FUTURE DEVELOPMENT OF THE SYSTEM DYNAMICS PARADIGM

by

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A theme of this conference is "Enlarging the Paradigm" of system dynamics. I believe that "enlargement" is premature and points inthe wrong direction for next developments in the field. Instead, I suggest that we look to "Strengthening the System Dynamics Paradigm." Enlargement wouldbe a timely topic if the core of the system dynamics paradigm were solid, if system dynamics had been substantially exploited, and if the need for a larger scope had been demonstrated. But I believe that none of these is yet true. There are weaknesses throughout the present scope of system dynamics. System dynamics has far to go before its potential is exhausted. The shortcomings arise not from lack of scope but, instead, from unfinished business in almost every dimension of the present system dynamics paradigm. I am pleased to see that most of the papers being presented in the plenary sessions of this conference sharethat view.

If we were to enlarge the paradigm now, without building a solid core first, it could accentuate many of the present weaknesses. The present paradigm is not sharply defined, and there is no consistent view shared broadly by the practitioners. Steps in the system dynamics process have not been adequately codified, and as a result they are not readily accessible to beginners. Many important issues about model-building and the linkage of models to real-world usage have been only partially explored. There has been too much construction of models of isolated systems, without converting such models to generic theories of classes of systems that could be transferred from one setting to another. The common criticisms of system dynamics have been inadequately addressed, and the opportunities they afford for influencing other paradigms have been little realized. System dynamics is thinly spread over many issues and applications, without being deep enough in any one place to demonstrate its full potential.

Many of the shortcomings of system dynamics exist and maybe even originate at M.I.T. While stressing some aspects of system dynamics, we have neglected numerous dimensions of the field. But that is unavoidable. One research center cannot do everything, or even provide examples of work in all the dimensions of a field as comprehensive as system dynamics.

This evening I will suggest areas in which the system dynamics paradigm should be strengthened. It is not a comprehensive list, but more in the way of illustration. The emphasis is on building stronger foundations under what we are already doing, rather than enlarging the scope of system dynamics to incorporate techniques and processes from other fields.

A. ISSUES IN MODELING AND THE BEHAVIOR OF SYSTEM

There are many issues in modeling that have been identified, both inside and outside of system dynamics, that have been only superficially explored. Where the issues have been addressed, treatment often does not penetrate deeply enough to resolve the controversies.

Validity or confidence in models.

Validity of models has been much discussed, often in the form of criticism of someone else's model. But the issues are not rapidly approaching a resolution. Given the accepted importance of the subject, there are surprisingly few papers in the literature on establishing validity of models. The importance of the subject is reflected by confidence in models being a second theme of this conference. But it will take much more to quell the misunderstandings about validity between system dynamics and other paradigms that come to modeling from different backgrounds. The issues should be joined more forcefully. Perhaps there could be an extended working exchange between experts of different initial persuasions to define the issues and evaluate the different attitudes toward confidence in models. There should be a book on model validity coauthored by recognized experts from several fields to evaluate the validity of the approaches to validity. The matter of validity already lies within the system dynamics paradigm, but the issues need to be sharpened, the cost and proper extent of validity testing assessed, the hidden foundations of belief about validity uncovered, and the disagreements between fields either resolved or at least explained.

Randomness.

Much has been written in engineering and in statistics about noise, or randomness, in systems. But even so, the student of system dynamics does not have available an adequate treatment of the subject. How does randomness affect cyclic modes of a system? How does error within a system, and in measurements, affect various statistical procedures? Work by Senge with synthetic data suggests that some of the assumptions underlying statistical parameter estimation are both more necessary and less likely to be true than is usually assumed. [1] What limit does noise set on the ability of models to predict future conditions of a system? How should the bandwidth of noise be determined for simulation experiments? These and other questions about randomness are important in handling models and relating them to the real world. Within the system dynamics paradigm, there should be a stronger treatment of randomness.

Oscillation.

Oscillation is a familiar behavior mode of many system dynamics models. But the underlying process of oscillation itself is intuitively understood by few people. How many in this audience can give a correct, concise, persuasive, and memorable description of why oscillation occurs? How can one anticipate the period and damping of an oscillation from knowledge of the structure? Why do economists have such a hard time believing that the economy could contain structures causing a 50-year economic long wave? How do apparently minor changes in simple structures make major changes in periodicity and the damping or expansion of an oscillation? Why does so much of the social science literature try to describe oscillation in terms of turning points and a stepwise description that attributes each phase of an oscillation to a different cause, rather than seeing oscillation as a total mode arising from negative feedback loops? Even in some of the most obvious and recurring aspects of system dynamics, insights and educational materials have not been sufficiently developed.

Learning Models.

To what extent do real systems learn and evolve? System dynamics models are criticized for being mechanistic and unable to change with conditions. But is the objection justified? Business cycles have existed since industrial societies began, without enough learning to eliminate them. Why then should there be a presumption that learning from the past will so modify other modes of behavior that models with fixed structure are inappropriate? And do not system dynamics models learn? Is not a simple trend generation a learning from past behavior of a model, as it is in the real system being represented? Does not a model that uses past traditions generated by the model itself show a kind of learning? [2] Mosekilde, Rasmussen, and Sorensen in this conference suggest emphasizing self-organizing systems, which I take to be similar to learning systems. I agree, but do not see learning models as an enlargement of the system dynamics paradigm. Instead, the modeling of self-organization and learning would be an explanation and deepening of how system dynamics should deal with an important aspect of real systems.

B. AIDS TO PROCESS

System dynamics practice incorporates a heavy overlay of art, judgment, intuition, and skill derived from practice. That is true of all professions. As in system dynamics, professions such as engineering and medicine have an underlying foundation of science and guiding principles beyond which the professional decisions rest on experience. But in system dynamics the underlying principles are not yet as fully developed as in the major professions. We should look at the system dynamics process and ask, "What does the beginner need to know?" Is it not possible to put a better foundation under the practice of system dynamics than is now available?

Interpreting the Art.

If the field of system dynamics is to advance rapidly, more of the art of the practice must be reduced to teachable form. I do not foresee that the art will ever be fully captured in rules and procedures. Perhaps some of the weaknesses of the social sciences arise from trying to make the procedures too "scientific" at the expense of insight, creativity, and relevance. System dynamics has been criticized for being subjective and because two practitioners would probably not arrive at the same model and conclusions. Such is also true in law and medicine; it is true because the very nature of a profession is to reach beyond rigid cookbook procedures. But even so, there must be a constant striving to turn today's art into teachable principles and procedures so that tomorrow's practitioners can have a better foundation from which to extend the art still further. Examples where improved guidance should be possible are to be found in conceptualizing the structure of a system and in setting the boundaries for a model. Can there not be better articulated principles than we now have for going from objectives of a system project and knowledge about a real system to the structure, boundaries, and content of a model?

Reducing Trial and Experimentation.

Policy design with a system dynamics model has been largely a trial-and-error process guided by intuition about dynamic behavior. Such an experimental procedure can be time-consuming and costly. In our work at MIT with the System Dynamics National Model over the last ten years, we have made many thousands of computer runs. There must be a better way. Perhaps linear analysis can reach further than previously thought in helping to understand nonlinear systems. In his paper at this meeting, "Eigenvalue Analysis of Dominant Feedback Loops," Nathan Forrester suggests that linear analysis can efficiently reveal much of the parameter sensitivity and structural contribution to behavior modes that have traditionally been discovered by repeated simulations. Alan Graham and Alexander Pugh report in their paper on extending the eigenvalue analysis methods to the System Dynamics National Model, which in its present version contains about 200 levels. Strengthening the system dynamics paradigm means a constant search for methods that will reduce the cost and time required in understanding a system and improving its performance.

C. GENERIC MODELS

A model is a theory of the system that the model represents. The assumptions embodied in the structure of a model state the causal theory of how the behavior of the model is generated. If the model is a good representation of an actual situation, then it becomes a theory of how that part of the real world operates.

The primary utility of a theory lies in its generality and transferability. Ohm's Law in electricity would have little usefulness if it applied only to one specific electrical circuit and another law had to be discovered for the next circuit. An important aspect of a theory is its generality and transferability.

However, most system dynamics models have been presented as special cases. They are cast as a theory of a unique situation. They are interpreted with the narrowness and limitation that in the physical sciences would lead us to believe Newton's laws of motion apply only to falling apples, but not to baseballs or planets. A special-case theory can be important, if enough people are concerned about the unique situation. But, for many system dynamics models presented at conferences and in the literature, few other persons can identify with the particular circumstances of the study.

But are system dynamics models actually so narrow and unique? Is the shortcoming in the particular model, or in its presentation and interpretation? I believe that most models have a generality well beyond what the author sees. In strengthening the foundations of system dynamics, we should be striving for the transferability of models. We should be seeking general theories of behavior. We should be working toward a library of manageable size from which one could hope to choose a model, or theory, to fit the next unique situation of interest. Several people are already moving in the direction of generic models.

John Sterman has been working toward a family of simple structures to explain economic behavior. One example is his paper for this meeting, "A Simple Model of the Economic Long Wave." [3] Such simple models are generic models that apply to a wide range of economic systems.

In the program, Johnsen offers a provocative title, "Dynamics of the Arms Race." The arms race deals with social conflict. Here is the opportunity to treat conflict in a general way, so that the reader can interpret and understand the arms race in the context of his own experience with conflict. Are not the fundamentals the same as conflict in the family or in a lawsuit between corporations. Are not the futility and misunderstandings similar? Does it not provide the opportunity to incorporate theories of conflict from the social and political sciences and to evaluate those theories? Would we not understand the arms race better if we were to see it as a special case of a far more general human condition?

Or we can ponder the paper title "Some Ideas for a History Dynamics Model" being offered by Torrealdea and Grana. If this paper deals with the rise and fall of civilizations, is it not the same process, on a different time scale, as the life cycle of a corporation? Or there might even be interesting parallels to the life of a person or of a product in the market. We should be looking for the transferability of concepts from one such situation to another.

I believe that it would be helpful in strengthening the system dynamics paradigm if one criterion for the selection of a paper for conferences and publication were the generality that the author could identify in the structures of the model with which he is working. The focus would be on the transferability of ideas from one setting to another.

Generality can exist at different degrees of complexity. A comprehensive model is built of simple structures. But even our library of simple structures is inadequate in system dynamics. I find confusion in people's thinking about the nature of positive and negative feedback loops, especially when two or more simple loops are combined. A model can represent theories within theories. The simpler structures are more widely transferable, but even comprehensive models can have meaning in multiple settings.

The concept and process of transferring a structure needs to be understood more widely. I recall one critic of Urban Dynamics who asserted that the model was of very limited use because there were only six cities in the world that were close to the land area chosen for the city in the book. [4] Apparently the author of that criticism was not even at home with the most elementary form of transferability, that achieved by scaling a system up or down in size.

More attention to generic structures means closer ties to theories already propounded in the fields to which system dynamics is applied. For example, in the social sciences and in medicine, many theories are almost certainly fragmentary, incomplete, and dynamically incorrect. The structures being described in such theories often will not lead to the dynamic consequences that are asserted. By not meticulously observing the proper relationships between levels and rates, the theorists will lack the structures necessary for generating the behavior observed in real-life systems. The system dynamics paradigm can be strengthened in its ties to other fields by applying system insights to theories that so far have existed only in descriptive form.

D. ADDRESSING THE CONTROVERSIES

System dynamics, as a paradigm, and applications of system dynamics have been subjected to a barrage of criticism, especially from the social sciences. System dynamics is a better match to the paradigms of professional engineers, managers, and medical doctors than to the traditions and research methods in the social sciences. System dynamicists have a natural tendency to turn toward those with whom they share overlapping paradigms. But by ignoring the critics, system dynamics loses an opportunity to strengthen its own paradigm. The opportunity exists in at least three dimensions--first, modifying system dynamics when a criticism is justified; second, clarifying the foundations of system dynamics and expressing the paradigm more effectively when the criticisms arise from misunderstanding; and third, infiltrating the critic's home territory when the system dynamics paradigm is correct, stronger, and a better choice.

There has been a tendency within system dynamics to ignore critics and to adopt a defensive posture. But the time has passed for both of those responses. We're now meeting in the ninth international system dynamics conference. A system dynamics professional society is being formed. A system dynamics journal exists. There is growing strength and identity in the field. That strength will be greater if we meet critics head-on. By dealing with the criticisms, the system dynamics paradigm will be on a more solid foundation, and will be in a better position to contribute its potential to understanding time-varying behavior of systems.

Criticisms should be analyzed deeply to evaluate their implications. If an objection is valid, system dynamics should respond by mending its ways. If an objection arises from a misunderstanding, better explanations should be sought. If an objection reveals a fallacy in the paradigm from which the criticism arises, an opportunity is at hand for extending the system dynamics viewpoint for the benefit of both fields.

By way of examples, I give here three areas where system dynamics clashes with other approaches to modeling. Each, and others not included here, provides rich opportunities for establishing the importance and special character of system dynamics.

Endogenous viewpoint.

In his paper for this conference, "The Feedback Concept in American Social Science, with Implications for System Dynamics," George Richardson identifies the endogenous viewpoint as a central characteristic of the system dynamics paradigm. [5] Yet, as he states, the idea of a closed boundary and the focus on internally generated behavior is alien to the thinking of many people. In contrast to the system dynamics approach, econometric models are driven and often dominated by exogenous variables, and equilibrium economics tends to see the system always near a balanced equilibrium and pushed away from equilibrium only by external disturbances. Managers tend to think of their problems as externally caused, rather than suspecting their own internal policies, even when competitors sharing the same environment do not share the same problems. System dynamics models have been criticized as "mechanistic," but is not the objective to identify mechanisms that are generating the behavior in question?

Prediction.

In economics, there is a common presumption that the ultimate and necessary test of a model is its ability to predictthe future state of a real system. The system dynamicist sees such a test as severely limited, not decisive, and of minor relevance in building confidence in a model's ability to discriminate between good and bad policies. Radiating out from this issue of prediction lie many important distinctions between system dynamics and other methodologies. Here lies fertile ground for clarifying the system dynamics paradigm and for influencing other approaches to modeling.

Quantizing intangible variables.

Depending on the viewpoint, the willingness to deal with so-called intangible variables identifies system dynamics as either more courageous or else more impressionistic than other schools of modeling. Here lies the matter of data bases from which to derive models. Are models to come only from variables that have been numerically measured, or should they be drawn from the full range of information that is available? [6] Certainly, the professions use all available information, why should not a person who is modeling behavior relevant to those professions? In the use of information sources, criticisms can be taken as a starting point for building a stronger argument for the system dynamics approach.

E. MANAGEMENT EDUCATION

In his paper for this conference, "Enlarge the Paradigm? Yes," Barry Richmond argues for concentration of system dynamics effort in a single fertile area of application until the full power of the approach can be demonstrated. I agree that such concentration is overdue and that management education is the best place to focus. System dynamics already has deeper penetration into management than into any other area. American management is in a state of turmoil, caught in the crosscurrents of worsening economic conditions and the onslaught of foreign competition. The opportunities are almost unlimited. A deep, successful, and pervasive penetration into management education would demonstrate the capability of system dynamics for clarifying issues, demonstrating how to deal with complexity, choosing better mixes of policies, and providing a more effective communications medium.

I have long believed that system dynamics would be the next major breakthrough in management education beyond the Harvard case study method. A system dynamics modeling project starts as a case study to identify the issues, relationships, problems, and possibilities in the managerial situation. After a descriptive analysis, one is inevitably faced, whether so recognized or not, with a situation that is properly described as a high-order, nonlinear system of differential or integral equations. We know that such complexity lies beyond the reach of reliable intuitive solution. But in the traditional case study method, there has been no alternative but to evaluate the described managerial system using only experience and judgment. The plight of a growing number of corporations indicates that the method is inadequate. System dynamics modeling picks up at the end point of a case study evaluation. The description and insights of the study are drawn together into a simulation model that allows the implications of the system structure to be reliably determined.

As system dynamics encompasses and extends the case study method, we must be sure that the lessons are teachable and that they can be interpreted into the context of everyday business. Toward that end we should be seeking generic models that carry with them transferable knowledge. John Morecroft at MIT has been working toward generic models of management situations. I estimate that as few as ten or twenty well-chosen models could cover more than eighty percent of the problems faced by managers. Such a library of thoroughly understood models could become a cornerstone of a management education.

We already see movement toward emphasizing system dynamics in management training. Barry Richmond is defining a field of "enterprise engineering" at Dartmouth. Alfred Thimm, dean of the business school at the University of Vermont, is working toward system dynamics as a central organizing thread through management education. At both places, the number of students enrolled in system dynamics already exceeds by many times the number we have at MIT. Such rapidly growing enrollment demonstrates the vitality of system dynamics as an approach to management education when a faculty has the time and inclination to concentrate on teaching rather than on research.

F. COMMUNICATION FOR STRENGTHENING THE PARADIGM

If we hope to strengthen the system dynamics paradigm rapidly, I believe that efficient, modern communications procedures are necessary. Computer conference facilities are now available that are ideally suited to communication within groups with shared goals.

For about a year, I participated in a computer conference using the conference facilities pioneered by Murray Turoff at the New Jersey Institute of Technology. The conference itself was among members of the General Systems Research Society. I found myself having little in common with those in the conference, so, from my viewpoint, the principal result was an opportunity to evaluate computer conferencing itself. I was impressed with its potential usefulness to a group with shared interests and a common objective that requires debate and the exchange of ideas.

In a computer conference, communications can be addressed to selected subgroups. Private and confidential messages are allowed. Each person can work at the time of day and week that he wishes. Turnaround of ideas and responses is far faster than through the mail and, of course, incomparably faster than communication through traditional conferences and journals. Priority of ideas is recorded by the dating and records of the system. The cost is reasonable. I believe data circuits are available on a basis that would make international participation feasible.

A computer conference system allows for sub-conferences. Those with narrowly defined interests can communicate among themselves without their messages overloading the output for those who are not interested. For example, those directly involved in applying system dynamics to management education could constitute a subgroup. Educational issues could be debated with rapid responses. Topics could be disseminated for student research projects. Teaching materials could be circulated. Greater visibility for the field could be created at the undergraduate level to draw students into graduate work in system dynamics. Some of the people here should consider a computer conference as a means of accelerating movement toward a stronger system dynamics paradigm.

Now is the time to work toward more solid foundations. Talented people are available. The goals are worthy. Ample opportunities are being identified at this conference. Nothing stands in the way of a combined effort to move forward.

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