginal efficiency of capital depends primarily on the prospective yield which, for a given stock of capital equipment, is determined by the aggregate expectations of businessmen as to future revenues and the

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* John M. Keynes, The General Theory of Employment, Interest, and Money, Harcourt, Brace & World, 1936, pg. 294.

associated profits. This in turn depends on observations of past levels and growth rates of demand. So that investment also is determined within a positive feedback structure. Keynes then went on to analyze the relation between parameters within this feedback structure required to produce a level of aggregate demand sufficient to sustain full employment.

This is only a small portion of the total set of structures and arguments that make up Keynes' General Theory, but it is sufficient to illustrate our main point. The essence of Keynes' theory was that he removed an invalid ceteris paribus assumption by showing that aggregate demand could not be considered an independent variable, but rather was part of a dynamic feedback structure--an understanding of which was essential to a valid understanding of the causes of unemployment and of aggregate economic behavior. And it is this type of analysis that is required if we are to correctly understand and solve our numerous other economic and social problems.

Most research has paid lip service to the complex interdependencies that determine economic and social behavior. But, when actually doing the analysis, important dependencies have been ignored. Independence has been assumed in places where everyone knows the assumption to be false. And complicated dynamics have been assumed away in favor of simple algebraic equilibrium relations even though our economy and society are never in fact in equilibrium. This particularly has been a problem with the more mathematically oriented work in economics, most of which Keynes thinks is of little or negative value.

> It is a great fault of symbolic pseudo-mathematical methods of formalizing a system of economic analysis...that they expressly assume strict independence between the factors involved and lose all their cogency and authority if this hypothesis is disallowed; whereas, in ordinary discourse, where we are not blindly manipulating but know all the time what we are doing and what the words mean, we can keep "at the back of our heads" the necessary reserves and qualifications and the adjustments which we shall have to make later on, in a way in which we cannot keep complicated partial differentials "at the back" of several pages of algebra which assume that they all vanish. Too large a proportion of recent "mathematical" economics are mere concoctions, as imprecise as the initial assumptions they rest on, which allow the author to lose sight of the complexities and interdependencies of the real world in a maze of pretentious and unhelpful symbols.*

It to me is one of the great ironies in the history of science that the standard neo-classical interpretation of Keynes found in most economic texts, does exactly what Keynes himself had so strongly criticised.

More interested in insight than in elegance, Keynes preferred to use his own intuitions, whatever their limitations, rather than encase himself in a straightjacket of formalized methods he knew to be unrealistic and inapplicable.

> The object of our analysis is, not to provide a machine, or method of blind manipulation, which will furnish an infallible answer, but to provide ourselves with an organized and orderly method of thinking out particular problems; and, after we have reached a provisional conclusion by isolating the complicating factors one by one, we then have to go back on ourselves and allow, as well as we can, for the probable interaction of the factors amongst themselves.*

Although I might disagree with Keynes as to the ease of following adequately the implications of the "interaction of the factors amongst themselves", his indictment of the methods of "blind manipulation" is even more applicable today than in his own time. Modern computers have provided a powerful tool

* Keynes, op. cit., pg. 297.

for aiding our intuition in tracing the "probable interactions of the factors amongst themselves". But like all powerful tools they can be misused, and have contributed immeasurably to the quantity of "blind manipulation".

Keynes developed what is by any standard an exceedingly good verbal model. But there has been a major problem in that very few have really understood it well. And although it revolutionized the theory of unemployment, inflation, business cycles, and the causes of growth in national wealth, there surprisingly has been very little in the way of subsequent work that has improved significantly on Keynes' original contribution.

This illustrates one of the basic limitations of a verbal model and why any such theory, if it is to maintain influence and undergo continuous and sustained improvement, must be formalized, as are the theories of physical science, into a more explicit framework. Keynes simply had no adequate way of clearly and precisely communicating his novel ideas. He had to express his theory by means of a very laborious and difficult to follow verbal presentation. Attempting in this way, by means of a purely verbal presentation, to relate the interactions and behavior of a great number of multiple interdependencies is no easy task. And his book, for this reason, has the justifiable reputation of being nearly indecipherable. This, perhaps more than anything else, explains why the neo-classical interpretation of his theory achieved such dominance. The neo-classical presentation was done in terms of graphs and equations that seemed precise, straightforward, and clear.

What is more, Keynes had no objective method for determining whether the intuitive analysis of the behavior implied by his theoretical structures was true. His own intuitions in this regard were in fact amazingly good. But he had no way of objectively justifying such insights to others whose intuitive

reasoning capacities were far less brilliant. And anything that is not easily communicable and intersubjectively verifiable could never be expected to exert a lasting scientific influence, especially when it must first overcome a previously entrenched and radically different way of thinking.

The formulation of new insight and theory will always be a creative act that could never be a mechanistic process of "blind manipulation". But once an innovative thinker such as Keynes has developed new insights, he must be able to communicate them to others. Otherwise they will be lost, or at least will never come to exert their proper influence. Keynes unfortunately had no such methods available to him. But there have been developments since his time, originating in engineering, that now enable us to express much more clearly and precisely the systematic interrelationships within a social system and to analyze objectively their behavioral implications.

AN EXAMPLE

These methods perhaps can be best understood by illustrating them in the context of a specific example. For that purpose, I choose a problem that seems simple enough to be easily understood, but realistic enough to establish that these methods are an important and useful tool for policy analysis. The problem is that of work load fluctuations in a small professional firm.

Most small firms composed primarily of professionals, such as for instance engineering or management consultants, seem regularly to go through cycles of boom and bust. They seem always to be either overloaded with work or not have nearly enough. Many would blame this problem simply on their being in an innately unstable market. But the real reason for the problem usually lies within the management policies of the firm itself. The explanation,

when viewed from the proper perspective, is relatively easy and straightforward. In a firm such as this, composed primarily of professionals, those doing the work are also the people who do the marketing. Thus, it is easy to move people (or to change their time allocation) back and forth quickly between marketing and production. When there is little work in house, everyone is out marketing hard. After a certain time delay, this marketing activity begins to pay off and new jobs start coming in. Before long, everyone has become overloaded with work, deadlines have become pressing, and everyone is working like mad on current projects so that they have no time left for marketing. But then, once the current workload starts to slacken, because no one has been doing any marketing, there are no new jobs in the pipeline. The firm then goes into a marketing panic and the cyclical process starts to repeat itself again.

The foregoing description is a verbal model proposed as an explanation of the problem. This explanation, or verbal model, has several important characteristics. First of all, the problem is explained as being due, not to outside or exogenous influences, but rather to the interaction of the internal decision and manpower allocation policies of the firm and the closed feedback interaction with its market. That is, the cause of the problem is contained within the structure of the model. Second, each individual relation or influence in the model is intuitively plausible--it makes good sense. But third, because it is a verbal model, it suffers from many of the same limitations we pointed out as being a problem in Keynes' theory. How do we know that the hypothesized structure really does cause the behavior described? And even if we can be sure that it does, how next could we objectively determine which changes in the firm's marketing or manpower allocation

policies, if any, would help to alleviate the problem?

A more formal model might help us deal better with both of these questions. First, it could be used to verify that the causal structures we have outlined really are sufficient to explain the problem. In this particular example, the explanation may seem so straightforward and so readily recognized by anyone who has had experience with such firms that a formal model, in addition to the verbal explanation, might seem superfluous. For such a simple problem, this may well be true. But most of our organizational, economic and social problems arise from structures that are much more complex than this one. And a formal model is required because it is the only solid test we have to assure that any given structure does adequately explain the problem.

It sometimes is difficult for those who have never gone through the process to appreciate how vitally necessary such formalization often can be. Generally, the first model one attempts to build does not generate the behavior it had been expected to reproduce. This of course indicates that the verbal model from which it was derived was inaccurate or at least incomplete. After analysing the causes of the unsatisfactory results, missing relations can be added or erroneous assumptions changed until we have arrived at a consistent set of plausible structures that produce the behavior observed in the real system. Working with a formal model in this way also forces us at the same time to improve our verbal model and hence our conceptual understanding of the problem.

But beyond the mere description of a problem, what we want to achieve in the end is improved behavior. And this is where a formal model becomes crucial. Dynamic feedback structures--the causes of all endogenously

determined behavior in a social system, or for that matter in any system--tend to behave in ways that until more clearly understood, seem counter-intuitive. A simple example of this is the behavior of a toy gyroscope. A gyroscope exhibits behavior that initially appears very strange. If we attempt to push the top of a spinning gyroscope in a particualr direction, the gyroscope will resist this push, and instead will move off at right angles. It is possible of course with brute force to overpower the gyroscope's inherent tendencies and to force it in the direction we want. But it is simpler and requires far less effort to move the gyroscope in the desired direction, if instead of using brute force, we push at right angles to the direction we would like it to move.

The gyroscope is a dynamic feedback system, and its counter-intuitive behavior is typical of such systems. Social systems also are dynamic feedback systems, but they usually are more difficult to overpower. Their internal resistance, as we often witness in the behavior of a bureaucracy, can be much stronger than any force applied from the outside. If therefore, we would like to affect an improvement in the behavior of such a system, we must do so in a manner consistent with its inherent behavior tendencies. Otherwise, as occurs all too often, we will fail. The only way to avoid such failure is to have a model of the system that correctly represents its inherent behavior. Given such a model, we then can try out various policies that have been suggested as ways of improving behavior. Many of the suggested changes will not have the effect intended, and these can be tested and scrapped before we waste time and money, or perhaps cause a disaster, trying them out on the real system.

Retur.ning to the example of the work load fluctuation problem, let us

now convert the verbal explanation into a formal model and see if it adequately reproduces observed behavior. Our verbal description said that professionals allocate their time to either marketing or production. Let us then, as shown in Figure 1, form two stocks or pools of manpower--one for marketing and one for production. Men are allocated to one of these two pools in whole or in part. That is, any one professional may spend a fraction of his time in one pool and the rest of his time in the other. But the sum of manpower allocated to both pools must be equal to the total professional manpower employed by the firm. These two manpower pools are connected, as shown in Figure 1, by a transfer rate that shifts the time allocation of professionals back and forth from one pool to the other.

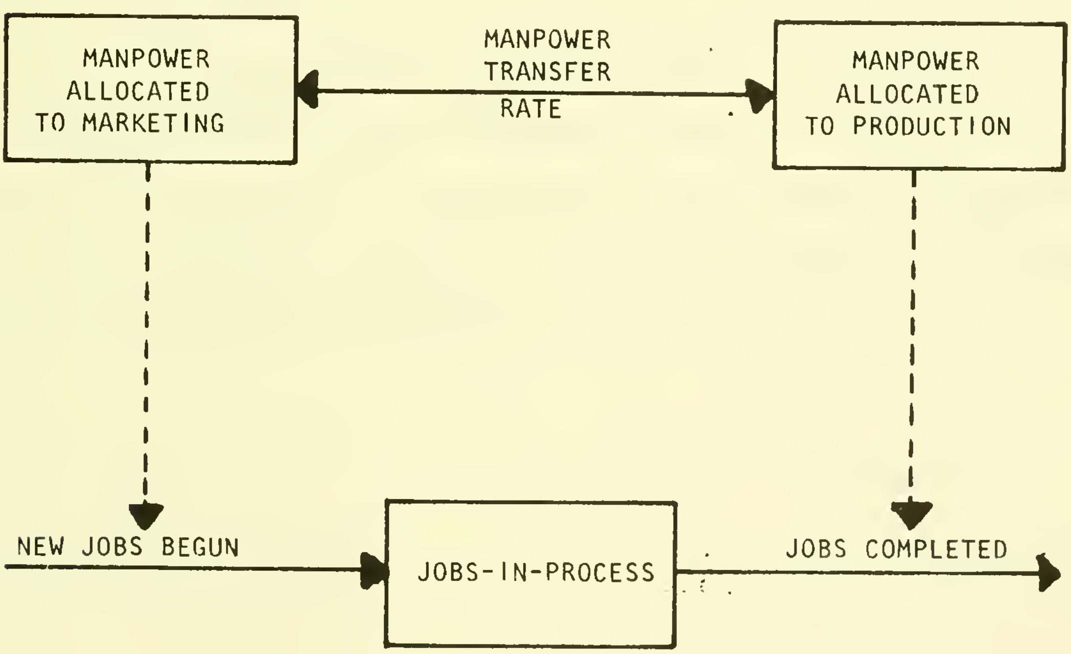

Figure 1. Physical Flows of the Work Load Fluctuation Problem.

Manpower allocated to marketing, after a delay, generates incoming jobs. These incoming jobs increase the number of jobs-in-process. Manpower allocated to production leads to job completions that reduce the number of jobs-in-process.

This completes the outline of what one might think of as the basic "physics" of the structure. What is still lacking is the decision mechanism that allocates available manpower to either marketing or production. Most firms naturally tend to allocate effort on the basis of the amount of work backlog, or as I have termed it here, the number of jobs-in-process. If there are many jobs being worked on and deadlines are pressing, more time is allocated to production and less to marketing. If there are only a few jobs in house, more time is allocated to marketing and less to production. Although there undoubtedly are other influences that impinge on the allocation decision, they usually are less crucial to the economic survival of the firm, and thus are easily overwhelmed by the pressures of having too little or too much work. There is, however, one other major influence on the transfer rate of manpower. This is the constraint imposed by there being only a limited amount of total manpower available to be reallocated. One obviously cannot transfer more manpower from marketing to production if there is no one left in marketing. The essential structure of the problem thus seems to be that shown in Figure 2.

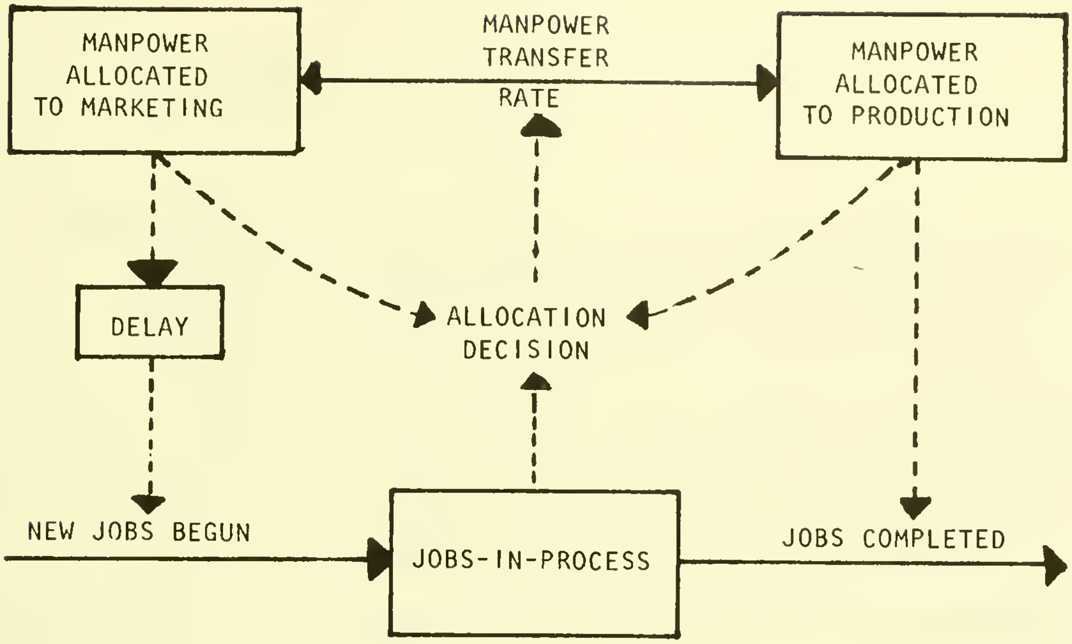

Figure 2. Flows and Decision Structure of the Work Load Fluctuation Problem.

System Equations

Now that the general structure has been outlined, we can begin to write equations. There are in this system three major stocks or pools, represented in Figure 2 as boxes--two of manpower resources and one of accumulated jobs-in-process. The present content of each pool is determined by the past history of flows into and out of it. These pools thus are the integrators or storage elements or state variables of the system. The equations representing each are as follows:

$$MM(t) = MM(t_o) - \int_{t_o}^{t} MTR(\sigma)\, d\sigma \qquad \text{Eq. 1}$$

$$MP(t) = MP(t_o) + \int_{t_o}^{t} MTR(\sigma)\, d\sigma \qquad \text{Eq. 2}$$

where $MM(t)$ is the manpower allocated to marketing.
$MM(t_o)$ is the initial amount of manpower allocated to marketing.
$MP(t)$ is the manpower allocated to production.
$MP(t_o)$ is the initial amount of manpower allocated to production.
$MTR(\sigma)$ is the transfer rate of manpower from marketing to production at each point in time over the period from t_o to t. (The reverse flow from production to marketing is represented as a negative value of the transfer rate.)

In this example, let us assume that the total number of professionals in the firm is held constant at 10. And we will start the model at a point in the firm's history when manpower is allocated such that there are four men assigned to marketing and six men assigned to production. Thus:

$$MM(t_o) = 4 \text{ men} \qquad \text{Eq. 3}$$

$$MP(t_o) = 6 \text{ men} \qquad \text{Eq. 4}$$

The number of jobs-in-process is treated similarly:

$$JIP(t) = JIP(t_o) + \int_{t_o}^{t} [JB(\sigma) - JC(\sigma)]\, d\sigma \qquad \text{Eq. 5}$$

where $JIP(t)$ is the number of jobs-in-process.
$JIP(t_o)$ is the initial number of jobs-in-process.
$JB(\sigma)$ is the number of new jobs begun per month at each time over the period from t_o to t.
$JC(\sigma)$ is the number of jobs completed per month at each time over the period from t_o to t.

The initial number of jobs-in-process let us assume to be equal to six.

$$JIP(t_o) = 6 \text{ jobs} \qquad \text{Eq. 6}$$

Jobs Sold.

The number of jobs sold per month is proportional to the marketing effort, i.e. the amount of manpower allocated to marketing. The average marketing effort required to bring in a job, let us suppose, is two man-months. This includes the unsuccessful effort spent soliciting jobs that did not materialize. The number of jobs sold per month then will be:

$$JS(t) = \frac{MM(t)}{MEJ} \qquad \text{Eq. 7}$$

$$MEJ = 2 \text{ man-months/job} \qquad \text{Eq. 8}$$

where JS is the number of jobs sold per month.
MM is the amount of manpower allocated to marketing.
MEJ is the average marketing effort required per job, measured in man-months.

Jobs Begun.

There is, however, a significant delay between the time that marketing effort is expended and the time when work on the new job is actually begun. New jobs begun thus are treated as a delayed function of jobs sold.

$$JB(t) = JB(t_o) + \int_{t_o}^{t} \frac{JS(\sigma) - JB(\sigma)}{SD} \, d\sigma \qquad \text{Eq. 9}$$

$$SD = 2 \text{ months} \qquad \text{Eq. 10}$$

where $JB(t)$ is the number of new jobs begun per month.
$JB(t_o)$ is the initial number of new jobs begun per month.
JS is the number of jobs sold per month.
SD is the average sales delay (the average delay between the time of marketing effort and the time work on a job is begun).

The initial number of new jobs begun per month we assume in this case to be two.

$$JB(t_o) = 2 \quad \text{jobs/month} \qquad \text{Eq. 11}$$

Eq. 9 is a first-order exponential lag, the simplest way of representing a continuous delay. There are other more precise and complex methods of representing delays, but the first-order lag is adequate for the purposes of this example.

Jobs Completed.

The number of jobs completed per month is proportional to the amount of manpower allocated to production. Suppose that the average job requires about eight man-months of effort. Then the number of jobs completed per month would be:

$$JC(t) = \frac{MP(t)}{AJS} \qquad \text{Eq. 12}$$

$$AJS = 8 \quad \text{man-months/job} \qquad \text{Eq. 13}$$

where JC is the number of jobs completed per month.
MP is the manpower allocated to production.
AJS is the average job size, measured in man-months.

Manpower Allocation.

The only equations remaining are those required to represent the manpower allocation decision. The transfer rate that reallocates manpower between marketing and production depends, as we said earlier, on the number of jobs-in-process. The firm ideally would like to have about six months of work backlog. If the backlog were to be much larger than this, the firm would become overloaded and start to have trouble meeting deadlines. If the backlog were much lower than six months, the chances are greatly increased of running short of work and therefore of income. Since the average job requires about two man-months of marketing effort and about eight man-months of production effort, the professionals in this firm must spend on the average about 20% of their time marketing and 80% of their time producing. Thus the firm ideally would like at any time to have about two of its ten professionals allocated to marketing and the other eight allocated to production. This means that the firm, to maintain a six month backlog of work, needs to have $\frac{\text{6 months} \cdot \text{8 men}}{\text{8 man-months/job}}$ equals six jobs-in-process, employing on the average about 1.5 men per job. The desired number of jobs-in-process therefore equals six.

$$DJP = 6 \quad \text{jobs} \qquad \text{Eq. 14}$$

where DJP is the desired number of jobs-in-process.

The manpower transfer rate then is taken to be proportional to the difference between the desired and the actual number of jobs-in-process.

$$MTR(t) = MMJ \cdot [JIP(t) - DJP]$$

where MTR is the manpower transfer rate between marketing and production, in men per month.
MMJ is the number of men transferred per month per excess or deficient job.
JIP is the number of jobs-in-process.
DJP is the desired number of jobs-in-process.

MMJ, the number of men transferred per month per excess or deficient job, depends on the rate at which the discrepancy between desired and actual jobs-in-process is to be corrected, and on the average number of men employed per job.

$$MMJ = \frac{MEJ}{RJD} \qquad \frac{\text{men/month}}{\text{job}}$$

where MMJ is the number of men transferred per month per excess or deficient job.
MEJ is the average number of men employed per job.
RJD is the rate of reduction of the discrepancy between desired and actual jobs-in-process, in months.

In this example, we will assume that:

MEJ = 1.5 men per job

RJD = 10 months

So that

$$MMJ = .15 \quad \frac{\text{men/month}}{\text{job}} \qquad \text{Eq. 15}$$

The equation for the manpower transfer rate however is still not complete because there are constraints other than just the number of excess or deficient jobs-in-process. It obviously is impossible to transfer men from marketing to production, whatever the number of excess jobs-in-process, if there is no manpower in marketing left to transfer. And, however deficient the number of

jobs-in-process, it is impossible to transfer men from production to marketing if there is no manpower left in production. We therefore must add an additional term to the manpower transfer equation to represent this additional constraint.

$$MTR(t) = MMJ \cdot [JIP(t) - DJP] \cdot MTC(t) \qquad \text{Eq. 16}$$

where MTR is the manpower transfer rate.
MTC is the manpower transfer constraint.
MMJ is the number of men transferred per month per excess or deficient job.
JIP is the number of jobs-in-process.
DJP is the desired number of jobs-in-process.

The manpower transfer constraint operates differently, depending on the direction of transfer. If there were no men engaged in marketing activities, then it would be impossible to move men from marketing to production. But it obviously should be easy to move men to marketing from production. If on the other hand there were no men in production, it would be impossible to move men from production to marketing, but easy to move to production from marketing. Thus manpower transfers from marketing to production are constrained by the amount of manpower in marketing. And transfers to marketing from production are constrained by the amount of manpower in production.

We therefore define separately a marketing manpower constraint and a production manpower constraint. The complete manpower transfer constraint then is defined to be equal to the marketing manpower constraint when manpower is being transferred from marketing to production, and is equal to the production manpower constraint when manpower is transferred to marketing from production.

$$MTC(t) = \begin{cases} MMC(t) & \text{if} \quad MTR > 0 \\ PMC(t) & \text{if} \quad MTR < 0 \end{cases} \qquad \text{Eq. 17}$$

where MTC is the manpower transfer constraint.
MMC is the marketing manpower constraint.
PMC is the production manpower constraint.
MTR is the manpower transfer rate from marketing to production. (Negative values represent a reverse flow to marketing from production).

The marketing manpower constraint, MMC, operates only when the direction of manpower transfer is from marketing to production. If there is no manpower in marketing, transfers from marketing to production are impossible, and MMC=0. If all the firm's manpower is in marketing, then there is no constraint on the movement from marketing to production, and MMC=1. At points in between the constraint is partial. We thus define the marketing manpower constraint to be equal to the ratio of marketing to total manpower.

$$MMC(t) = MMR(t) \qquad \text{Eq. 18}$$

$$MMR(t) = \frac{MM(t)}{MM(t) + MP(t)} \qquad \text{Eq. 19}$$

where MMC is the marketing manpower constraint.
MMR is the marketing to total manpower ratio.
MM is the manpower allocated to marketing.
MP is the manpower allocated to production.

The production manpower constraint, PMC, operates on transfer flows in the other direction. If there is no manpower in production, transfers from production to marketing are impossible, and PMC=0. If all the firm's manpower is in production, there is no constraint on the movement from production to marketing, and PMC=1. At points in between the constraint is partial. The marketing manpower constraint was a linear function of manpower in marketing. The production manpower constraint, however, will operate a little differently. We normally would expect 80 percent of total manpower on the average to be in

production. The production manpower constraint, therefore, we would expect to become effective sooner (i.e. at higher levels of remaining manpower) than was the case for the marketing manpower constraint. The production manpower constraint therefore is defined as being equal to the square of the ratio of production to total manpower.

$$PMC(t) = [PMR(t)]^2 \qquad \text{Eq. 20}$$

$$PMR(t) = \frac{MP(t)}{MM(t) + MP(t)} \qquad \text{Eq. 21}$$

where PMC is the production manpower constraint.
PMR is the production manpower ratio.
MM is the manpower allocated to marketing.
MP is the manpower allocated to production.

This completes the equations defining the work load fluctuation model. The complete set of equations and symbol definitions is summarized in Appendix A.

Model Behavior

Programming these equations on a computer and simulating to determine their behavior produces the results shown in Figure 3. The model, we see, does successfully reproduce the unstable behavior experienced by the firm. The boom and bust cycle repeats itself about once every three years, with large variations in the work backlog, ranging between 1.5 and 15 jobs-in-process. Manpower allocation between marketing and production also varies widely with marketing manpower ranging between 4 and 0.5 men, and production manpower ranging between 6 and 9.5 men.

This verifies that our hypothesis does successfully explain the work load fluctuations that have been experienced by the firm. Now that we have

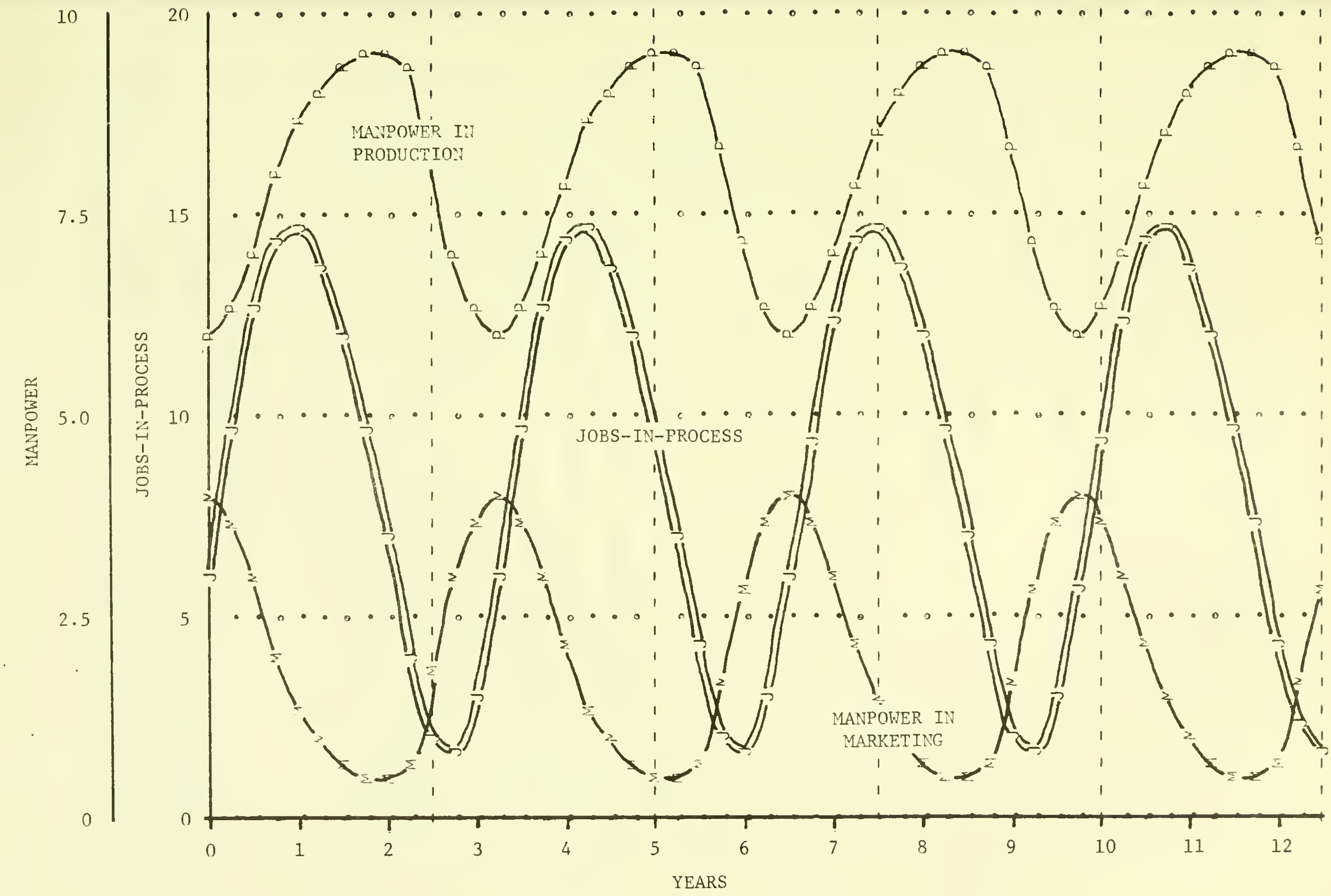

Figure 3. Behavior of the Work Load Fluctuation Model.

a model that satisfactorily reproduces this unstable behavior, however, the next step is to use the model to help design better policies that will improve behavior. Looking at Figure 2, we see no reasonable changes that could be made to the basic "physics" of the structure, so the only point of leverage we have to work with is the allocation decision that transfers manpower between marketing and production.

Note that the model already has served to direct and focus our attention to a particular point of leverage within the system. Without a clear understanding of the causes of the problem, we would be unable to determine possible remedies. Attention most likely would be directed toward the most pressing current symptom. Toward a "sales problem" when the work backlog is low, and toward an "overload problem" when backlog is high. The blame for such problems generally is ascribed to causes outside the firm--to a capricious market or an unstable industry or whatever. Rarely if ever would attention be directed toward the internal management policies of the firm. But with a model that correctly reproduces the problem, we know that we need to look for the cause and therefore the remedy to that problem only within the set of relations contained within the model. This allows us to focus more clearly on the true causes of the problem and to avoid much wasteful groping in areas that are irrelevant. In this case, as we said, the model clearly focuses out attention on the manner in which manpower is transferred or reallocated between marketing and production.

Increasing the Speed of Manpower Reallocation.

The first change in reallocation policy that most people think of, when looking at the problem for the first time and trying to find possible ways of stabilizing the firm's behavior, is to increase the firm's responsiveness

to changing workload conditions, i.e. to increase the speed of manpower reallocation. This is controlled in the model by the parameter MMJ, the number of men reallocated per month per excess or deficient job. In the initial case, I had supposed that the firm responds to a discrepancy between the desired and actual number of jobs-in-process by transferring 0.15 men per month for each job in excess or deficit of the jobs desired. To increase the speed of response, then, let us double the value of MMJ from 0.15 to 0.3.

$$MMJ = 0.3 \quad \frac{\text{men/month}}{\text{job}} \qquad \text{Eq. 15a}$$

Making this change and again simulating model behavior on a computer produces the behavior shown in Figure 4. The results, we see, are not as good as one might at first have expected. In fact, the problem if anything is worse. The fluctuation in work backlog has decreased ever so slightly, ranging now between 2 and 14 jobs-in-process. But the fluctuation in manpower allocation has increased, and even worse, the boom and bust cycles now occur more frequently--about once every 2.5 years instead of as before about once every 3.2 years.

Decreasing the Speed of Manpower Reallocation

Since this attempted policy change proved ineffective, let us then see what would happen if we made the opposite change. Instead of doubling the speed of response, let us cut it in half, that is reduce MMJ to be equal to 0.07.

$$MMJ = 0.07 \quad \frac{\text{men/month}}{\text{job}} \qquad \text{Eq. 15b}$$

Making this change and simulating model behavior produces the behavior shown in Figure 5. Again the results are not particularly impressive. Manpower

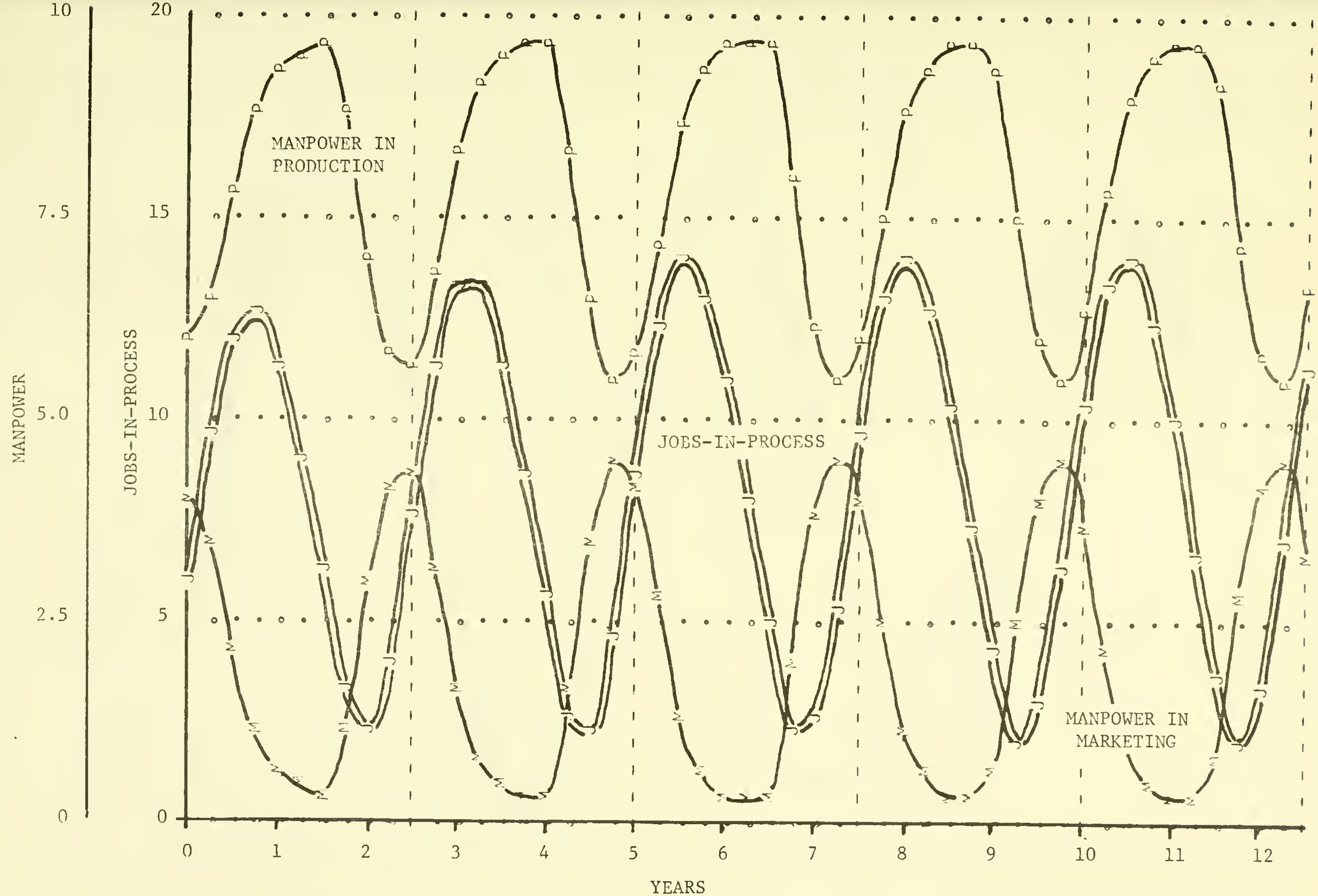

Figure 4. Effect of Increasing the Speed of Manpower Reallocation.

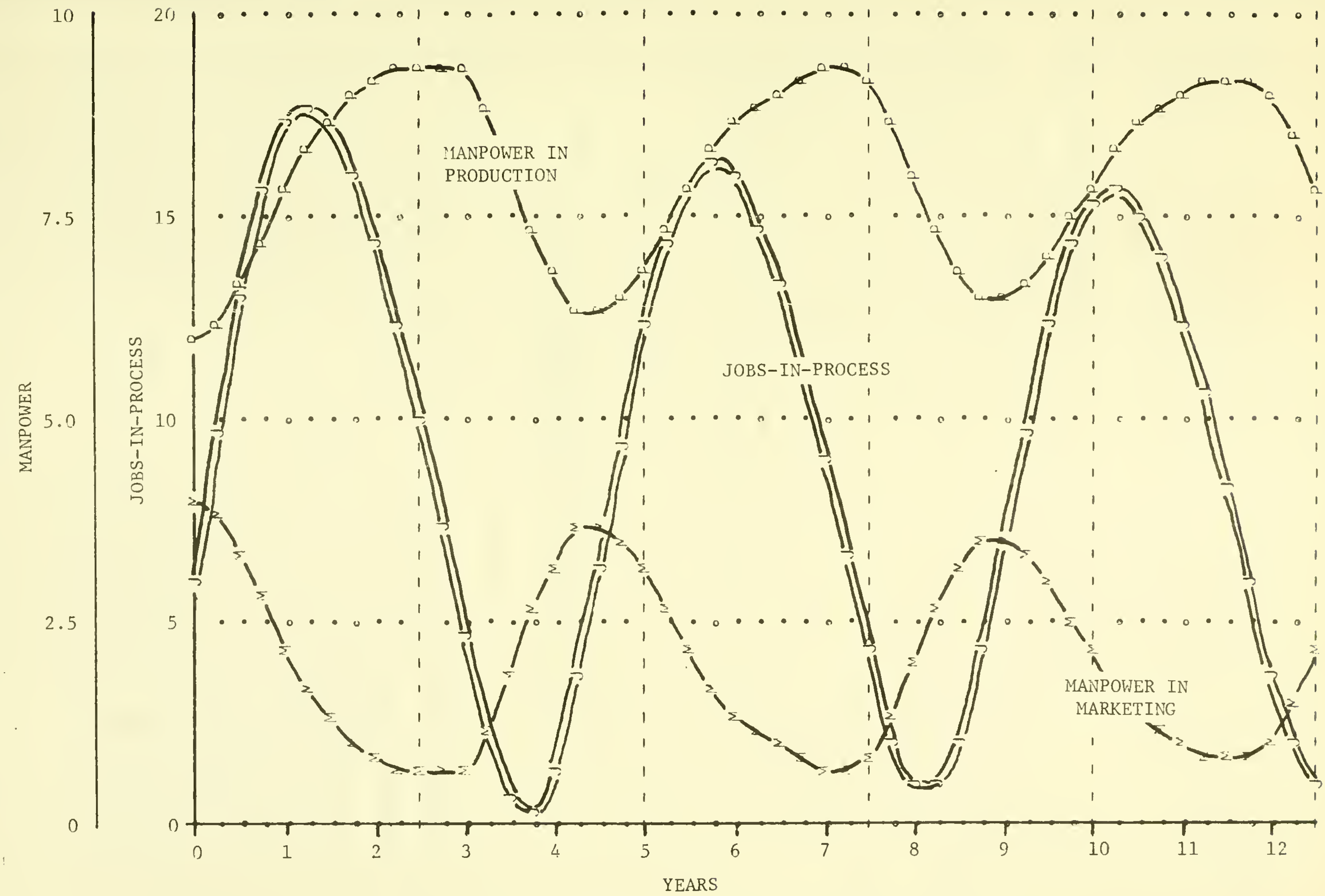

Figure 5. Effect of Decreasing the Speed of Manpower Reallocation.

fluctuation has been reduced slightly and the boom and bust cycles occur less frequently--now only once every 4.5 years. But the variation in work backlog has increased, now ranging between 0.8 and 16 jobs-in-process.

Basing Manpower Reallocation on the Number of Incoming Jobs.

Since modifications to the existing policy structure have proven ineffective, let us next attempt a more radical change. In all the previous simulations, manpower has been reallocated solely on the basis of the amount of work backlog, or jobs-in-process. Let us now change the reallocation policy so that it is based not only on the present work backlog, but also on the number of new jobs begun. Based on new jobs begun, we can define the desired manpower allocation to production, which is simply equal to the number of new jobs begun per month times the average job size.

$$DMP(t) = JB(t) \cdot AJS \qquad \text{Eq. 22}$$

where DMP is the desired manpower allocation to production.
JB is the number of new jobs begun per month.
AJS is the average job size.

The average job size, AJS, was previously defined in Eq. 13.

The difference between the desired manpower allocation to production and the present amount of manpower in production then is used to determine the manpower transfer rate. The number of men to be transferred per month depends on the difference between desired and actual manpower, and on the rate at which the discrepancy is to be corrected. In this case, we will assume that any discrepancy is to be made up over a ten month period.

Thus the manpower transfer rate now is determined as the sum of two separate influences--a production manpower adjustment rate that transfers

manpower based on the difference between desired and actual manpower in production, and a backlog adjustment rate that, as before, transfers manpower based on the difference between desired and actual jobs-in-process.

$$MTR(t) = [PMA(t) + BA(t)] \cdot MTC(t) \qquad \text{Eq. 16a}$$

$$PMA(t) = \frac{DMP(t) - MP(t)}{MAT} \qquad \text{Eq. 23}$$

$$MAT = 10 \text{ months} \qquad \text{Eq. 24}$$

$$BA(t) = MMJ \cdot [JIP(t) - DJP] \qquad \text{Eq. 25}$$

where MTR is the manpower transfer rate.
PMA is the production manpower adjustment rate.
MAT is the manpower adjustment time.
BA is the backlog adjustment rate.
MTC is the manpower transfer constraint. (Eq. 17)
DMP is the desired manpower in production. (Eq. 22)
MP is the present manpower in production. (Eq. 2)
MMJ is the number of men transferred per month per excess or deficient job. (Eq. 15)
JIP is the number of jobs-in-process. (Eq. 5)
DJP is the desired number of jobs-in-process. (Eq. 14)

Making these changes and additions, and again simulating to determine system behavior produces the results shown in Figure 6. This new policy, we see, decidedly improves performance. Starting from the same initial conditions as before, work load fluctuations are quickly damped. Jobs-in-process equilibriate to be equal to the desired number of six. Marketing manpower equilibriates to the desired value of two and production manpower at eight.

The analysis of why this particular policy change produced the desired behavior and the others did not, and how I know to choose this as a policy that would be effective, is beyond the scope of this paper. But the results certainly are clear. It also is clear that the model has been able to provide

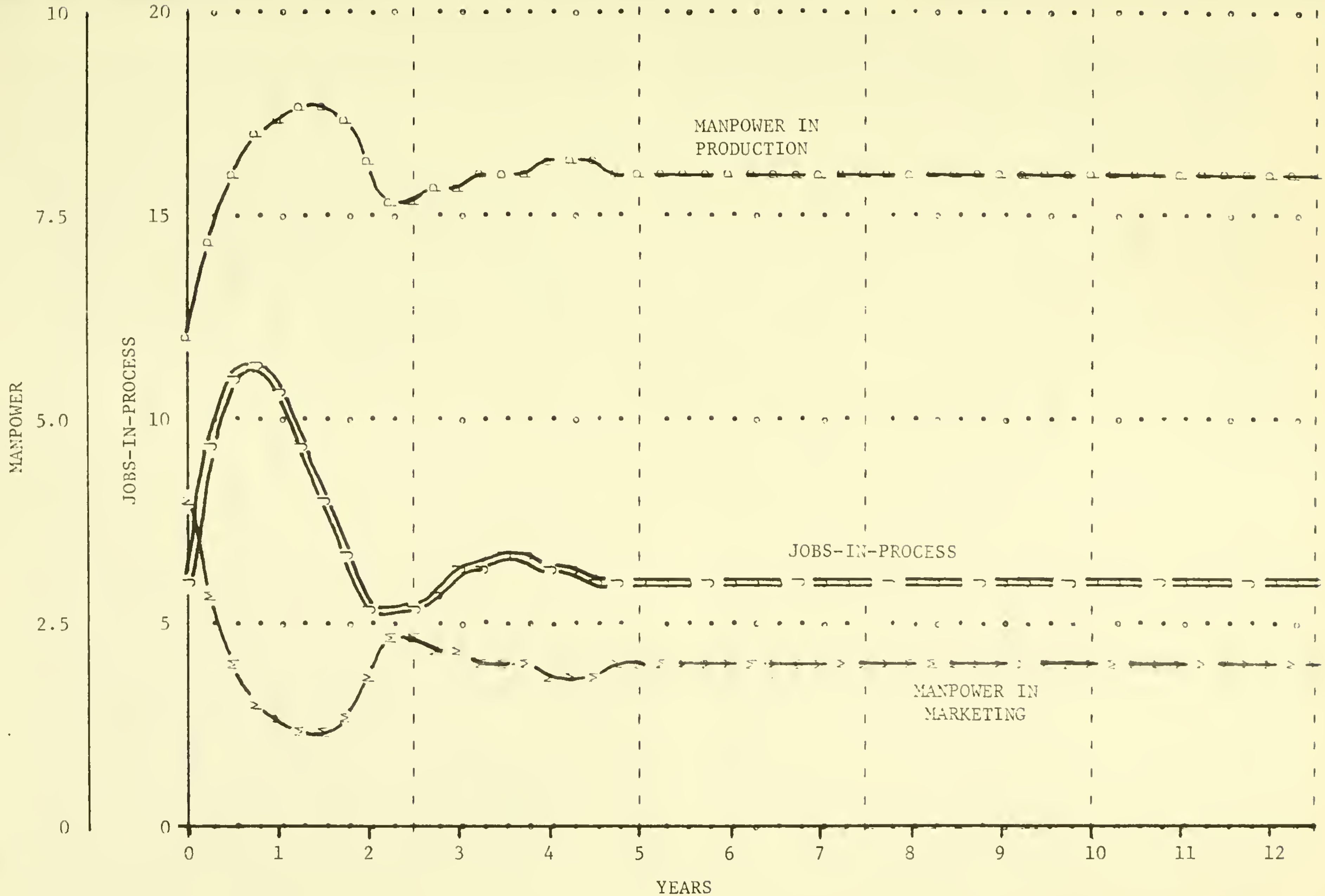

Figure 6. Effect of Basing Reallocation on Incomming Jobs in addition to Jobs-in-Process.

unambiguous and objective conclusions as to which policies would be effective and which not.

CONCLUSIONS

This example has been concerned with the problem of work load fluctuations in a small firm. But it should be obvious that the same general approach should apply as well to the analysis of behavior and improved policy design for almost any social system. The above model, although simple, contains most of the essential elements. It deals with certain aspects of the behavior of people. It deals with the way decisions are made in a social system based on information about the conditions of that system and its environment. It deals with the problem of resource allocation, a crucial problem at all levels of social, economic, and cultural behavior.

It also illustrates graphically some basic principles. One important principal is that the type of information used in making a decision is usually much more important in determining system behavior than is the accuracy or the exact way a particular piece of information is processed. As long as the allocation decision is based only on information about jobs-in-process, it does not matter how accurate the information is or how quickly one responds to it, the behavior always will be unsatisfactory. But by introducing a new type of information into the decision process (the number of new jobs begun compared to present manpower in production) we were able to significantly improve behavior. Another significant point is that to affect this improvement, it was not necessary to collect new data, but simply to make use of information already available that previously had been ignored. This is not to say that improved data collection is not important, but simply that it is not a panacea. Most decision makers already have more raw information

than they can possibly use. What they most need is a better means of determining which information it is they ought to be using. And this is why policy models of the preceding sort are essential, if we are ever truly to understand and to improve the behavior of our industrial, economic, and social systems.

APPENDIX A

Summary of Equations

$$MM(t) = MM(t_o) - \int_{t_o}^{t} TR(\sigma)\, d\sigma \qquad \text{Eq. 1}$$

$$MP(t) = MP(t_o) + \int_{t_o}^{t} TR(\sigma)\, d\sigma \qquad \text{Eq. 2}$$

$$MM(t_o) = 5 \quad \text{men} \qquad \text{Eq. 3}$$

$$MP(t_o) = 5 \quad \text{men} \qquad \text{Eq. 4}$$

$$JIP(t) = JIP(t_o) + \int_{t_o}^{t} [JB(\sigma) - JC(\sigma)]\, d\sigma \qquad \text{Eq. 5}$$

$$JIP(t_o) = 6 \quad \text{jobs} \qquad \text{Eq. 6}$$

$$JS(t) = \frac{MM(t)}{MEJ} \qquad \text{Eq. 7}$$

$$MEJ = 2 \quad \text{man-months} \qquad \text{Eq. 8}$$

$$JB(t) = JB(t_o) + \int_{t_o}^{t} \frac{JS(\sigma) - JB(\sigma)}{SD}\, d\sigma \qquad \text{Eq. 9}$$

$$SD = 3 \quad \text{months} \qquad \text{Eq. 10}$$

$$JB(t_o) = 2 \quad \text{jobs/month} \qquad \text{Eq. 11}$$

$$JC(t) = \frac{MP(t)}{ATS} \qquad \text{Eq. 12}$$

$$AJS = 8 \quad \text{man-months} \qquad \text{Eq. 13}$$

$$DJP = 6 \quad \text{jobs} \qquad \text{Eq. 14}$$

$$MMJ = .15 \ \frac{\text{men/month}}{\text{job}} \qquad \text{Eq. 15}$$

$$MTR(t) = MMJ \cdot [JIP(t) - DJP] \cdot MTC(t) \qquad \text{Eq. 16}$$

$$MTC(t) = \begin{cases} MMC(t) & \text{if } MTR > 0 \\ PMC(t) & \text{if } MTR < 0 \end{cases} \qquad \text{Eq. 17}$$

$$MMC(t) = MMR(t) \qquad \text{Eq. 18}$$

$$MMR(t) = \frac{MM(t)}{MM(t) + MP(t)} \qquad \text{Eq. 19}$$

$$PMC(t) = [PMR(t)]^2 \qquad \text{Eq. 20}$$

$$PMR(t) = \frac{MP(t)}{MM(t) + MP(t)} \qquad \text{Eq. 21}$$

Equations for Basing Reallocation Decision on Incoming Jobs in Addition to Jobs-in-Process.

$$MTR(t) = [PMA(t) + BA(t)] \cdot MTC(t) \qquad \text{Eq. 16a}$$

$$DMP(t) = JB(t) \cdot AJS \qquad \text{Eq. 22}$$

$$PMA(t) = \frac{DMP(t) - MP(t)}{MAT} \qquad \text{Eq. 23}$$

$$MAT = 10 \quad \text{months} \qquad \text{Eq. 24}$$

$$BA(t) = MMJ \cdot [JIP(t) - DJP] \qquad \text{Eq. 25}$$

Symbol Definitions

AJS	average job size, in man-months.
BA	backlog adjustment rate.
DJP	desired number of jobs-in-process.
DMP	desired manpower in production.
JB	new jobs begun per month.
JC	jobs completed per month.
JIP	jobs-in-process.
JS	jobs sold per month.
MAT	manpower adjustment time.
MEJ	average marketing effort required per job, measured in man-months.
MM	manpower allocated to marketing.
MMC	marketing manpower constraint.
MMJ	number of men reallocated per month per excess or deficient job.
MMR	marketing manpower ratio.
MP	manpower allocated to production.
MTC	manpower transfer constraint.
MTR	manpower transfer rate.
PMA	production manpower adjustment rate.
PMC	production manpower constraint.
PMR	production manpower ratio.
SD	average sales delay.