SLICING A COMPLEX PROBLEM FOR SYSTEM DYNAMICS MODELLING

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ABSTRACT
Since formal modelling requires having a model boundary encompassing finite complexity, so deductive logic is possible, complex problems must be partitioned into simpler parts before being analysed. There are many ways to slice a complex problem but not all create partitions that keep together processes contributing to effective policy design. This paper explore ways in which a complex problem may be appropriately sliced so the models of the partitions can serve as effective tools for policy design.

Key Words: System Dynamics, Problem Solving, Policy Design, Scientific Method

INTRODUCTION

Policy design has traditionally incorporated an interventionist perspective, requiring a precise forecast of events so an external hand can intervene to assure meeting of the exogenously determined targets. Models created for the interventionist policy design must subsume the simultaneously existing multiple modes in a historical pattern so future events can be projected precisely. Policy design based on system dynamics, on the other hand, must aim at mobilizing the internal forces of the system into creating functional patterns and avoiding dysfunctions. Thus, understanding the mechanisms of change must take precedence over a precise forecast of events. Models created for such a policy design perspective must incorporate multiple patterns potentially existing in the system and observed and recorded at different times and locations, so mechanisms of change from one pattern to another can be searched through experimentation.

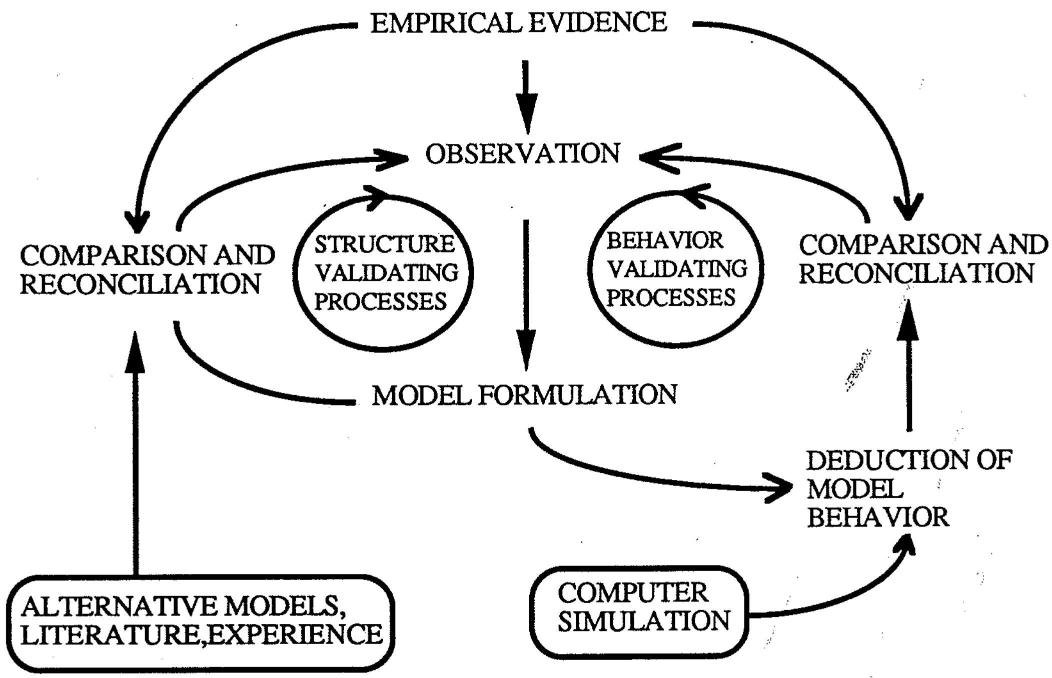
Models cannot be made overly complex if they are to remain understandable. Therefore, complex problems must be sliced into smaller parts in a way that the parts meet the requirements of the intended policy design. There exist many ways to partition a problem, although not all models so created are useful for identifying sensitive entry points for system change that a system dynamics modelling effort must seek. This paper attempts to outline a problem slicing process that should facilitate creating relatively simple models without disconnecting symbiotic processes in a system contributing to change, so policy design can be attempted in parts without loss of value.

SYSTEM DYNAMICS MODELLING PROCESS AND PROBLEM SLICING

There are many ways system dynamists represent the widely practiced, although informally implemented, modelling heuristics they use. My own view of these is shown in Figure 1. Empirical evidence is the driving force both for delineating micro-structure of the model and verifying its behavior, although the information concerning the behavior may reside in the historical data and that concerning the micro-structure in the experience of the people [Forrester 1980].

The first requirement of the method is to organize historical information into what is known in the jargon as "reference mode." The reference mode leads to formulation of a "dynamic hypothesis" expressed in terms of the important feedback loops existing between the decision elements in the system that create the particular time variant patterns contained in the reference mode. The dynamic hypothesis must incorporate causal relations based on information about the decision rules used by the actors of the system, and not on correlations between variables observed in the historical data.

Figure 1: System dynamics Modelling Process



A formal model is then constructed incorporating the dynamic hypothesis along with the other structural detail of the system relating to the problem being addressed. The model structure must be "robust" to extreme conditions and be "identifiable" in the "real world" for it to have credibility, where real world consists both of theoretical expositions and experiential information. A model might undergo several iterations to arrive at an acceptable structure.

Once a satisfactory correspondence between the model and the real world structure has been reached, the model is subjected to behavior tests. Computer simulation is used to deduce time paths of the variables of the model, which are reconciled with the reference mode. If a discrepancy is observed between the model behavior and reference mode, the model structure is re-examined and modified if necessary. In rare cases, such testing might also unearth missing detail concerning the reference mode, leading to a restatement of the reference mode, although for most cases, the reference mode delineated at the start of the modelling exercise must be held sacred.

When a close correspondence is simultaneously achieved between structure of the model and the theoretical and experiential information about the system, and also between the behavior of the model and the empirical evidence about the behavior of the system, the model is accepted as a valid representation of the system. [Bell & Senge 1980, Forrester

& Senge 1980, Richardson & Pugh 1981].

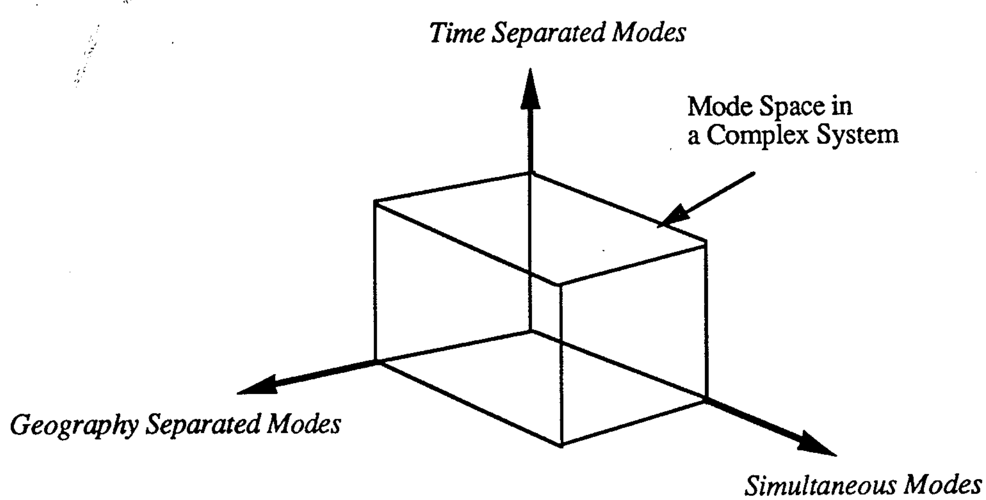
Although quite consistent with the requirements of the scientific method of existence, verifiability, uniqueness and reputability of a model [Casti 1981], above protocol creates a tendency to proceed to build a model subsuming all the complex social and ecological relationships underlying a complicated historical pattern, while disregarding the multiple modes separated by time and geography in an effort to keep the model simple. Such a model, although precisely tracking a particular history, may be so closely tied to the specific behavioral pattern it reproduces that it may not contain the policy space for designing any mechanisms of change. Unfortunately, there is little utility for such modelling except forecasting, the policy implications of which are direct exogenous intervention. In my observation, many system dynamics models are being built in this way, creating interventionist policy agenda for fighting internal trends rather than changing them, which is considerably removed from the classical system dynamics perspective.

PROBLEM SLICING CONSIDERATIONS

It is possible to partition the system to be modelled into smaller sub-systems and develop a policy design based on the many models representing these sub-systems. However, the policy design attempted in this way will be effective only if the model of each subsystem subsumes multiple modes of behavior separated by time and geography so that it is possible to identify policies that may cause a change from one mode to another. Unfortunately, the term "multiple modes" is used a bit loosely by system dynamists and not all classes of multiple modes may be relevant to the design of change. Thus, intuitively sensible schemes of partitioning a system may often create sub-models that do not incorporate policy space for attempting a design of change.

Multiple behavioral modes occurring in a system may extend in three dimensions as shown in Figure 2. They may refer to the simultaneously existing components of a complex pattern of behavior that is exhibited by a system over a given period; they may represent patterns experienced over different periods of time in a system of relationships; or even patterns experienced in similar organizations that are separated by geographic space.

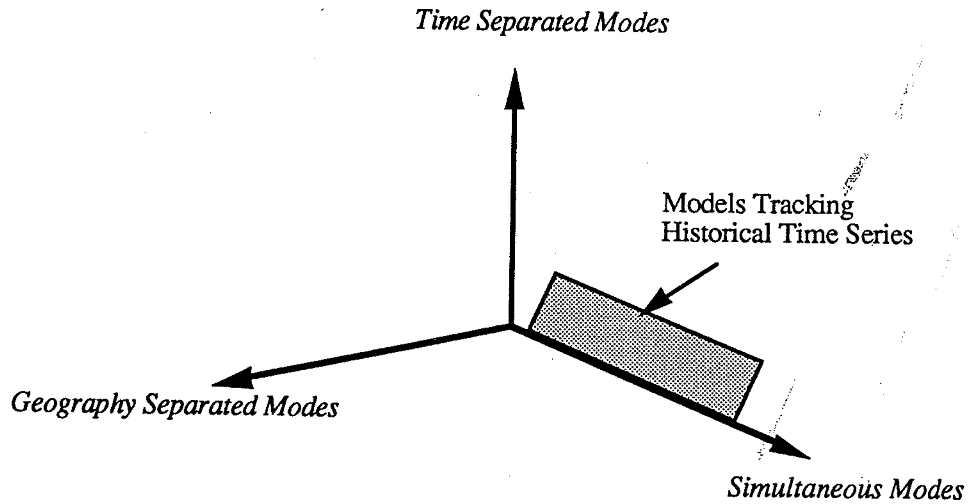
Figure 2: Multiple behavioral modes occurring in a system



A functional example of the multiple modes interpreted as simpler components of a complex pattern of behavior is the cycles of different periodicities that constitute a complex composite trend in Mass's Economic Cycles model which is aimed largely at developing a theory to explain these cycles, not changing them [Mass 1975].

Dysfunctional examples include myriads of policy-related models using numerical time series data as reference mode and attempting to precisely reproduce it as a test of validity. Figure 3 shows the direction in which such models will be extended. As they are enlarged, such models will be able to track history more and more precisely, although they will rarely incorporate any organizational means for changing the patterns they replicate.

Figure 3: Modes included in models attempting to precisely replicate history



An example of a model incorporating many patterns experienced over different periods of time, although not tracking any history precisely is Saeed's Income Distribution model [Saeed 1988], which attempts to identify policies for changing wage and income distribution patters. Many income wage and distribution patterns can emerge from this model depending on how people and assets are distributed among the multiple stocks in the conservative systems representing the latent types of employment and asset portfolios. Figure 4 shows the direction in which such a model will be extended. As the model is enlarged, it will be able to address a larger variety of patterns separated by time. It will also incorporate policy space to change from one pattern to another.

An Example of a model subsuming many patterns of behavior experienced in similar organizations separated by geographic space is Forrester's Urban Dynamics model [Forrester 1969]. Many patterns of social class structure can emerge from this model depending on how businesses, housing and workforce are distributed among the multiple stocks in the conservative systems representing those variables. Figure 5 shows the direction in which such a model will be extended. Enlarging such a model will address a larger variety of patterns separated by geography and and thus also incorporate policy space to change from one pattern to another.

Figure 4: Modes subsumed in models addressing multiple patterns separated by time

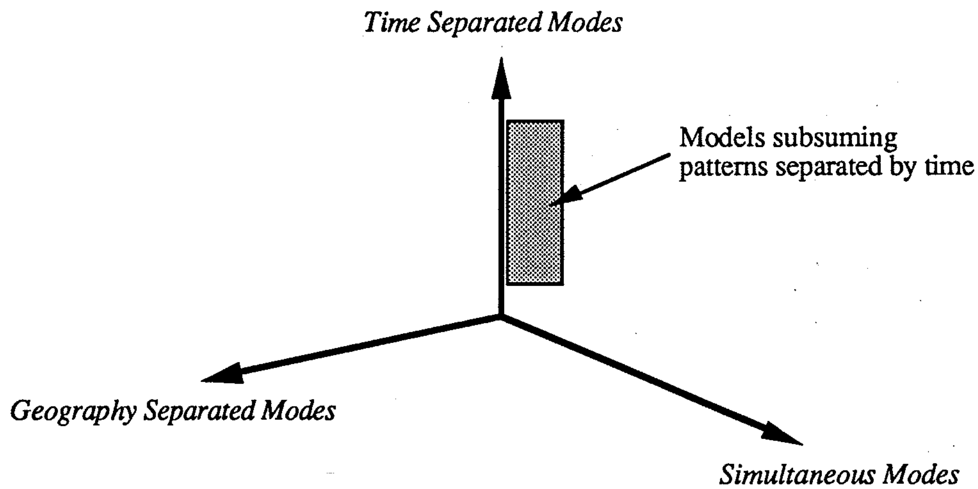
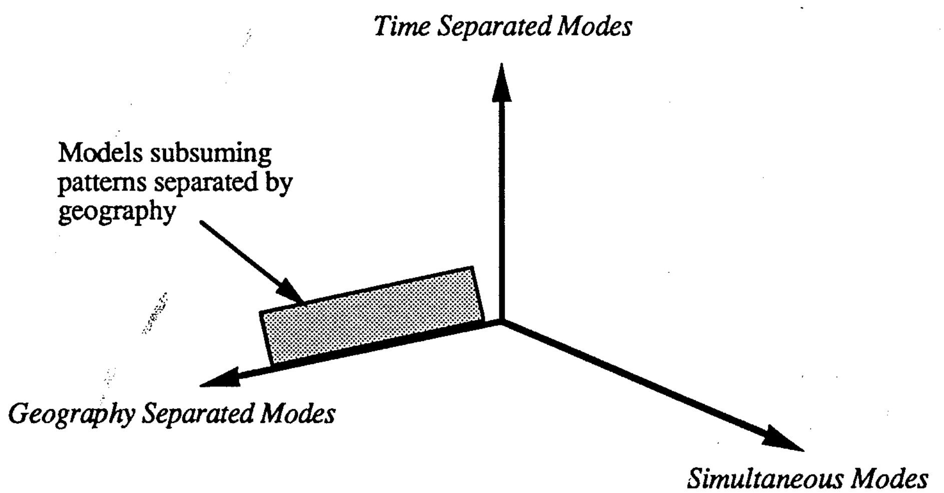


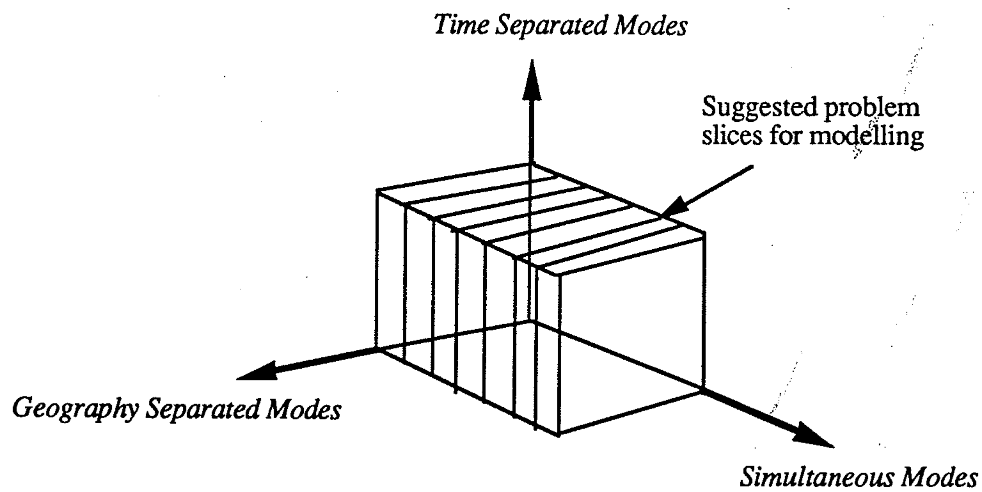
Figure 5: Modes subsumed in models addressing multiple patterns separated by geography



A model that is suitable for designing a change must correspond to an equifinal system which can assume many patterns of behavior [Bertalanffy 1968, Katz & Kahn 1978]. Such a model must subsume multiple modes that are separated by time and geographic space since the underlying structure of such a model would contain the mechanisms of change from one mode to another. It may not necessarily incorporate multiple modes that exist simultaneously in the system behavior since interaction between the mechanisms creating these may not provide any additional policy space, although this may enhance a model's ability to track history accurately. Thus, a problem must be partitioned in such a way that the partitions retain the ability to subsume multiple modes separated by time and geographic space, while simultaneously existing multiple modes and their underlying structure can be separated and addressed in different models for limiting complexity contained in a single model. Such a partitioning process is illustrated in Figure 6.

Unfortunately, the available historical data cannot be used directly to serve as reference mode for the models created through this process since they will not reproduce the complex pattern subsuming the simultaneously existing multiple modes but will concern only one of its components representing a set of the trends potentially existing in the system. Partitioning a system into subsystems that produce behavior different from what might exist in historical data will require defining reference mode differently from historical behavior. For example, each of the two complex time histories shown in Figure 7(a) contains a trend simultaneously existing with a cyclical tendency.

Figure 6: Suggested problem slicing method

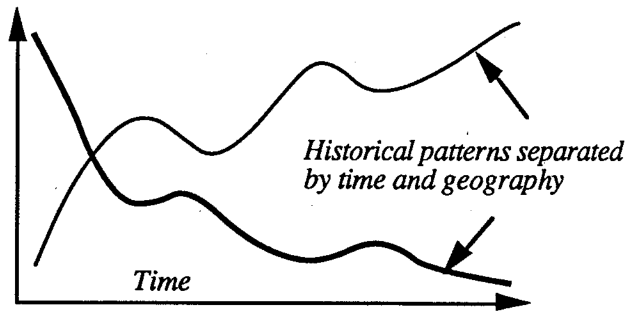


To be able to address the two issues concerning the cycles and the trends, this problem may be represented by two models: One subsuming the multiple modes existing in the two trends, the other subsuming the cyclical mode existing in both of them. These modes are shown in Figure 7(b). The two models so created will keep together the synergistic processes underlying the potential multiple patterns thus providing the policy space to attempt a design for change. Also, the two components of the design so created can be pursued quite independently.

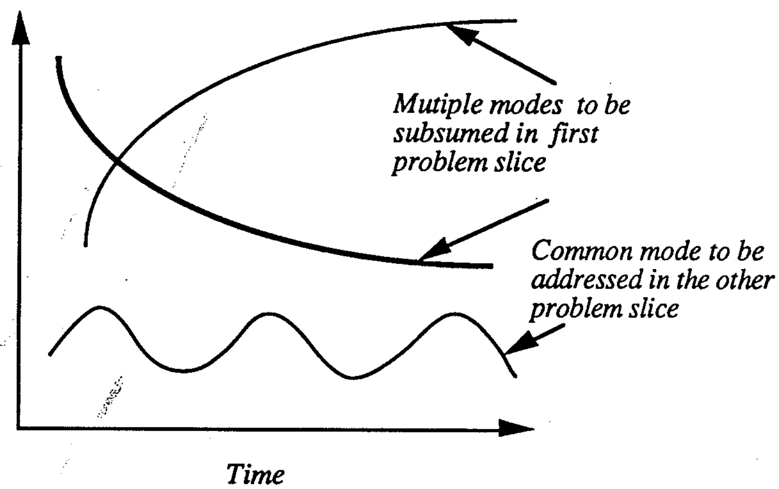
RELATED MODELLING CONSIDERATIONS

Partitioning a system into subsystems that produce behavior different from what might exist in historical data complicates the task of verifying the behavior of the sub-models. Since composite historical data will not directly relate to the patterns generated by the sub-models, it is necessary to analyse history carefully to be able to discern trends that are specific to the problem partitions created for analysis. Such partitioning also makes it difficult to use automated procedures of parameter estimation for the model that require historical data as input, which are now becoming commercially available. To overcome these shortcomings of the existing modelling procedure, following considerations must be subsumed in the system dynamics modelling process.

Figure 7: Decomposing time histories



a) Complex historical patterns



b) Decomposed patterns serving as reference modes for model partitions

a) Historical data should be used to delineate multiple modes existing in the system, not directly be a reference mode

Historical data in the form of a record of sequence of events, in qualitative or numerical forms, may often be of little value in formulating and validating a structural hypothesis about the process of change. Much time has to be spent to search and organize data for delineating a reference mode for a model that can give clues to change. This reference mode must outline the various historical patterns, separated by time and geography, which might be relevant to the problem under consideration. As a first requirement for delineating such a reference mode, the search for data must expand beyond a single historical pattern concerning a specific organization and attempt to find a class of patterns observed in history in various times and locations. Some of these patterns might even conflict with one another.

Interesting examples of isolated theories arising from local patterns of behavior are the neo-classical and marxist models of economic growth. Each of these models makes different static assumptions about an existing income distribution pattern, which are based on isolated historical experiences. Both these models cannot identify an evolutionary mechanism of change from one pattern to another and issue highly interventionist designs of change. If it is acknowledged that many income distribution patterns existed in history, a model can be formulated that not only has latent structure to create such patterns but is also able to provide clues to how a given pattern may evolve into another [Saeed 1991].

Historical data also has to be decomposed, either informally or using formal spectral analysis algorithms, into the various trends that may together constitute a complex composite pattern. Growth trends may be separated from cyclical trends. Cyclical trends of different frequencies may be separated from one another. Trends concerning variables that do not have a direct bearing on one another but which contribute significantly to the creation of the events experienced in history may also be separated. An example of the last stated trends is those concerning social, political and technology related decisions in an organization or country.

A reference mode constituting multiple trends that are separated by time and location, and those representing the simultaneously existing simpler components of a complex pattern, should then be carefully described. One can conceive of a matrix of patterns arising from this exercise. Each element of the matrix will pertain to a specific component of a composite pattern existing in a specific period or location while each row may contain elements existing simultaneously and each column those separated by time or location. There can be blank cells existing in this matrix. Modelling agenda for the design of change can then be prepared on the basis of the focus of the effort by partitioning the system of patterns into the columns of the matrix described above and outlining a model for the agenda of the patterns contained in each of the columns that is desired to be addressed.

b) The dynamic hypothesis should address the issue of change not merely the creation of local patterns

Thinking about change must prevail upon all modelling details starting with the dynamic hypothesis designating the model boundary and identifying the key feedback loops underlying the behavioral patterns described by the reference mode. It may not be too difficult to formulate a hypothesis concerning change when many behavioral patterns form the point of reference instead of a single pattern. It would often concern the feedback loops affecting the distribution of quantities among the latent stocks included in the system partition in an effort to subsume the multiple patterns of behavior separated by time and geography.

c) Each model developed as a part of the policy design effort should have latent structure to create multiple patterns corresponding to the reference mode and more

Creating a model keeping in view many possible patterns of behavior need not lead to a contrived structure that is activated by a switch or two. On the other hand, it will usually require that there exist conservative subsystems in the model that make possible distribution of the contents of the relevant levels between functional and dysfunctional categories. A latent structure would, therefore, exist to create an infinite number of patterns relating to the distribution of the contents of these levels in equilibrium and during the transitory period.

The various categories of businesses, housing, and workforce in Forrester's Urban Dynamics model [Forrester 1969], the various categories of land and capital portfolios in the Income Distribution model of Saeed [Saeed 1988], and the various categories of product users in Homer's Diffusion model [Homer 1987] are examples of latent structure that can create an infinite number of distributions between categories. Such latent structure can be conceived only if information about multiple modes separated by time and location exists.

Disaggregating levels in a conservative system into many categories, of course, increases complexity of the model. The increase in complexity will however be off-set by treating the simultaneously existing multiple modes in separate models.

d) Policy design should aim at influencing the day-to-day decisions of the actors not at designating an autonomous hand to make critical decisions

A design requiring centralization of the power to make decisions by an outside autonomous hand is mostly unfeasible. Firstly, such centralization may not be possible to achieve. Secondly, even when decision making can be centralized, the actors entrusted with making the decisions may no more sympathize with the objectives of the design. Finally, centralization may conflict with a prevalent management ideology and may be unacceptable to the members of the organization in which the design is to be implemented and may invoke much conflict that is destructive [Saeed 1990]. The design, therefore, must aim at an evolutionary change in the system by influencing motivations of the actors that guide their day to day decisions.

In the presence of a latent structure for the model suggested in para (c) above, policies indicated for creating a desired pattern would usually translate into influencing day-to-day decisions of the actors. This may be possible by influencing the relative strengths of the feedback loops that affect the weighting function of the information used for taking critical decisions [Forrester 1987].

If the model has a critical parameter, it may still lead to conceiving a policy design in terms of changing this parameter. In actual practice, however, such a change may require a powerful intervention by the leadership who may have no motivation or means to implement the policy. The guidelines for the policy design, therefore, are to be conceived in terms of either the new feedback loops that must be created to modify the anatomy of a critical decision or the way the influence structure of the existing feedback loops is to be changed so that the dominance of insidious mechanisms is minimized and the role of benign mechanisms enhanced.

CONCLUSION

The quality of a policy design created by a system dynamics modelling exercise is closely linked to how the complex problem of design is sliced. Since multiple modes potentially existing in a system can be seen as a part of a complex historical patterns as well as multiple patterns separated by time and geography, the problem can be sliced in many ways with respect to these modes. The conventional modelling procedures are predisposed to slicing a problem in a way that its partitions subsume the first type of modes, which creates models precisely tracking history but not useful to identifying organizational means of change. To be able to create effective policy designs, these procedures need to be modified to slice problems in a way that they subsume modes separated by time and geography while the simultaneously existing modes are separated. This requires analysing carefully historical data and decomposing complex patterns into simpler components in addition to focussing analysis on the issue of change among patterns separated by time and geography.

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