SYSTEM DYNAMICS AS A HEURISTIC FOR SYSTEMS DESIGN*

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ABSTRACT

Socio-economic planning primarily addresses the solution of problems relating to inherently indeterminate systems. This class of systems exhibits two sources of complexity which can be conceptualized as the complexity of the idea system and the complexity of the actual physical system. The idea system introduces a multiplicity of available theories, disciplinary differences between the stakeholder roles. The actual system is complex because there usually is not sufficient empirical data relevant to the particular problem since the situational context is unprecedented and non-repeating.

It can be argued that problem solving in this context involves designing a new system structure to facilitate social learning, using a heuristic approach. Such a heuristic is different from the more conventional approaches to modeling and problem solving in that it bounds the search space and enhances further inquiry rather than just reflecting the real world conditions. In this paper the main characteristics of this approach are discussed and methodological implications for System Dynamics modeling are drawn.

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I. INTRODUCTION

Many scholars have expressed a need for a better defined methodology for System Dynamics modeling to enhance model credibility and confidence in the modeling approach. System Dynamics has found application in a variety of contexts where perception of problems differ widely in terms of purpose, scope and complexity. Therefore existing methodological studies have aimed at generating procedural guidelines which will apply to any or all situations where System Dynamics may be used. In this paper a different approach will be taken. It will be argued that the appropriate problem solving and inquiry methodologies will differ according to the perception of the real world situation as fitting one of the systems classes within a conceptual map of systems.

A brief account of various systems classification schemes will be given in the next section. The System Dynamics method is general enough to be used for problem solving in any of these contexts. However its widest application, where the approach promises to be most effective, is in the area of human activity systems management. From a methodological standpoint, this type of real world system shows certain characteristics that require distinctly different strategies for inquiry and problem solving. These systems are characterized by a turbulent (or emergent) environment and a corresponding indeterminancy in systems response. The indeterminancies are reflected in a highly complex idea system representing various incommensurable conceptualizations and actions concerning the future course of the system.

The main challenge under these circumstances is to structure a search space for social learning. The 'learning' framework is expected to increase conceptual and perceptual insight by consistently improving the constructs (or models) which provide the necessary interface between the idea system and the real world. An appropriate methodology to meet the above challenge is proposed in section three of the paper. This approach copes with the complexity of the idea system by developing a shared perspective, and by adopting a system design as opposed to a system analysis perspective. The social context of inquiry is continuously restructured by specifying the linkages between the conceptual and action components of the problem solving process.

The System Dynamics approach is exceptionally well suited to be an integral part of the methodological framework as described. Such a merger implies a major reversal in model conceptualization and various guidelines for model formulation and implementation. These and the significance of the approach for structuring further methodological inquiry are discussed in the final section.

II. SYSTEMS CLASSES AND INDETERMINATE SYSTEMS

Human Activity Systems

Different systems classifications have been developed to analyze real world systems and to suggest corresponding problem solving modalities. Among these Miller's (1) and Boulding's (2) system hierarchies, Emery and Trist's (3) field types, Dunn's (4) systems taxonomy, Ackoff and Emery's (5) behavioral systems may be cited as the most frequently utilized by system scientists. More recently Checkland (6) has proposed a classification consisting of natural systems, designed physical and abstract systems, and human activity systems. The human activity system encompasses the sets of consciously ordered human activities where the ordering is a result of some underlying purpose or mission. It is this class of systems that is of interest here.

Abstract-Ideal System Types

An equally important system classification occurs at the idea level where the real system of interest is mapped out for analysis and problem solving. Accordingly the real world systems may be perceived as one of the four abstract-ideal types consisting of deterministic, moderately stochastic, severely stochastic and indeterminate systems. All types are comprehensible in terms of the event-probability distributions that the observer may impose on them. These measures provide the reference frame in which the observer can evaluate his ability to predict system structure or behavior in the face of a set of initial conditions (7).

Indeterminate Systems

For reasons which will be apparent presently, human activity systems will most likely be perceived as indeterminate systems. These systems are seen to exist in a turbulent environment where inferences about emergent properties cannot be made on the basis of empirical observations of the past. Since this field can be identified equally well with opportunities or anxiety, it offers a great deal of freedom of choice. Therefore the resident system itself responds in an essentially indeterminate way, contributing to the re-creation of its own environment. The indeterminate system is further characterized by causal discontinuities (7). The context of inquiry is ill-structured and the empirico-deductive method of analysis cannot be employed since the system description will always be dependent on the point of view of the observer rather than being publicly ascertainable (6).

It should be noted here that the assignment of a real system to its abstract-ideal type becomes more problematic as its characteristics closely match the indeterminate type. Most problems related to human activity systems will necessarily be ill-structured due to the existance of individuals with ultimate freedom of choice. It will be difficult to obtain agreement on system description and membership with respect to any of the classes. Hence, the complexity of the real system will be reflected in the idea system in that there will be a number of competing explanatory theories concerning the nature of the real system.

Heuristic Modality

When the problem context is perceived to be an indeterminate system, the corresponding strategy for problem solving has to be a heuristic modality. The main function of the heuristic is to structure the problem so as to derive the resolvent learning system. This will be achieved by developing hypothetical constructs or possible futures and by successively improving them through iterative and exploratory experiments in social action. Thus the heuristic will simultaneously serve to solve problems as well as improve the problem solving process itself.

To summarize, the human activity systems present themselves as indeterminate systems. Problem solving in this context is different from the approaches taken in less complex situations in that it bounds the search space and enhances further inquiry rather than attempting to reflect the real system as it presently exists.

III. METHODOLOGICAL IMPLICATIONS

Emphasis on Systems Design

As discussed earlier, human activity systems present problems of ill-structured type. The sources of complexity lie in the nature of the real system, the nature of observers, and the interaction between the two.

The major source of complexity lies with the indeterminate nature of the real system. This characteristic precludes possibilities of prescribing alternative policies through experimental manipulation of a model of the system as it exists, built by using information about past behavior. Adopting a systems design perspective, on the other hand, one focuses attention on future opportunities and possibilities without being totally captivated within the present system structure as depicted in the model. A shared model of desired future states, and the corresponding system structure expected to generate these, will be the basis for hypothetico-deductive inquiry. In other words, such a model will provide an elaborate hypothesis about systemic interdependencies to be tested through social action.

Structuring a Shared Perspective

The methodological implications of the complexity introduced by the observers are several. First, each observer has a varying degree of committment to different styles of thinking or inquiry models (8) or disciplinary bias. These differences are unresolvable in the context of an indeterminate system, since extant criteria for adopting a particular worldview will be absent. Under these circumstances, a reflective-dialectical stance has to be taken where no one particular disciplinary viewpoint is prematurely imposed on the problem situation (9). Taking to such a strategy will enable meta-theoretical development in the long run.

Secondly, there exists multiple interest groups or stakeholder roles. Their perceptions of the relevant systemic properties or attributes are expected to be different. Since the system's survival depends on the adaptive responses of all parties involved (4), all of these individual perceptions are equally important. Even more importantly, these different views need to be reconciled in terms of a shared perspective to enable collective action. Techniques which facilitate the development of this basis will have to be an integral aspect of a problem solving process.

Social Learning Perspective

Another source of complexity in indeterminate systems, may be traced to the implementation of plans through the interaction between the real system and the observers who are also role takers within it. The social learning that takes place during this interaction appears intractable due to discontinuities between the plan generation process, the plans generated and the actual action in the field. Since the improvement of the future state of the system depends on successive improvements in the plan generation (system design) process, the feedback from the action field to the methodology of system design should be formalized. An important role of heuristic instrumentalities in this context is that they provide a medium for the manifestation of changes in the action field by explicitly specifying the actors or the participants in the process as well as the nature of their participation.

Inquiring Social Reality

The methodology described here emphasizes the process of inquiry rather than the substantive properties of the real system. It provides a formal means of initiating, consciously reflecting, and systematic recording of the problem solving process. The social reality implied by this methodology

is an account of interactions among human beings, their negotiations concerning different interpretations of reality where these interpretations constitute the reality itself (10). The data generated through the application of this methodology is about the observers' constructs, how these change and the satisfaction with the states reached following the methodology. In time, the methodology will yield a data base for the development of a grounded theory of societal problem solving.

IV. EMBEDDING SYSTEM DYNAMICS IN A SOCIAL LEARNING FRAMEWORK

Adopting the Systems Design Perspective

Although the System Dynamics has been developed to address problem solving issues, its main use has eventually drifted to structure analysis to identify the causes of long term social problems. The argument for this trend is that most problems which are of interest to the System Dynamics researcher originates from a faulty system structure. Therefore a clear understanding of system structure is of primary importance. Within the framework of this argument the first step in modeling is to achieve a consensus on the cause of the problem and the nature of the generating system. This then is followed by policy formulation. In other words, modeling at first aims at learning and describing but then gently glides into prescribing (11).

This approach creates several problems in modeling indeterminate systems. Since the objective is to simulate the existing system, gaining confidence in the model becomes difficult. The model structure constructed to replicate the reference mode or the characteristic behavior of the existing system is not unique. This difficulty is further compounded as there are no extant theories to explain system behavior. The data necessary to operationalize the model is of judgemental type. Another problem arises when the descriptive model of the existing system is used as the basis of a prescriptive exercise. It is often observed that such a model is overwhelmingly insensitive to most policy alternatives. Hence remedies for the problem require a change in the system structure. Searching for structural change departs radically from the usual mode of model experimentation. In most cases the proposed changes in structure are rejected by the client. Therefore the analytical-prescriptive approach does not resolve the problematic issue and may inhibit innovative solutions that are outside the reference frame of the existing system scenario.

Adopting a system design perspective avoids the above described difficulties while retaining the learning process involved in identifying the structure-behavior relationships. With this perspective modeling is recognized and treated as a prescriptive activity based on perceived or hypothetical causal relationships.

After problem identification, a reference mode describing the desired system behavior is defined. The assumptions about the causes of the reference mode determine the major policy options which can be endogenously implemented. Focusing on these particular policy options provides a set of criteria for what to include or exclude from the model (12). Only those interactions hypothesized to be necessary and sufficient to generate the desired reference mode are included in the initial model. As opposed to the system analytic approach there is no need to attempt to simplify an infinitely complex conceptualization of the real system. Consequently it is also expected that a system design perspective would allow for various alternative models.

Model experimentation then consists of refining the designed structure and calibrating its parameters to approximate the desired system behavior

as closely as possible. The choice of the most appropriate model is done via relevant decision criteria as defined by the model users.

Obtaining and Modeling Shared Perceptions

System Dynamics is very well suited to reach and establish a shared world view among scholars and other interest groups concerning the system structure. The approach has been developed as an alternative to 'fuzzy' mental models that people use to analyze the causal nature of events. The System Dynamics model is externalized and each model component has a real-life meaning in the operating world. The model can serve as an effective communication medium for resolving disagreements in model formalization because each of its components can be identified and compared with descriptive knowledge about their real world counterparts. This type of communication is further encouraged by the user-friendliness of the formalism which does not require disciplinary expertise in model structuring, operationalization and use.

Although the method offers great potential for creating a medium of debate to arrive at a shared perception of the system structure through the active participation of all involved, this advantage hasn't been fully explored. Previous studies have limited direct user input to experts, specifically in parameter specification and policy evaluation stages of modeling. Similarly, it has also been coupled with various techniques of information and consensus generation.

In one of the first applications, Arnold, Young and Brewer (13) utilized experts in generating the major System Dynamics transformation functions through a cross-impact type questionnaire. In this study, the experts (mainly social scientists) remained within their disciplinary boundaries by responding to questions relating to their own expertise. More recently, seeking agreement among individuals has also been emphasized, as in Stover (14) using a cross-impact analysis coupled with the Delphi procedure to incorporate interactions among event forecasts based on expert responses.

The participation of a wider population of users (interest parties) into policy evaluation has been achieved in a study of 'Boom Towns' where a multiattribute decision making technique has been applied (15). This approach is found to reduce the conflict on outcomes even tough there may be significant value differences among participants (16). Similarly, partial structure specification and model formulation by the interest groups via worth assessment and Delphi techniques have been successfully carried out (17).

In the studies cited above the overall models generally reflect the world views of the modelers. The structure specification remains as an art exclusively at the discression of the modeler. To explore a wider application of user generated model structures, systematization of the model conceptualization stage through Interpretive Structural Modeling has been suggested (18) and applied (19).

Thus, systematization of the modeling process using participatory techniques has gained a wider application with the constituents of active participants being more and more varied. This trend has also necessitated and increased emphasis on consensus building techniques. Furthermore, seeking agreement on the nature and magnitude of specific interactions and/or parameters has shifted to representing a shared perception of system structure.

It is interesting to note that normative modeling and the associated techniques such as Delphi, cross-impact, interpretive structural modeling, multiattribute decision making techniques and worth assessment are compatible and complimentary with the System Dynamics approach. In contrast, empirical models based on statistical analysis of past data have found limited use.

Within the systems learning framework, System Dynamics can be placed along a continuum of normative modeling exercises where alternative system designs based on shared perceptions and assumptions are generated. These different designs are then tested for consistency and desirability. The above systems learning process consists of the following stages:

a. Problem structuring using normative techniques to develop a network of statements concerning opportunities and/or problems,

b. Reaching an agreement on the reference mode (or the desired system performance) and on the relevant state variables, using consensus building techniques,

c. Developing hypotheses concerning major decisions or policies which will generate the reference mode(s),

d. 1. Identifying the transformation functions which describe the causal relationships between the policies and the reference mode,
   2. Classifying the transformation functions according to their derivations based on accepted theory, empirical data or a normative decision process,
   3. Specifying the transformation functions using a combination of worth assessment, Delphi and structured debate, and

e. Choosing among the alternative system designs using a multiattribute decision analytic technique.

Adopting this procedure is expected to reconcile varied interpretations of the causal relationships that are observed in the real world and resolve the value differences among the interest groups. Hence, the system design alternative that emerges will reflect a shared perspective of what the system ought to be and how it should operate.

Social Context of Modeling

The ultimate aim of the proposed methodology outlined here is to provide a medium for facilitating social learning. Solving problems, gaining insight, and enhancing problem solving capabilities through non-expert and local user manipulation in modeling constitute the essence of the learning process. Successful implementation of the approach requires the formulation of an action strategy which addresses the following issues:

a. Specification of rules for defining the relevant participants,
b. Development of instructions for non-expert recursive manipulation of the model to modify and expand the normative aspects,
c. Determination of rewards and sanctions to be integrated with the procedural guidelines to insure a satisfactory level of participation throughout the modeling process,
d. Evaluation of the process by the participants, and
e. Specification of a standard documentation procedure to record the successive models as well as the social dynamics of modeling.

Following these guidelines will place the modeling effort within the action field and ensure continuous feedback between the model and the actors.

Towards a Grounded Theory of Societal Problem Solving

The strategy described here formalizes and documents the necessary linkages between the idea system and the action realm. Repeated implementation of the approach is expected to result in an accumulation of the information base necessary to formulate a 'grounded theory' (20) of societal problem solving. Such a theory will contain generalized guidelines for the self-improvement of the problem solving methodology. These guidelines may be classified into two categories, consisting of the cognitive and the social-behavioral. In cognitive studies, successive model structures will be the main information base which can be used independently to expand the cognitive aspects of decision making. The dynamics of social participation, the types of participants, their interests, expertise, level of participation, and the degree of satisfaction with the process will provide the social-behavioral basis of the investigation.

V. CONCLUSION

In this paper, the implementation of the System Dynamics approach using a systems design perspective as opposed to a systems analytic perspective is studied. It is discussed that adopting such a perspective has several advantages both from methodological and implementation points of view.

From a methodological point of view, this approach focuses on searching for alternative system structures based on a shared view of the desired mode of operation, rather than focusing on the existing system structure. Modeling within this framework provides a clear set of criteria for model conceptualization and facilitates the testing of the policy options which require structural change.

From an implementation point of view, the social context of the problem solving process is emphasized. Taking this approach, model generation becomes a part of every day life; an ongoing activity where members of a human activity system restructure their environment.

It is expected that this combination of characteristics will eventually lead to a well grounded theory of societal problem solving.

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