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highlights and comments
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System dynamics has demonstrated how companies and how urban systems behave in ways that run against most of what man would do to correct their ills. Now the same obtuse behavior can be assigned to the largest social issues which confront the nation and the world.

System Dynamics explains why
transforming from: an automobile pattern of land-use
to: a transit-served pattern
will likely increase auto congestion in the short run
while signifcantly decreasing it in the long run.

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Counterintuitive Behavior of Social Systems

This paper addresses several issues of broad concern in the United States: population trends; the quality of urban life; national policy for urban growth; and the unexpected, ineffective, or detrimental results often generated by government programs in these areas.

The nation exhibits a growing sense of futility as it repeatedly attacks deficiencies in our social system while the symptoms continue to worsen. Legislation is debated and passed with great promise and hope. But many programs prove to be ineffective. Results often seem unrelated to those expected when the programs were planned. At times programs cause exactly the reverse of desired results.

It is now possible to explain how such contrary results can happen. There are fundamental reasons why people misjudge the behavior of social systems. There are orderly processes at work in the creation of human judgment and intuition that frequently lead people to wrong decisions when faced with complex and highly interacting systems. Until we come to a much better understanding of social systems, we should expect that attempts to develop corrective programs will continue to disappoint us.

The purpose of this paper is to leave with its readers a sense of caution about continuing to depend on the same past approaches that have led to our present feeling of frustration and to suggest an approach which can eventually lead to a better understanding of our social systems and thereby to more effective policies for guiding the future.

A New Approach to Social Systems

It is my basic theme that the human mind is not adapted to interpreting how social systems behave. Our social systems belong to the class called multi-loop nonlinear feedback systems. In the long history of evolution it has not been necessary for man to understand these systems until very recent historical times. Evolutionary processes have not given us the mental skill needed to properly interpret the dynamic behavior of the systems of which we have now become a part.

In addition, the social sciences have fallen into some mistaken "scientific" practices which compound man's natural shortcomings. Computers are often being used for what the computer does poorly and the human mind does well. At the same time the human mind is being used for what the human mind does poorly and the computer does well. Even worse, impossible tasks are attempted while achievable and important goals are ignored.

Until recently there has been no way to estimate the behavior of social systems except by contemplation, discussion, argument, and guesswork. To point a way out of our present dilemma about social systems, I will sketch an approach that combines the strength of the human mind and the strength of today's computers. The approach is an outgrowth of developments over the last 40 years, in which much of the research has been at the Massachusetts Institute of Technology. The concepts of feedback system behavior apply sweepingly from physical systems through social systems. The ideas were first developed and applied to engineering systems. They have now reached practical usefulness in major aspects of our social systems.

I am speaking of what has come to be called industrial dynamics. The name is a misnomer because the methods apply to complex systems regardless of the field in which they are located. A more appropriate name would be system dynamics. In our own work, applications have been made to corporate policy, to the dynamics of diabetes as a medical system, to the growth and stagnation of an urban area, and most recently to world dynamics representing the interactions of population, pollution, industrialization, natural resources, and food. System dynamics, as an extension of the earlier design of physical systems, has been under development at M.I.T. since 1956. The approach is easy to understand but difficult to practice. Few people have a high level of skill; but preliminary work is developing all over the world. Some European countries and especially Japan have begun centers of education and research.

Computer Models of Social Systems

People would never attempt to send a space ship to the moon without first testing the equipment by constructing prototype models and by computer simulation of the anticipated space trajectories. No company would put a new kind of household appliance or electronic computer into production without first making laboratory tests. Such models and laboratory tests do not guarantee against failure, but they do identify many weaknesses which can then be corrected before they cause full-scale disasters.

Our social systems are far more complex and harder to understand than our technological systems. Why, then, do we not use the same approach of making models of social systems and conducting laboratory experiments on those models before we try new laws and government programs in real life? The answer is often stated that our knowledge of social systems is insufficient for constructing useful models. But what justification can there be for the apparent assumption that we do not know enough to construct models but believe we do know enough to directly design new social systems by passing laws and starting new social programs? I am suggesting that we now do know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social systems directly without first going through a model-building experimental phase. But I am confident, and substantial supporting evidence is beginning to accumulate, that the proper use of models of social systems can lead to far better systems, laws, and programs.

We should study the relationship between patterns of land-use and the economic operation of transit systems.

It is now possible to construct in the laboratory realistic models of social systems. Such models are simplifications of the actual social system but can be far more comprehensive than the mental models that we otherwise use as the basis for debating governmental action.

Before going further, I should emphasize that there is nothing new in the use of models to represent social systems. Each of us uses models constantly. Every person in his private life and in his business life instinctively uses models for decision making. The mental image of the world around you which you carry in your head is a model. One does not have a city or a government or a country in his head. He has only selected concepts and relationships which he uses to represent the real system. A mental image is a model. All of our decisions are taken on the basis of models. All of our laws are passed on the basis of models. All executive actions are taken on the basis of models. The question is not to use or ignore models. The question is only a choice among alternative models.

The mental model is fuzzy. It is incomplete. It is imprecisely stated. Furthermore, within one individual, a mental model changes with time and even during the flow of a single conversation. The human mind assembles a few relationships to fit the context of a discussion. As the subject shifts so does the model. When only a single topic is being discussed, each participant in a conversation employs a different mental model to interpret the subject. Fundamental assumptions differ but are never brought into the open. Goals are different and are left unstated. It is little wonder that compromise takes so long. And it is not surprising that consensus leads to laws and programs that fail in their objectives or produce new difficulties greater than those that have been relieved.

For these reasons we stress the importance of being explicit about assumptions and interrelating them in a computer model. Any concept or assumption that can be clearly described in words can be incorporated in a computer model. When done, the ideas become clear. Assumptions are exposed so they may be discussed and debated.

But the most important difference between the properly conceived computer model and the mental model is in the ability to determine the dynamic consequences when the assumptions within the model interact with one another. The human mind is not adapted to sensing correctly the consequences of a mental model. The mental model may be correct in structure and assumptions but, even so, the human mind — either individually or as a group consensus — is most apt to draw the wrong conclusions. There is no doubt about the digital computer routinely and accurately tracing through the sequences of actions that result from following the statements of behavior for individual points in the model system. This inability of the human mind to use its own mental models is clearly shown when a computer model is constructed to reproduce the assumptions held by a single person. In other words, the model is refined until it is fully agreeable in all its assumptions to the perceptions and ideas of a particular person. Then, it usually happens that the system that has been described does not act the way the person anticipated. Usually there is an internal contradiction in mental models between the assumed structure and the assumed future consequences. Ordinarily the assumptions about structure and internal motivations are more nearly correct than are the assumptions about the implied behavior.

The kind of computer models that I am discussing are strikingly similar to mental models. They are derived from the same sources. They may be discussed in the same terms. But computer models differ from mental models in important ways. The computer models are stated explicitly. The "mathematical" notation that is used for describing the model is unambiguous. It is a language that is clearer, simpler, and more precise than such spoken languages as English or French. Its advantage is in the clarity of meaning and the simplicity of the language syntax. The language of a computer model can be understood by almost anyone, regardless of educational background. Furthermore, any concept and relationship that can be clearly stated in ordinary language can be translated into computer model language.

There are many approaches to computer models. Some are naive. Some are conceptually and structurally inconsistent with the nature of actual systems. Some are based on methodologies for obtaining input data that commit the models to omitting major concepts and relationships in the psychological and human reaction areas that we all know to be crucial. With so much activity in computer models and with the same terminology having different meanings in the different approaches, the situation must be confusing to the casual observer. The key to success is not in having a computer; the important thing is how the computer is used. With respect to models, the key is not to computerize a model, but instead to have a model structure and relationships which properly represent the system that is being considered.

I am speaking here of a kind of computer model that is very different from the models that are now most common in the social sciences. Such a computer model is not derived statistically from time-series data. Instead, the kind of computer model I am discussing is a statement of system structure. It contains the assumptions being made about the system. The model is only as good as the expertise which lies behind its formulation. Great and correct theories in physics or in economics are few and far between. A great computer model is distinguished from a poor one by the degree to which it captures more of the essence of the social system that it presumes to represent. Many mathematical models are limited because they are formulated by techniques and according to a conceptual structure that will not accept the multiple-feedback-loop and nonlinear nature of real systems. Other models are defective because of lack of knowledge or deficiencies of perception on the part of the persons who have formulated them.

But a recently developed kind of computer modeling is now beginning to show the characteristics of behavior of actual systems. These models explain why we are having the present difficulties with our actual social systems and furthermore explain why so many efforts to improve social systems have failed. In spite of their shortcomings, models can now be constructed that are far superior to the intuitive models in our heads on which we are now basing national social programs.

This approach to the dynamics of social systems differs in two important ways from common practice in social sciences and government. There seems to be a common attitude that the major difficulty is shortage of information and data. Once data is collected, people then feel confident in interpreting the implications. I differ on both of these attitudes. The problem is not shortage of data but rather our inability to perceive the consequences of the information we already possess. The system dynamics approach starts with the concepts and information on which people are already acting. Generally these are sufficient. The available perceptions are then assembled in a computer model which can show the consequences of the well-known and properly perceived parts of the system. Generally, the consequences are unexpected.

Counterintuitive Nature of Social Systems

Our first insights into complex social systems came from our corporate work. Time after time we have gone into a corporation which is having severe and well-known difficulties. The difficulties can be major and obvious such as a falling market share, low profitability, or instability of employment. Such difficulties are known throughout the company and by anyone outside who reads the management press. One can enter such a company and discuss with people in key decision points what they are doing to solve the problem. Generally speaking we find that people perceive correctly their immediate environment. They know what they are trying to accomplish. They know the crises which will force certain actions. They are sensitive to the power structure of the organization, to traditions, and to their own personal goals and welfare. In general, when circumstances are conducive to frank disclosure, people can state what they are doing and can give rational reasons for their actions. In a troubled company, people are usually trying in good conscience and to the best of their abilities to solve the major difficulties. Policies are being followed at the various points in the organization on the presumption that they will alleviate the difficulties. One can combine these policies into a computer model to show the consequences of how the policies interact with one another. In many instances it then emerges that the known policies describe a system which actually causes the troubles. In other words, the known and intended practices of the organization are fully sufficient to create the difficulty, regardless of what happens outside the company or in the marketplace. In fact, a downward spiral develops in which the presumed solution makes the difficulty worse and thereby causes redoubling of the presumed solution.

The same downward spiral frequently develops in government. Judgment and debate lead to a program that appears to be sound. Commitment increases to the apparent solution. If the presumed solution actually makes matters worse, the process by which this happens is not evident. So, when the troubles increase, the efforts are intensified that are actually worsening the problem.

Dynamics of Urban Systems

Our first major excursion outside of corporate policy began in February, 1968, when John F. Collins, former mayor of Boston, became Professor of Urban Affairs at M.I.T. He and I discussed my work in industrial dynamics and his experience with urban difficulties. A close collaboration led to applying to the dynamics of the city the same methods that had been created for understanding the social and policy structure of the corporation. A model structure was developed to represent the fundamental urban processes. The proposed structure shows how industry, housing, and people interact with each other as a city grows and decays. The results are described in my book *Urban Dynamics*, and some were summarized in *Technology Review* (April, 1969, pp. 21-31).

I had not previously been involved with urban behavior or urban policies. But the emerging story was strikingly similar to what we had seen in the corporation. Actions taken to alleviate the difficulties of a city can actually make matters worse. We examined four common programs for improving the depressed nature of the central city. One is the creation of jobs as by bussing the unemployed to the suburbs or through governmental jobs as employer of last resort. Second was a training program to increase the skills of the lowest-income group. Third was financial aid to the depressed city as by federal subsidy. Fourth was the construction of low-cost housing. All of these are shown to lie between neutral and detrimental almost irrespective of the criteria used for judgment. They range from ineffective to harmful judged either by their effect on the economic health of the city or by their long-range effect on the low-income population of the city.

The results both confirm and explain much of what has been happening over the last several decades in our cities.

In fact, it emerges that the fundamental cause of depressed areas in the cities comes from excess housing in the low-income category rather than the commonly presumed housing shortage. The legal and tax structures have combined to give incentives for keeping old buildings in place. As industrial buildings age, the employment opportunities decline. As residential buildings age, they are used by lower-income groups who are forced to use them at a higher population density. Therefore, jobs decline and population rises while buildings age. Housing, at the higher population densities, accommodates more low-income urban population than can find jobs. A social trap is created where excess low-cost housing beckons low-income people inward because of the available housing. They continue coming to the city until their numbers so far exceed the available income opportunities that the standard of living declines far enough to stop further inflow. Income to the area is then too low to maintain all of the housing. Excess housing falls into disrepair and is abandoned. One can simultaneously have extreme crowding in those buildings that are occupied, while other buildings become excess and are abandoned because the economy of the area cannot support all of the residential structures. But the excess residential buildings threaten the area in two ways — they occupy the land so that it cannot be used for job-creating buildings, and they stand ready to accept a rise in population if the area should start to improve economically.

Any change which would otherwise raise the standard of living only takes off the economic pressure momentarily and causes the population to rise enough that the standard of living again falls to the barely tolerable level. A self-regulating system is thereby at work which drives the condition of the depressed area down far enough to stop the increase in people.

At any time, a near-equilibrium exists affecting population mobility between the different areas of the country. To the extent that there is disequilibrium, it means that some area is slightly more attractive than others and population begins to move in the direction of the more attractive area. This movement continues until the rising population drives the more attractive area down in attractiveness until the area is again in equilibrium with its surroundings. Other things being equal, an increase in population of a city crowds housing, overloads job opportunities, causes congestion, increases pollution, encourages crime, and reduces almost every component of the quality of life.

This powerful dynamic force to re-establish an equilibrium in total attractiveness means that any social program must take into account the eventual shifts that will occur in the many components of attractiveness. As used here, attractiveness is the composite effect of all factors that cause population movement toward or away from an area. Most areas in a country have nearly equal attractiveness most of the time, with only sufficient disequilibrium in attractiveness to account for the shifts in population. But areas can have the same composite attractiveness with different mixes in the components of attractiveness. In one area component A could be high and B low, while the reverse could be true in another area that nevertheless had the same total composite attractiveness. If a program makes some aspect of an area more attractive than its neighbor's, and thereby makes total attractiveness higher momentarily, population of that area rises until other components of attractiveness are driven down far enough to again establish an equilibrium. This means that efforts to improve the condition of our cities will result primarily in increasing the population of the cities and causing the population of the country to concentrate in the cities. The overall condition of urban life, for any particular economic class of population, cannot be appreciably better or worse than that of the remainder of the country to and from which people may come. Programs aimed at improving the city can succeed only if they result in eventually raising the average quality of life for the country as a whole.

On Raising the Quality of Life

But there is substantial doubt that our urban programs have been contributing to the national quality of life. By concentrating total population, and especially low-income-population, in urban locations, undermining the strength and cohesiveness of the community, and making government and bureaucracy so big that the individual feels powerless to influence the system within which he is increasingly constrained, the quality of life is being reduced. In fact, if they have any effect, our efforts to improve our urban areas will in the long run tend to delay the concern about rising total population and thereby contribute directly to the eventual overcrowding of the country and the world.

Any proposed program must deal with both the quality of life and the factors affecting population. "Raising the quality of life" means releasing stress and pressures, reducing crowding, reducing pollution, alleviating hunger, and treating ill health. But these pressures are exactly the sources of concern and action aimed at controlling total population to keep it within the bounds of the fixed world within which we live. If the pressures are relaxed, so is the concern about how we impinge on the environment. Population will then rise further until the pressures reappear with an intensity that can no longer be relieved. To try to raise quality of life without intentionally creating compensating pressures to prevent a rise in population density will be self-defeating.

Consider the meaning of these interacting attractiveness components as they affect a depressed ghetto area of a city. First we must be clear on the way population density is, in fact, now being controlled. There is some set of forces determining that the density is not far higher or lower than it is. But there are many possible combinations of forces that an urban area can exert. The particular combination will determine the population mix of the area and the economic health of the city. I suggest that the depressed areas of most American cities are created by a combination of forces in which there is a job shortage and a housing excess. The availability of housing draws the lowest-income group until they so far exceed the opportunities of the area that the low standard of living, the frustration, and the crime rate counterbalance the housing availability. Until the pool of excess housing is reduced, little can be done to improve the economic condition of the city. A low-cost housing program alone moves exactly in the wrong direction. It draws more low-income people. It makes the area differentially more attractive to the poor who need jobs and less attractive to those who create jobs. In the new population equilibrium that develops, some characteristic of the social system must compensate for the additional attractiveness created by the low-cost housing. The counterbalance is a further decline of the economic condition for the area. But as the area becomes more destitute, pressures rise for more low-cost housing. The consequence is a downward spiral that draws in the low-income population, depresses their condition, prevents escape, and reduces hope. All of this is done with the best of intentions.

My paper, "Systems Analysis as a Tool for Urban Planning" from a symposium in October, 1969, at the National Academy of Engineering, suggests a reversal of present practice in order to simultaneously reduce the aging housing in our cities and allocate land to income-earning opportunities. The land shifted to industry permits the "balance of trade" of the area to be corrected by allowing labor to create and export a product to generate an income stream with which to buy the necessities of modern life from the outside. But the concurrent reduction of excess housing is absolutely essential. It supplies the land for new jobs. Equally important, the resulting housing shortage creates the population-stabilizing pressure that allows economic revival to proceed without being inundated by rising population. This can all be done without driving the present low-income residents out of the area. It can create upward economic mobility to convert the low-income population to a self-supporting basis.

The first reaction of many people to these ideas is to believe that they will never be accepted by elected officials or by residents of depressed urban areas. But some of our strongest support and encouragement is coming from those very groups who are closest to the problems, who see the symptoms first-hand, who have lived through the failures of the past, and who must live with the present conditions until enduring solutions are found.

Over the last several decades the country has slipped into a set of attitudes about our cities that are leading to actions that have become an integral part of the system that is generating greater troubles. If we were malicious and wanted to create urban slums, trap low-income people in ghetto areas, and increase the number of people on welfare, we could do little better than follow the present policies. The trend toward stressing income and sales taxes and away from the real estate tax encourages old buildings to remain in place and block self-renewal. The concessions in the income tax laws to encourage low-income housing will in the long run actually increase the total low-income population of the country. The highway expenditures and the government loans for suburban housing have made it easier for higher-income groups to abandon urban areas than to revive them. The pressures to expand the areas incorporated by urban government, in an effort to expand the revenue base, have been more than offset by lowered administrative efficiency, more citizen frustration, and the accelerated decline that is triggered in the annexed areas. The belief that more money will solve urban problems has taken attention away from correcting the underlying causes and has instead allowed the problems to grow to the limit of the available money, whatever that amount might be.[2]

Characteristics of Social Systems

I turn now to some characteristics of social systems that mislead people. These have been identified in our work with corporate and urban systems and in more recent work that I will describe concerning the worldwide pressures that are now enveloping our planet.

First, social systems are inherently insensitive to most policy changes that people select in an effort to alter the behavior of the system. In fact, a social system tends to draw our attention to the very points at which an attempt to intervene will fail. Our experience, which has been developed from contact with simple systems, leads us to look close to the symptoms of trouble for a cause. When we look, we discover that the social system presents us with an apparent cause that is plausible according to what we have learned from simple systems. But this apparent cause is usually a coincident occurrence that, like the trouble symptom itself, is being produced by the feedback-loop dynamics of a larger system. For example, as already discussed, we see human suffering in the cities; we observe that it is accompanied (some think caused) by inadequate housing. We increase the housing and the population rises to compensate for the effort. More people are drawn into and trapped in the depressed social system. As another example, the symptoms of excess population are beginning to overshadow the country. These symptoms appear as urban crowding and social pressure. Rather than face the population problem squarely we try to relieve the immediate pressure by planning industry in rural areas and by discussing new towns. If additional urban area is provided it will temporarily reduce the pressures and defer the need to face the underlying population question. The consequence, as it will be seen 25 years hence, will have been to contribute to increasing the population so much that even today's quality of life will be impossible.

A second characteristic of social systems is that all of them seem to have a few sensitive influence points through which the behavior of the system can be changed. These influence points are not in the location where most people expect. Furthermore, if one identifies in a model of a social system a sensitive point where influence can be exerted, the chances are still that a person guided by intuition and judgment will alter the system in the wrong direction. For example in the urban system, housing is a sensitive control point but, if one wishes to revive the economy of a city and make it a better place for low-income as well as other people, it appears that the amount of low-income housing must be reduced rather than increased. Another example is the world-wide problem of rising population and the disparity between the standards of living in the developed and the underdeveloped countries, an issue arising in the world system to be discussed in the following paragraphs. But it is beginning to appear that a sensitive control point is the rate of generation of capital investment.

And how should one change the rate of capital accumulation? The common answer has been to increase industrialization, but recent examination suggests that hope lies only in reducing the rate of industrialization. This may actually help raise quality of life and contribute to stabilizing population.

As a third characteristic of social systems, there is usually a fundamental conflict between the short-term and long-term consequences of a policy change. A policy which produces improvement in the short run, within five to ten years, is usually one which degrades the system in the long run, beyond ten years. Likewise, those policies and programs which produce long-run improvement may initially depress the behavior of the system.

This is especially treacherous. The short run is more visible and more compelling. It speaks loudly for immediate attention. But a series of actions all aimed at short-run improvement can eventually burden a system with long-run depressants so severe that even heroic short-run measures no longer suffice. Many of the problems which we face today are the eventual result of short-run measures taken as long as two or three decades ago.

A Global Perspective

I have mentioned social organizations at the corporate level and then touched on work which has been done on the dynamics of the city. Now we are beginning to examine issues of even broader scope.

In July, 1970, we held a two-week international conference on world dynamics. It was a meeting organized for the Club of Rome, a private group of about 50 individuals drawn from many countries who have joined together to attempt a better understanding of social systems at the world level. Their interest lies in the same problems of population, resources, industrialization, pollution, and world-wide disparities of standard of living on which many groups now focus. But the Club of Rome is devoted to taking actions that will lead to a better understanding of world trends and to influencing world leaders and governments. The July meeting at M.I.T. included the general theory and behavior of complex systems and talks on the behavior of specific social systems ranging from corporations through commodity markets to biological systems, drug addiction in the community, and growth and decline of a city. Especially prepared for this conference was a dynamic model of the interactions between world population, industrialization, depletion of natural resources, agriculture, and pollution. A detailed discussion of this world system will soon appear in my book World Dynamics, and its further development is the purpose of the "Project on the Predicament of Mankind" being sponsored by the Club of Rome at M.I.T. for a year under the guidance of Professor Dennis Meadows. The plan is to develop a research group of men from many countries who will eventually base their continuing efforts in a neutral country such as Switzerland. The immediate project will reexamine, verify, alter, and extend the preliminary dynamic study of the world system and will relate it to the present world-wide concern about trends in civilization.

The simple model of world interactions as thus far developed shows several different alternative futures depending on whether population growth is eventually suppressed by shortage of natural resources, by pollution, by crowding and consequent social strife, or by insufficient food. Malthus dealt only with the latter, but it is possible for civilization to encounter other controlling pressures before a food shortage occurs.

It is certain that resource shortage, pollution, crowding, food failure, or some other equally powerful force will limit population and industrialization if persuasion and psychological factors do not. Exponential growth cannot continue forever. Our greatest immediate challenge is how we guide the transition from growth to equilibrium. There are many possible mechanisms of growth suppression. That some one or combination will occur is inevitable. Unless we come to understand and to choose, the social system by its internal processes will choose for us. The natural mechanisms for terminating exponential growth appear to be the least desirable. Unless we understand and begin to act soon, we may be overwhelmed by a social and economic system we have created but can't control.

Figure 1[3] shows the structure that has been assumed. It interrelates the mutual effects of population, capital investment, natural resources, pollution, and the fraction of capital devoted to agriculture. These five system "levels" are shown in the rectangles. Each level is caused to change by the rates of flow in and out, such as the birth rate and death rate that increase and decrease population. As shown by the dotted lines, the five system levels, through intermediate concepts shown at the circles, control the rates of flow. As an example, the death rate at Symbol 10 depends on population P and the "normal" lifetime as stated by death rate normal DRN. But death rate depends also on conditions in other parts of the system. From Circle 12 comes the influence of pollution that here assumes death rate to double if pollution becomes 20 times as severe as in 1970; and, progressively, that death rate would increase by a factor of 10 if pollution became 60 times as much as now. Likewise from Circle 13 the effect of food per capita is to increase death rate as food becomes less available. The detailed definition of the model states how each rate of flow is assumed to depend on the levels of population, natural resources, capital investment, capital devoted to food, and pollution.

Individually the assumptions in the model are plausible, create little disagreement, and reflect common discussions and assertions about the individual responses within the world system. But each is explicit and can be subjected to scrutiny. From one viewpoint, the system of Figure 1 is very simplified. It focuses on a few major factors and omits most of the substructure of world social and economic activity. But from another viewpoint, Figure 1 is comprehensive and complex. The system is far more complete and the theory described by the accompanying computer model is much more explicit than the mental models that are now being used as a basis for world and governmental planning. It incorporates dozens of nonlinear relationships. The world system shown here exhibits provocative and even frightening possibilities.

Transition from Growth to Equilibrium

With the model specified, a computer can be used to show how the system, as described for each of its parts, would behave. Given a set of beginning conditions, the computer can calculate and plot the results that unfold through time.

The world today seems to be entering a condition in which pressures are rising simultaneously from every one of the influences that can suppress growth — depleted resources, pollution, crowding, and insufficient food. It is still unclear which will dominate if mankind continues along the present path. Figure 2 shows the mode of behavior of this world system given the assumption that population reaches a peak and then declines because industrialization is suppressed by falling natural resources. The model system starts with estimates of conditions in 1900. Adjustments have been made so that the generated paths pass through the conditions of 1970.

In Figure 2 the quality of life peaks in the 1950's and by 2020 has fallen far enough to halt further rise in population. Declining resources and the consequent fall in capital investment then exert further pressure to gradually reduce world population.

But we may not be fortunate enough to run gradually out of natural resources. Science and technology may very well find ways to use the more plentiful metals and atomic energy so that resource depletion does not intervene. If so, the way then remains open for some other pressure to arise within the system. Figure 3 shows what happens within this system if the resource shortage is foreseen and avoided. Here the only change from Figure 2 is in the usage rate of natural resources after the year 1970. In Figure 3, resources are used after 1970 at a rate 75 per cent less than assumed in Figure 2. In other words, the standard of living is sustained with a lower drain on the expendable and irreplaceable resources. But the picture is even less attractive! By not running out of resources, population and capital investment are allowed to rise until a pollution crisis is created. Pollution then acts directly to reduce birth rate, increase death rate, and to depress food production. Population which, according to this simple model, peaks at the year 2030 has fallen to one-sixth of the peak population within an interval of 20 years — a world-wide catastrophe of a magnitude never before experienced. Should it occur, one can speculate on which sectors of the world population will suffer most. It is quite possible that the more industrialized countries (which are the ones which have caused such a disaster) would be the least able to survive such a disruption to environment and food supply. They might be the ones to take the brunt of the collapse.

Figure 3 shows how a technological success (reducing our dependence on natural resources) can merely save us from one fate only to fall victim to something worse (a pollution catastrophe). There is now developing throughout the world a strong undercurrent of doubt about technology as the savior of mankind. There is a basis for such doubt. Of course, the source of trouble is not technology as such but is instead the management of the entire technological-human-political-economic-natural complex.

Figure 3 is a dramatic example of the general process discussed earlier wherein a program aimed at one trouble symptom results in creating a new set of troubles in some other part of the system. Here the success in alleviating a natural resource shortage throws the system over into the mode of stopping population caused by industrialization which has been freed from natural resource restraint. This process of a solution creating a new problem has defeated many of our past governmental programs and will continue to do so unless we devote more effort to understanding the dynamic behavior of our social systems.

Alternatives to Decline or Catastrophe

Suppose in the basic world system of Figures 1 and 2 we ask how to sustain the quality of life which is beginning to decline after 1950. One way to attempt this, and it is the way the world is now choosing, might be to increase the rate of industrialization by raising the rate of capital investment. Models of the kind we are here using make such hypothetical questions answerable in a few minutes and at negligible cost. Figure 4 shows what happens if the "normal" rate of capital accumulation is increased by 20 per cent in 1970. The pollution crisis reappears. This time the cause is not the more efficient use of natural resources but the upsurge of industrialization which overtaxes the environment before resource depletion has a chance to depress industrialization. Again, an "obvious" desirable change in policy has caused troubles worse than the ones that were originally being corrected.

This is important, not only for its own message but because it demonstrates how an apparently desirable change in a social system can have unexpected and even disastrous results.

Figure 4 should make us cautious about rushing into programs on the basis of short-term humanitarian impulses. The eventual result can be anti-humanitarian. Emotionally inspired efforts often fall into one of three traps set for us by the nature of social systems: The programs are apt to address symptoms rather than causes and attempt to operate through points in the system that have little leverage for change; the characteristic of systems whereby a policy change has the opposite effect in the short run from the effect in the long run can eventually cause deepening difficulties after a sequence of short-term actions; and the effect of a program can be along an entirely different direction than was originally expected, so that suppressing one symptom only causes trouble to burst forth at another point.

Figure 5 retains the 20 per cent additional capital investment rate after 1970 from Figure 4 but in addition explores birth reduction as a way of avoiding crisis. Here the "normal" birth rate has been cut in half in 1970. (Changes in normal rates refer to coefficients which have the specified effect if all other things remain the same. But other things in the system change and also exert their effect on the actual system rates.) The result shows interesting behavior. Quality of life surges upward for 30 years for the reasons that are customarily asserted. Food-per-capita grows, material standard of living rises, and crowding does not become as great. But the more affluent world population continues to use natural resources and to accumulate capital plant at about the same rate as in Figure 4. Load on the environment is more closely related to industrialization than to population and the pollution crisis occurs at about the same point in time as in Figure 4.

Figure 5 shows that the 50 per cent reduction in "normal" birth rate in 1970 was sufficient to start a decline in total population. But the rising quality of life and the reduction of pressures act to start the population curve upward again. This is especially evident in other computer runs where the reduction in "normal" birthrate is not so drastic. Serious questions are raised by this investigation about the effectiveness of birth control as a means of controlling population. The secondary consequence of starting a birth control program will be to increase the influences that raise birth rate and reduce the apparent pressures that require population control. A birth control program which would be effective, all other things being equal, may largely fail because other things will not remain equal. Its very incipient success can set in motion forces to defeat the program.

Figure 6 combines the reduced resource usage rate and the increased capital investment rate of Figures 3 and 4. The result is to make the population collapse occur slightly sooner and more severely. Based on the modified system of Figure 6, Figure 7 then examines the result if technology finds ways to reduce the pollution generated by a given degree of industrialization. Here in Figure 7, the pollution rate, other things being the same, is reduced by 50 per cent from that in Figure 6. The result is to postpone the day of reckoning by 20 years and to allow the world population to grow 25 per cent greater before the population collapse occurs. The "solution" of reduced pollution has, in effect, caused more people to suffer the eventual consequences. Again we see the dangers of partial solutions. Actions at one point in a system that attempt to relieve one kind of distress produce an unexpected result in some other part of the system. If the interactions are not sufficiently understood, the consequences can be as bad as or worse than those that led to the initial action.

There are no Utopias in our social systems. There appear to be no sustainable modes of behavior that are free of pressures and stresses. But there are many possible modes and some are more desirable than others. Usually, the more attractive kinds of behavior in our social systems seem to be possible only if we have a good understanding of the system dynamics and are willing to endure the self-discipline and pressures that must accompany the desirable mode. The world system of Figure 1 can exhibit modes that are more hopeful than the crises of Figures 2 through 7. But to develop the more promising modes will require restraint and dedication to a long-range future that man may not be capable of sustaining.

Figure 8 shows the world system if several policy changes are adopted together in the year 1970. Population is stabilized. Quality of life rises about 50 per cent. Pollution remains at about the 1970 level. Would such a world be accepted? It implies an end to population and economic growth.

In Figure 8 the normal rate of capital accumulation is reduced 40 per cent from its previous value. The "normal" birth rate is reduced 50 per cent from its earlier value. The "normal" pollution generation is reduced 50 per cent from the value before 1970. The "normal" rate of food production is reduced 20 per cent from its previous value. (These changes in "normal" values are the changes for a specific set of system conditions. Actual system rates continue to be affected by the varying conditions of the system.) But reduction in investment rate and reduction in agricultural emphasis are counterintuitive and not likely to be discovered or accepted without extensive system studies and years of argument — perhaps more years than are available. The changes in pollution generation and natural resource usage may be easier to understand and to achieve. The severe reduction in world-wide birth rate is the most doubtful. Even if technical and biological methods existed, the improved condition of the world might remove the incentive for sustaining the birth reduction emphasis and discipline.

Future Policy Issues

The dynamics of world behavior bear directly on the future of the United States. American urbanization and industrialization are a major part of the world scene. The United States is setting a pattern that other parts of the world are trying to follow. That pattern is not sustainable. Our foreign policy and our overseas commercial activity seem to be running contrary to overwhelming forces that are developing in the world system. The following issues are raised by the preliminary investigations to date. They must, of course, be examined more deeply and confirmed by more thorough research into the assumptions about structure and detail of the world system.

» Industrialization may be a more fundamentally disturbing force in world ecology than is population. In fact, the population explosion is perhaps best viewed as a result of technology and industrialization. I include medicine and public health as a part of industrialization.

» Within the next century, man may be facing choices from a four-pronged dilemma — suppression of modern industrial society by a natural resource shortage, collapse of world population from changes wrought by pollution, population limitation by food shortage, or population control by war, disease, and social stresses caused by physical and psychological crowding.

» We may now be living in a "golden age" where, in spite of the world-wide feeling of malaise, the quality of life is, on the average, higher than ever before in history and higher now than the future offers.

» Efforts for direct population control may be inherently self-defeating. If population control begins to result as hoped in higher per capita food supply and material standard of living, these very improvements can generate forces to trigger a resurgence of population growth.

» The high standard of living of modern industrial societies seems to result from a production of food and material goods that has been able to outrun the rising population. But, as agriculture reaches a space limit, as industrialization reaches a natural-resource limit, and as both reach a pollution limit, population tends to catch up. Population then grows until the "quality of life" falls far enough to generate sufficiently large pressures to stabilize population.

» There may be no realistic hope for the present underdeveloped countries reaching the standard of living demonstrated by the present industrialized nations. The pollution and natural resource load placed on the world environmental system by each person in an advanced country is probably 20 to 50 times greater than the load now generated by a person in an underdeveloped country. With four times as much population in underdeveloped countries as in the present developed countries, their rising to the economic level of the United States could mean an increase of 200 times in the natural resource and pollution load on the world environment. Noting the destruction that has already occurred on land, in the air, and especially in the oceans, no capability appears to exist for handling such a rise in standard of living for the present total population of the world.

» A society with a high level of industrialization may be nonsustainable. It may be self-extinguishing if it exhausts the natural resources on which it depends. Or, if unending substitution for declining natural resources is possible, the international strife over "pollution and environmental rights" may pull the average world-wide standard of living back to the level of a century ago.

» From the long view of a hundred years hence, the present efforts of underdeveloped countries to industrialize along Western patterns may be unwise. They may now be closer to the ultimate equilibrium with the environment than are the industrialized nations. The present underdeveloped countries may be in a better condition for surviving the forthcoming world-wide environmental and economic pressures than are the advanced countries. When one of the several forces materializes that is strong enough to cause a collapse in world population, the advanced countries may suffer far more than their share of the decline.

A New Frontier

It is now possible to take hypotheses about the separate parts of a social system, to combine them in a computer model, and to learn the consequences. The hypotheses may at first be no more correct than the ones we are using in our intuitive thinking. But the process of computer modeling and model testing requires these hypotheses to be stated more explicitly. The model comes out of the hazy realm of the mental model into an unambiguous model or statement to which all have access. Assumptions can then be checked against all available information and can be rapidly improved. The great uncertainty with mental models is the inability to anticipate the consequences of interactions between the parts of a system. This uncertainty is totally eliminated in computer models. Given a stated set of assumptions, the computer traces the resulting consequences without doubt or error. This is a powerful procedure for clarifying issues. It is not easy. Results will not be immediate.

We are on the threshold of a great new era in human pioneering. In the past there have been periods characterized by geographical exploration. Other periods have dealt with the formation of national governments. At other times the focus was on the creation of great literature. Most recently we have been through the pioneering frontier of science and technology. But science and technology are now a routine part of our life. Science is no longer a frontier. The process of scientific discovery is orderly and organized.

I suggest that the next frontier for human endeavor is to pioneer a better understanding of the nature of our social systems. The means are visible. The task will be no easier than the development of science and technology. For the next 30 years we can expect rapid advance in understanding the complex dynamics of our social systems. To do so will require research, the development of teaching methods and materials, and the creation of appropriate educational programs. The research results of today will in one or two decades find their way into the secondary schools just as concepts of basic physics moved from research to general education over the past three decades.

What we do today fundamentally affects our future two or three decades hence. If we follow intuition, the trends of the past will continue into deepening difficulty. If we set up research and educational programs which are now possible but which have not yet been developed, we can expect a far sounder basis for action.

The Nation's Real Alternatives

The record to date implies that our people accept the future growth of United States population as preordained, beyond the purview and influence of legislative control, and as a ground rule which determines the nation's task as finding cities in which the future population can live. But I have been describing the circular processes of our social systems in which there is no unidirectional cause and effect but instead a ring of actions and consequences that close back on themselves. One could say, incompletely, that the population will grow and that cities, space, and food must be provided. But one can likewise say, also incompletely, tha the provision of cities, space, and food will cause the population to grow. Population generates pressure for urban growth, but urban pressures help to limit population.

Population grows until stresses rise far enough, which is to say that the quality of life falls far enough, to stop further increase. Everything we do to reduce those pressures causes the population to rise farther and faster and hastens the day when expediencies will no longer suffice. The United States is in the position of a wild animal running from its pursuers. We still have some space, natural resources, and agricultural land left. We can avoid the question of rising population as long as we can flee into this bountiful reservoir that nature provided. But it is obvious that the reservoirs are limited. The wild animal usually flees until he is cornered, until he has no more space. Then he turns to fight, but he no longer has room to maneuver. He is less able to forestall disaster than if he had fought in the open while there was still room to yield and to dodge. The United States is running away from its long-term threats by trying to relieve social pressures as they arise. But if we persist in treating only the symptoms and not the causes, the result will be to increase the magnitude of the ultimate threat and reduce our capability to respond when we no longer have space to flee.

What does this mean? Instead of automatically accepting the need for new towns and the desirability of locating Industry in rural areas, we should consider confining our cities. If it were possible to prohibit the encroachment by housing and industry onto even a single additional acre of farm and forest, the resulting social pressures would hasten the day when we stabilize population. Some European countries are closer to realizing the necessity of curtailing urban growth than are we. As I understand it, farm land surrounding Copenhagen cannot be used for either residence or industry until the severest of pressures forces the government to rezone small additional parcels. When land is rezoned, the corresponding rise in land price is heavily taxed to remove the incentive for land speculation. The waiting time for an empty apartment in Copenhagen may be years. Such pressures certainly cause the Danes to face the population problem more squarely than do we.

Our greatest challenge now is how to handle the transition from growth into equilibrium. Our society has behind it a thousand years of tradition that has encouraged and rewarded growth. The folklore and the success stories praise growth and expansion. But that is not the path of the future. Many of the present stresses in our society are from the pressures that always accompany the conversion from growth into equilibrium.

In our studies of social systems, we have made a number of investigations of life cycles that start with growth and merge into equilibrium. There are always severe stresses in the transition. Pressures must rise far enough to suppress the forces that produced growth. Not only do we face the pressure that will stop the population growth; we also encounter pressures that will stop the rise of industrialization and standard of living. The social stresses will rise. The economic forces will be ones for which we have no precedent. The psychological forces will be beyond those for which we are prepared. Our studies of urban systems demonstrated how the pressures from shortage of land and rising unemployment accompany the usual transition from urban growth to equilibrium. But the pressures we have seen in our cities are minor compared to those which the nation is approaching. The population pressures and the economic forces in a city that was reaching equilibrium have in the past been able to escape to new land areas.

But that escape is becoming less possible. Until now we have had, in effect, an inexhaustible supply of farm land and food-growing potential. But now we are reaching the critical point where, all at the same time, population is overrunning productive land, agricultural land is almost fully employed for the first time, the rise in population is putting more demand on the food supplies, and urbanization is pushing agriculture out of the fertile areas into the marginal lands. For the first time demand is rising into a condition where supply will begin to fall while need increases. The crossover from plenty to shortage can occur abruptly.

The fiscal and monetary system of the country is a complex social-economic-financial system of the kind we have been discussing. It is clear the country is not agreed on behavior of the interactions between government policy, growth, unemployment, and inflation. An article by a writer for Finance magazine in July, 1970, suggests that the approach I have been discussing be applied in fiscal and monetary policy and their relationships to the economy. I estimate that such a task would be only a few times more difficult than was the investigation of urban growth and stagnation. The need to accomplish it becomes more urgent as the economy begins to move for the first time from a history of growth into the turbulent pressures that will accompany the transition from growth to one of the many possible kinds of equilibrium. We need to choose the kind of equilibrium before we arrive.

In a hierarchy of systems, there is usually a conflict between the goals of a subsystem and the welfare of the broader system. We see this in the urban system. The goal of the city is to expand and to raise its quality of life. But this increases population, industrialization, pollution, and demands on food supply. The broader social system of the country and the world requires that the goals of the urban areas be curtailed and that the pressures of such curtailment become high enough to keep the urban areas and population within the bounds that are satisfactory to the larger system of which the city is a part. If this nation chooses to continue to work for some of the traditional urban goals, and if it succeeds, as it may well do, the result will be to deepen the distress of the country as a whole and eventually to deepen the crisis in the cities themselves. We may be at the point where higher pressures in the present are necessary if insurmountable pressures are to be avoided in the future.

I have tried to give you a glimpse of the nature of multi-loop feedback systems, a class to which our social systems belong. I have attempted to indicate how these systems mislead us because our intuition and judgment have been formed to expect behavior different from that actually possessed by such systems. I believe that we are still pursuing national programs that will be at least as frustrating and futile as many of the past. But there is hope. We can now begin to understand the dynamic behavior of our social systems. Progress will be slow. There are many cross-currents in the social sciences which will cause confusion and delay. The approach that I have been describing is very different from the emphasis on data gathering and statistical analysis that occupies much of the time of social research. But there have been breakthroughs in several areas. If we proceed expeditiously but thoughtfully, there is a basis for optimism.

Suggested Readings

Jay W. Forrester, *Industrial Dynamics*. Cambridge: The M.I.T. Press, 1961.

Jay W. Forrester, *Principles of Systems*. Cambridge (238 Main St.): Wright-Allen Press, 1968.

Jay W. Forrester, *Urban Dynamics*. Cambridge: The M.I.T. Press, 1969.

Jay W. Forrester, *World Dynamics*. Cambridge: Wright-Allen Press, forthcoming.

Jay W. Forrester studied electrical engineering at the University of Nebraska and M.I.T. and made outstanding contributions to digital computer technology in the Digital Computer and Lincoln Laboratories at M.I.T. betore joining the Sloan School of Management, where he has developed what has become known as "industrial dynamics." In 1968 he received the Inventor of the Year Award from George Washington University and in 1969 the Valdemar Poulsen Gold Medal from the Danish Academy of Technical Sciences. His book Industrial Dynamics received the Academy of Management award in 1962 and his Urban Dynamics was chosen as best publication in 1969 by the Organization Development Council.

Figure 1. Upon this world model are based the author's analyses of the effects of changing population and economic growth factors in the next 50 years. It shows the interrelation of population, capital investment, natural resources, pollution, and the fraction of capital devoted to agriculture on which is based the following discussion.

Figure 2. Basic world model behavior showing the mode in which industrialization and population are suppressed by falling natural resources.

Figure 3. Pollution crisis precipitated by lower usage rate of natural resources. In 1970 natural resource usage is reduced 75 per cent by more effective technology without affecting material standard of living.

Figure 4. In 1970 the rate of capital accumulation is increased 20 per cent in an effort to reverse the beginning decline in quality of life. The pollution crisis occurs belore natural resources are depleted.

Figure 5. In 1970 the 20 per cent increase in capital accumulation of Figure 4 is retained and "normal" birth rate is reduced 50 per cent. Capital investment continues to grow until the pollution crisis develops. After an initial decline, population is again pushed up by the rapid rise in quality of life that precedes the collapse.

Figure 6. The 20 per cent increase of capital investment from Figure 4 and the 75 per cent reduction of natural resource usage from Figure 3 are combined.

Figure 7. Increased capital investment rate and reduced natural resource usage from Figure 6 are retained. In addition in 1970 the "normal" rate of pollution generation is reduced 50 per cent. The effect of pollution control is to allow population to grow 25 per cent further and to delay the pollution crisis by 20 years.

Figure 8. One set of conditions that establishes a world equilibrium. In 1970 capital investment rate is reduced 40 per cent, birth rate is reduced 50 per cent, pollution generation is reduced 50 per cent, natural resource usage rate is reduced 75 per cent, and food production is reduced 20 per cent.

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1. It is based on testimony for the Subcommittee on Urban Growth of the Committee on Banking and Currency, U.S. House of Representatives, on October 7, 1970.

2. Our continuing examination of urban behavior has been made possible through a grant to M.I.T. from the Independence Foundation of Philadelphia.

3. All figures are taken from the manuscript for World Dynamics by Jay W. Forrester, Wright-Allen Press, 238 Main Street, Cambridge, Mass. 02142, available about February, 1971.

A reprint of this paper complete with figures is available for $4.00 from

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