LESSONS FROM SYSTEM DYNAMICS MODELING

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Abstract. The power and utility of system dynamics depends on going beyond a model to implications and generalizations that can be drawn from the process of modeling. System dynamics papers too often stop with the description of a model. But to be effective, models should become part of a more persuasive communications process that interacts with people's mental models, creates new insights, and unifies knowledge. In doing so, modeling can make use of the full range of available information--the mental data base and the written data base, as well as the numerical data base. The last century has been devoted to exploring the frontier of physical science. During the next century the great frontier will be exploring the dynamic nature of social and economic systems.

INTRODUCTION

From the last three decades in system dynamics modeling have come insights that I hope will be useful guides for working toward a better understanding of the world around us.

The search for such a better understanding of social and economic systems represents the next great frontier. Frontiers of the past have included establishing great literatures, exploring geographical limits of earth and space, and penetrating mysteries of physical science. Those fields are no longer frontiers; they have become a part of everyday activity. By contrast, insights into behavior of social systems have not advanced in step with understanding of the natural world. To quote B. F. Skinner:

> "Twenty-five hundred years ago it might have been said that man understood himself as well as any other part of his world... Today he is the thing he understands least. Physics and biology have come a long way, but there has been no comparable development of anything like a science of human behavior... Aristotle could not

have understood a page of modern physics or biology, but Socrates and his friends would have little trouble in following most current discussions of human affairs."[1]

The challenge for the next several decades will be to advance our understanding of social systems in the same way that the past century has advanced our understanding of the physical world.

MODELING FOR WHAT PURPOSE?

The ultimate significance of a system dynamics model depends on a clear initial identification of an important purpose and objective. Presumably the model will organize, clarify, and unify knowledge. The model should give people a more effective view of an important system that has exhibited puzzling or controversial behavior. Creating a more effective viewpoint means that the relevant mental models are being altered. But whose mental models are to be influenced? If a model is to to have impact, it must couple to the concerns of a target audience. Successful modeling should start by identifying the target audience for the model.

Unifying Knowledge

Complex systems defy intuitive solutions. Even a third order, linear differential equation is unsolvable by inspection. Important situations in management, economics, medicine, and social behavior usually lose reality if simplified to less than a fifth-order (many must be twentieth order or more) highly nonlinear dynamic systems.

Attempts to deal with nonlinear dynamic systems, using the ordinary processes of description and debate, lead to internal inconsistencies. The underlying assumptions may have been left unclear and contradictory. The assumed resulting behavior is likely to be contrary to that implied by the assumptions about system structure and governing policies.

System dynamics modeling can be effective because it builds on the reliable part of our understanding of systems while compensating for the unreliable part. Figure 1 divides knowledge of systems into three categories to illustrate wherein lie the strengths and weaknesses of mental models and simulation models.

1 Skinner (1971), p. 3

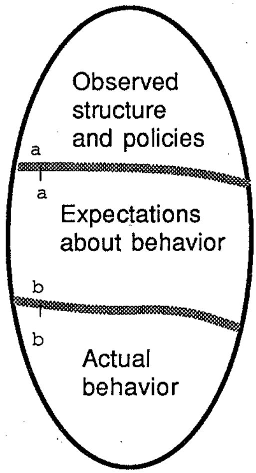

Figure 1. Three categories of information in the mental data base.

The top of the figure represents knowledge about structure and policies, that is, about the elementary parts of a system. This is local non-dynamic knowledge. It describes the information available at each decision-making point. It identifies who controls each part of the system. It reveals how pressures and crises influence decisions. In general, information about structure and policies is far more reliable than generally assumed. It is only necessary to dig out the information, guided by knowing how structure is related to dynamics, that is, by using system dynamics insights about how to organize structural information to address a particular set of dynamic issues.

The middle of the figure represents assumptions about how the system will behave, based on the observed structure and policies. This second body of assertions are, in effect, the intuitive solutions to the dynamic equations described by the structure and policies in the top section of the diagram. In the middle lie the presumptions that lead managers to change policies or lead governments to change laws. The policies and laws in the top section are changed to achieve the behavior that is assumed in the middle section.

The bottom of the figure represents the actual system behavior as observed. Very often, actual behavior differs from expected behavior. Discrepancies exist across the boundary b-b. The surprise, arising from the fact that observed structure and policies lead not to the expected behavior but to the actual behavior, is usually explained by assuming that information about structure and policies must have been incorrect.

Blaming inadequate knowledge about parts of the system has resulted in investment of uncounted millions of man-hours in data gathering, questionnaires, and interviews that have failed to significantly improve the understanding of systems.

But a system dynamics investigation usually shows that the important discrepancy is not across the boundary b-b, but across the boundary a-a. A model is built from the observed structure and policies. The model then exhibits the actual behavior of the real system. The knowledge about the parts of the system is shown to explain the actual behavior. The dissidence in the diagram arises from the intuitive solution leading to the expected behavior.

The discrepancies of Figure 1 have been observed many times in the corporate world. A company has a severe and widely known difficulty, such as falling market share or unusual instability of employment. Interviews reveal descriptions of policies followed within the company. Such policies are often justified on the basis that they are aimed at solving the difficulty. The asserted policies are then used to construct a system dynamics model and, to the surprise of most people, the model manifests the serious symptoms arising within the actual company. In other words, the corporate difficulty is implicit in the policies that people know they are following. Such a situation is treacherous. If people believe that the policies lead toward a solution, but, in the complexity of the situation they do not realize that the policies are causing the problem, then, as matters get worse the incentives become stronger and stronger to take the very actions that are causing the difficulties.

In a similar way at the national level, we find from the System Dynamics National Model that puzzling and controversial economic behavior arises directly from known structure and managerial policies.[2] By building production sectors of the National Model using managerial policies derived from 20 years of corporate modeling, we find that most economic behavior arises from the private sector. Governmental taxation and monetary policies have far less effect than usually assumed and lack the expected leverage for controlling economic behavior. The Great Depression of the 1930s has been blamed both on restrictive monetary policy and on protective tariffs, but we find that depressions arise at 45 to 60 year intervals as a result of the economic long wave, or Kondratieff cycle, which is driven primarily by capital investment and closely related policies in the private sector.

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[2] Forrester (1979)

Because of errors in mental models, policy changes aimed at improving behavior both in business and government, have often led to ineffective results, or worse, to the opposite of the intended results.

A policy giving opposite of the intended result was identified in Urban Dynamics.[3] Economic distress in declining American cities in the 1960s generated symptoms of high unemployment and deteriorating housing. It appeared natural enough to combat such symptoms by government intervention to build low cost housing. But the modeling study showed, as events have since confirmed, that such areas already had more low-cost housing than the economy of the city could maintain. Public policy to build more such housing merely occupied land that could have been used for job-creating businesses, while at the same time the housing attracted people who needed jobs. The low-cost housing program was a powerful force for increasing the unemployment ratio both by reducing employment while at the same increasing the number of people needing jobs. The policy of building low-cost housing was actually creating poor and unemployed people, rather than alleviating personal hardship. The lesson here is to avoid attacking symptoms of difficulty until the causes of those symptoms have been identified, and a high-leverage policy has been found that will cause the system itself to correct the problem.

Enhancing Mental Models

System dynamics models have little impact unless they change the way people perceive a situation. The model must help to organize information in a more understandable way, link the past to the present by showing how present conditions arose, and project persuasively the present into alternative futures under a variety of scenarios determined by policy alternatives. In other words, a system dynamics model, if it is to be effective, must communicate with and modify the prior mental models. Only people's beliefs, that is, their mental models, will determine action.

What kind of system dynamics model interacts best with mental models? Clearly, a small model has advantages over a large model. A recent trend in system dynamics has been toward small models to be used for enhancing insight. Often, such models have been built directly from the mental models. The process is one of discussing with a person his concerns, assumptions, and expectations. While the conversation is in progress, a system dynamics model can be created on a desktop computer. Recent software advances, especially STELLA,[4] facilitate the

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[3] Forrester (1969), p. 65-70.

[4] Richmond (1985), p. 706-718. STELLA is available from High Performance Systems, 13 Dartmouth Highway, Lyme, NH 03768, USA.

interaction between mental models and computer models.[5,6] Simple models used as interactive games, such as the one demonstrating the economic long wave or Kondratieff cycle,[7] can also create a dramatic impact as they reveal unexpected implications of existing mental models.

Small models versus Large models

If small models align best with mental models, and thereby have the greatest effect, what is the role for large models? The answer must depend of the circumstances. First, the size of model that can interact with mental models depends on the amount of time and effort that will be devoted to making connections between the mental and the computer simulation models. If the available time is a half day, clearly the computer model can have no more than a few variables. On the other hand, if the computer model is for research purposes and months or even years are available to explore its implications, then the model can be of far wider scope. Even with more time available, there must be a clear justification for a large model.

The System Dynamics National Model serves to put large and small models into perspective. The National Model is large, with several thousand equations. However, it is much smaller than was originally projected. As we have come to understand the Model better, and to relate its behavior to actual economic behavior, it has become apparent that the originally envisioned far larger model was not necessary. The proper balance between size and clarity suggested simplification. Many planned production sectors have now been aggregated into just two--capital and labor. Within sectors, there has been simplification especially in labor mobility and banking.

Research with the National Model focuses on four distinct modes of economic behavior--business cycles, the economic long wave, money inflation, and growth. Simple models have been created for demon - strating most of these modes separately.[8] Such simple models are possible because the separate modes arise from different structures within an economy. Such simple models are far easier to understand than the full National Model and for many purposes are more effective. However, simple models alone do not answer many important questions.

There are many important interactions between the four basic modes of the National Model that do not reveal themselves in any one of the simple models. An example is the way in which the long wave, having

5 Senge (1985), p. 788-798.
6 Vescuso (1985), p. 964-974.
7 Sterman and Meadows (1985), p. 878-885.
8 See Forrester, Nathan (1982); Low (1980)); Sterman (1985)

some 45 to 60 years between peaks, modulates the amplitude of short-term 3-to-10-year business cycles. We find that shortages of capital and labor and excess of demand during long-wave expansions, as in the 1950s and 1960s, suppresses business cycles. Near and after the long-wave peak, as in the 1970s and 1980s, the amplitude of business cycles becomes larger because of the excess of capital and labor that allow business-cycle expansions to be aggressive, to overbuild inventories, and to then require sharper cutbacks. This puts a different interpretation on economic behavior of the last several decades. After World War II, mild business cycles were attributed to monetary policy, but such beliefs were shattered when business cycles again became more severe. We see the shifting nature of business-cycle behavior as arising from interactions among major dynamic modes in the private economy, rather than from governmental policies. Furthermore, interactions between business cycles and the long wave explain most of the disappointments and confusion in the 1970s over the meaning and significance of the Phillips curve as a relationship between money supply and unemploy - ment.

THE SYSTEM DYNAMICS PARADIGM

System dynamics adheres to viewpoints and practices that set it apart from other fields dealing with the behavior of systems. But even so, the unique character of system dynamics has never been adequately set forth. Each aspect of system dynamics is accepted by some other group at least to some degree. System dynamics is distinguished not only by the particular cluster of beliefs that guide the work but also by the degree to which those characteristic are indeed practiced.

Endogenous Behavior

I believe the best system dynamics practice puts rather extreme demands on a model for generating within itself the behavior modes of interest. That is, the model boundary is to be established so that the causal mechanisms lie inside the boundary. This expectation of finding endogenous causes of behavior is in sharp contrast to the view often found elsewhere.[9]

In contrast to the endogenous viewpoint, economists often imply that the economic system is almost in equilibrium almost all the time with important behavior arising only from unexpected exogenous forces. The exogenous viewpoint common in economics leads to seeing the monetary authority as a free-will arm of government policy for unilaterally controlling economic behavior, whereas, in the National Model, we see

[9] Richardson (1984)

the monetary authority as an integral part of the economic system and as being responsive to forces such as unemployment and interest rates. Economists have explained business cycles in terms of exogenous actions of government, whereas, we find that business cycles arise out of internal oscillatory tendencies in production, employment, and inventories excited by those continuous streams of small random variations existing in all decision processes.

The system dynamics emphasis on endogenous behavior is more like that of an engineer in designing an oil refinery. The engineer looks at the individual working characteristics of the chemical reactors, evaporators, and distillation towers; considers how they are interconnected and controlled; and evaluates the dynamic behavior implied by their feedback loops. The engineer does not attempt to improve a refinery by using only information about the feed stocks that go in and the products that come out. He does not assume that the refinery exists in a state of equilibrium that is affected only by exogenous events that impact the plant from outside its surrounding fence.

System dynamics models build from the inside to determine and to modify the processes that cause desirable and undesirable behavior.

Sources of Information

Effectiveness of a model depends on how it uses the wide range of information arising from the system being represented.[10] In creating a system dynamics model, information is used in a substantially different way from that in other branches of the social sciences. The differences arise from the system dynamics focus on policy statements as the basic building blocks of a model and from a broader range of information sources used for creating a model.

Information is available from many sources. Figure 2 suggests three classifications of information--the mental data base, the written data base, and the numerical data base. Although "data" is a term that is often used to mean only numerical information, the dictionary meaning is far broader. Data is "something that is given from being experientially encountered" and "material serving as a a basis for discussion, inference, or determination of policy" and "detailed information of any kind."[11]

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10 Forrester (1980)

11 Webster's Third unabridged dictionary.

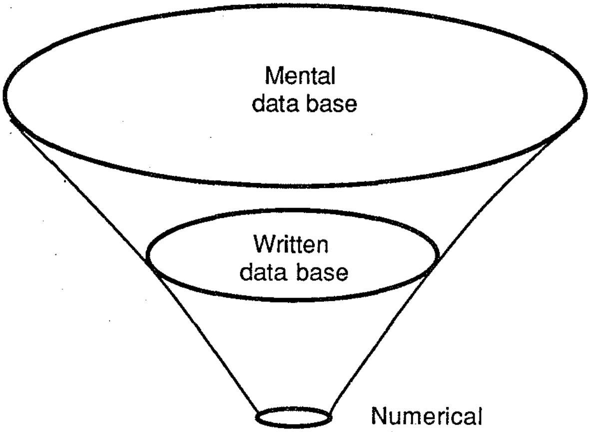

Figure 2. Decreasing information content in moving from mental to written to numerical data bases.

Human affairs are conducted primarily from the mental data base. Anyone who doubts the dominance of remembered information should imagine what would happen to an industrial society if it were deprived of all knowledge in people's heads and if action could be guided only by written policies and numerical information. There is no written description adequate for building an automobile, or managing a family, or governing a country. The dominant significance of information from the mental data base is not adequately appreciated in the social sciences.

The mental data base contains perhaps a million times as much information as the written data base, which, in turn, must contain a million times more information than in the numerical data base. Furthermore, the character of the information differs in the three categories. As one moves down the diagram, each category of information contains a smaller fraction devoted to structure and to description of policies. That is, the written and numerical data bases contain progressively smaller proportions of the information needed for constructing a dynamic model.

If the mental data base is so important to the conduct of human systems, then a model of such a system should include knowledge that resides only in the mental data. The mental data base is rich in structural detail; in it is knowledge of what information is available at various decision-making points, where people and goods move, and what decisions are made. The mental data base is especially concerned with policy, that is, why people respond as they do, what each decision-making center is trying to accomplish, what are the perceived penalties and rewards, and where self-interest clashes with institutional objectives.

In general, the mental data base relating to policy and structure is reliable. Of course, it must be cross-checked with all other available information. Exaggerations and over simplifications exist and must be corrected. Interviewees must be pressed beyond quick first responses. Interrogation must be guided by a system dynamics knowledge of what different structures imply for behavior. But from the mental data base, a consensus usually emerges that is useful and sufficiently correct.

The written data base contributes to a dynamic model at several stages. Published material makes information more widely available than if it is only exchanged between mental data bases. In terms of usefulness for modeling of business and economic systems, the daily and weekly public and business press is frequently more useful than the professional press or historical accounts that adopt a longer time horizon. The current press reports the pressures of the moment that surround decisions. The temporal nature of a decision sharply restricts the kind of literature in which operating policy will be revealed. Policies govern decisions and decisions control action. Decisions are fleeting. There is only a single instant in time when one can act. That time is now. Action must take place in the present moment that separates history from the future.

The ever-advancing present moment is the business person's and politician's world of action. It is the world of placing orders, hiring people, buying equipment, borrowing money, bargaining with unions, and extending credit. As a consequence of the short life of a decision, it is primarily in the literature of the present that decisions are discussed in terms of goals, threats, limited information, and restraints on action. The multifaceted conflicting pressures of real decision making are almost absent from economics textbooks and professional journals. The professional literature emphasizes how decisions should be made rather than how they actually are made, how equilibrium is determined rather than how dynamic behavior arises, and how macroeconomic theory might apply rather than how the microstructure creates the macrobehavior.

The numerical data base is of narrower scope than either the written or mental data bases. Missing from numerical data is direct evidence of the structure and policies that created the data. The numerical data do not reveal the cause and effect direction between variables. Even so, numerical data can contribute to system dynamics model building in three ways. First, numerical information is available on some parameter values. For example, average delivery delays for filling orders, typical ratios of factor inventories to production, normal bank balances, and usual inventory coverages can be determined from business records. Second, numerical data has been collected by many authors in the professional literature summarizing characteristics of economic behavior such as average periodicity of business cycles and phase relationships between variables. Third, the numerical data base contains time series information that in system dynamics is often best used for comparison with model output rather than for determining model parameters.

With regard to the use of data, system dynamics operates more like the engineering and medical professions, and less like practices in economics. All information is admissible to the process of model building. Information from the mental data base is recognized as a rich source of knowledge about structure and the policies governing decisions. Parameter values are drawn from all available sources, not merely from statistical analysis of time series. The mental and written data bases are the only sources of information about limiting conditions that have not occurred in practice but which are important in determining the nonlinear relationships that govern even normal behavior.

DURING MODEL BUILDING

During the process of modeling, the system dynamicist should always be alert to new discoveries about behavior. The new discoveries may relate either to the particular system being studied or to the general nature of systems.

Surprise Discoveries

Model building should be a continuous process of creating the model structure, testing behavior of the model, and comparing that behavior with knowledge about the real world being represented. Only if there is a standard against which the model is being compared--the real system--can one be prepared for surprises from the model. Surprising behavior means behavior that was not expected in terms of what was known about behavior of the actual system. Surprising behavior will usually point to model defects. But the modeler must be always alert to the possibility that the unexpected behavior of the model is revealing a new insight about the real system.

Our work on the economic long wave (Kondratieff cycle)[12] in the System Dynamics National Model Project arose as a surprise discovery. When sectors for consumer goods and capital equipment were first connected, a large fluctuation arose in the demand for capital equipment

[12] Forrester (1977)

with peaks some 50 years apart. In response to such a surprise, one first assumes a major error in the model. However, as a model is improved and errors are removed, there is a rising probability that surprising behavior is revealing a new insight about the real system. In the model, after study, the 50-year rise and fall of activity seemed plausible. Turning to historical economic behavior, we found extensive and diverse evidence of behavior like that which the model was generating. As other sectors of the model were added, additional model variables became involved in the long-wave process and repeatedly the expanded model behavior was found to have a real-life counterpart. For example, only recently we found that real interest rates in the model are low or negative before the long-wave peak, just as they were in the 1970s, and that real interest rates in the model move quickly positive after the peak, as they did in the early 1930s and as they have done again recently in the 1980s.

General Characteristics of Systems

Even more important than finding unexpected behavior of a specific system is the discovery of general characteristics that are applicable to a broad class of systems, or even to nearly all systems. In complex nonlinear systems, such generalizing is hazardous, but, even so, rules of thumb can be identified that are usually valid and give a useful basis for thinking about systems.

In such generalizing, one should make ties to history, myths, fables, and lessons from the great religions. The lessons that come to us from such traditional sources contain powerful threads of truth that are being ignored in modern attitudes dominated by short-run considerations.

Several general characteristics of systems were identified in Urban Dynamics.[13] A characteristic like the long-term versus short-term trade off applies to most decisions, yet is not given its proper weight in management and political decisions. On the other hand, the recognition of the trade off goes back at least as far as the ancient Greeks. Aesop's fable of the grasshopper and the ant contrasts the short-term advantage of playing in the summer with the long-term penalty of freezing in the winter. In building a public understanding of systems, we should seek general insights and make connections to where the same themes have appeared in literature.

Another inadequately appreciated general characteristic of systems lies in high resistance to policy changes. Perhaps as many as 98 percent of the policies in a system have little effect on its behavior because of the ability of the system to compensate for changes in most

[13] Forrester (1969), Chapter 6.

policies. One author criticized Urban Dynamics on the basis that it was a very bad model because the critic had been unable to find a policy that substantially changed the behavior of the model. But that insensitivity is not a defect in the model, it is the nature of the cities being represented by the model. Governments of American cities have expended billions of dollars over several decades without substantially altering the social problems with which they started. In a similar way, national governments have debated monetary policy, have tried all variations and theories, and are still left with worsening economic problems. In our work with the National Model, we find that monetary policy has low leverage over economic well-being.

SYSTEM DYNAMICS AND PUBLIC RESPONSES

System dynamics models have the potential for raising the quality of managerial and political debate. The World Dynamics,[14] and Limits to Growth,[15] books launched intense world-wide debate even though their subject had been treated in many preceding publications. Why? I believe there are two reasons.

The first reason for intense public involvement arose because a presentation based on a system dynamics model can have an internal consistency that is beyond the reach of the usual discussion process. The usual writing and debate about a complex social system contains internal contradictions. These contradictions usually occur in going from the structural assumptions to the implied dynamic consequences. In this step from assumptions to behavior, the writer tries to solve intuitively in his head the high-order nonlinear equations of the system; such is done correctly only rarely. But a model simulation provides certainty in going from the assumptions about structure and policies to the implied behavior. A presentation based on a model can have complete internal consistency. One knows the assumptions in the model. Simulation gives the behavior implied by those assumptions. Policy changes can be made and the resulting changes in behavior can be determined beyond doubt within the context of the model. Within the modeling process, there need be no contradictions.

But internal consistency is not enough. An argument can be internally consistent and still erroneous in comparison with the real world. But, the persuasiveness of the system dynamics process reaches its full power when the listener or reader finds agreement wherever his independent knowledge matches the presentation of assumptions, behavior, and policy implications. With Limits to Growth, readers found

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14 Forrester (1971)

15 Meadows (1972)

an embodiment of their concerns. The model contained assumptions that had everyday meaning, and behavior that corresponded to what they saw in the world around them. More and more in the intervening fifteen years, newspaper headlines are revealing the accentuation of those pressures--polluted wells, acid rain damage to forests, falling water tables, atomic waste disposal uncertainties, hunger in many parts of the world, and social pressures from crowding such as terrorism and illegal immigration.

The second reason for intense public response to the two books arose because of the way the books illuminated long-run issues. It is commonplace to assert that people take only a short-run view of life, but that is only partially true. In fact, most people live in a world of split personalities in which business and political actions are dominated by short-run objectives while at the same time personal goals remain long-term. Individuals intensely hope for the future happiness of their children and grandchildren even while responding unknowingly to short-run pressures in ways that jeopardize that future. Limits to Growth gave a way to understand the past and present that could assist in seeing into the future. Good system dynamics modeling contributes to relating the legacy of the past to decisions of the moment and actions of the present to their implications for years to come.

The greatest impact of system dynamics on public understanding probably will come from expansion of those isolated projects now starting for introducing systems thinking into high school and undergraduate studies. Traditional educational methods tend to discourage synthesis and use of the knowledge that the student has already acquired. Too much emphasis is put of the written data base and not enough on the mental data base. Education tends to be based on static facts rather than on the dynamics of natural and social change. Several years are needed to adjust one's thinking to a dynamic frame of reference.

Only when the concepts we deal with in system dynamics are more fully developed and then woven throughout the educational process will students have time to develop improved mental models to guide personal and public action. Just as understanding of the natural world rests on science studies woven into all educational levels, so will a comparable understanding of dynamic systems in man and nature need to be made a part of the entire educational sequence. The frontier is shifting. We have been through the frontier of science and technology. The next frontier is to achieve a broadly based understanding of social systems that can provide a foundation for effectively dealing with rising economic and international stresses.

REFERENCES

Forrester, Jay W. (1969). Urban Dynamics, MIT Press, Cambridge, MA

____________ (1971). World Dynamics, MIT Press, Cambridge, MA

____________ (1977). "Growth Cycles," De Economist, v. 125, no. 4, Kroese, Leiden.

____________ (1979). "An Alternative Approach to Economic Policy: Macrobehavior from Microstructure," in Economic Issues of the Eighties, Nake M. Kamrany and Richard H. Day,editors, Johns Hopkins University Press, Baltimore.

____________ (1980). "Information Sources for Modeling the National Economy," J. of the American Statistical Association, v. 75, no. 371, September, pp. 555-574.

Forrester, Nathan B. (1982). A Dynamic Synthesis of Basic Macroeconomic Theory: Implications for Stabilization Policy Analysis, Ph.D. Thesis, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA, USA

Low, Gilbert W. (1980). "The Multiplier-Accelerator Model of Business Cycles Interpreted from a System Dynamics Perspective," in Jorgen Randers (editor), Elements of the System Dynamics Method, M.I.T. Press, Cambridge, Mass., USA

Meadows, Donella H., et al., (1972). The Limits to Growth, Universe Books, New York

Richardson, George P. (1984). The Evolution of the Feedback Concept in American Social Science, Ph. D. Thesis, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Richmond, Barry (1985). STELLA: "Software for Bringing System Dynamics to the Other 98%," Proceedings of the 1985 International Conference of the System Dynamics Society.

Senge, Peter M. (1985). "System Dynamics, Mental Models, and the Development of Management Intuition," Proceedings of the 1985 International Conference of the System Dynamics Society .

Skinner, B. F. (1971). Beyond Freedom and Dignity, Bantam Books.

Sterman, John D. (1985). "A Behavioral Model of the Economic Long Wave," J. of Economic Behavior and Organization, v. 6, p. 17-53, North-Holland.

Sterman, John D. and Dennis Meadows (1985), "STRATEGEM-2: A Microcomputer Simulation Game of the Kondratiev Cycle," Proceedings of the 1985 International Conference of the System Dynamics Society.

Vescuso, Peter (1985). "Using STELLA to Create Learning Laboratories: An Example from Physics," Proceedings of the 1985 International Conference of the System Dynamics Society.