SYSTEM DYNAMICS MODELLING FOR THE DESIGN OF CHANGE

Khalid Saeed
Asian Institute of Technology

ABSTRACT

While the informal modelling procedure of system dynamics qualifies as scientific according to the definitions of the epistemological literature, the application of this procedure may create models of phenomena that provide few clues to the design of change. Policy design exercises based on such models may often end with a moral statement about what should be done by the organization as a whole instead of providing motivational instruments through which its various members realize evolutionary change. Unfortunately, a change prescribed by a moral statement can only be realized by a powerful intervention by an outside agent which is, if at all possible to implement, often dysfunctional. This paper attempts to define heuristics for the construction of models that may lead to viable designs of evolutionary change. A model is viewed as an instrument for understanding a problem not as a source of design. Guidelines for partitioning complex problems into multiple models are discussed. Models containing conservative systems capable of generating a large number of time variant patterns, which are in reality separated by time and location, appear to be sound instruments for facilitating the design of change.

INTRODUCTION

A few years ago, I attended an international symposium held in India, organised by the regional planning scientists. Many scholarly papers were presented outlining various interesting plans of change for the developing countries. These papers had one common feature: they invariably called for an outside intervening hand to implement the plans they proposed. Unfortunaltely, the identity of the intervening hand was rarely revealed, while it was implicitly assumed that this hand was able and willing to exercise complete control over the system.

In the concluding session of this symposium I objected strongly to the practice of presenting such impracticable designs and my objections were quite well received. Sadly, however, neither the practice of preparing impracticable designs for change nor my objections to these are atypical of the transactions of such meetings or of the treatises on planning appearing in the learned journals.

The real problem, perhaps, is that these practices have become a part of an accepted academic culture. Hence, the designs that identify niether the mechanisms of change nor its agents continue to be made and objected to, independently of the functioning of the relevant systems in reality. Designs based on system dynamics modelling are often no exception to this rule, in spite of the power this method offers for the construction of realistic models of decision systems and the interpretation of their behavior.

The dysfunctional culture of academe has been widely discussed and I do not wish to add to these discussions [Blair 1982, Cairncross 1985, Mitroff 1984]. Suffice it here to say that much of what has been written and said about this malaise has come to apply to system dynamics, even though the rationale for the system dynamics method was originally to bridge the gap between theory and practice.

I would like, however, to outline an agenda for the use of system dynamics modelling in preparing practical designs for change. I am assuming there is sufficient motivation on our part to implement this agenda, even if it means going beyond the call of duty of an academic and viewing our research as a means for improving the working of the social system we live in, not merely for creating artifacts necessary to complement an academic profile.

THE PERFECTLY REASONABLE HEURISTICS OF SYSTEM DYNAMICS MODELLING

There are many ways in which 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 the micro-structure of the model and verifying its behavior, although the information on behavior may reside in the historical data and that concerning the micro-structure in the experience of the people [Forrester 1980].

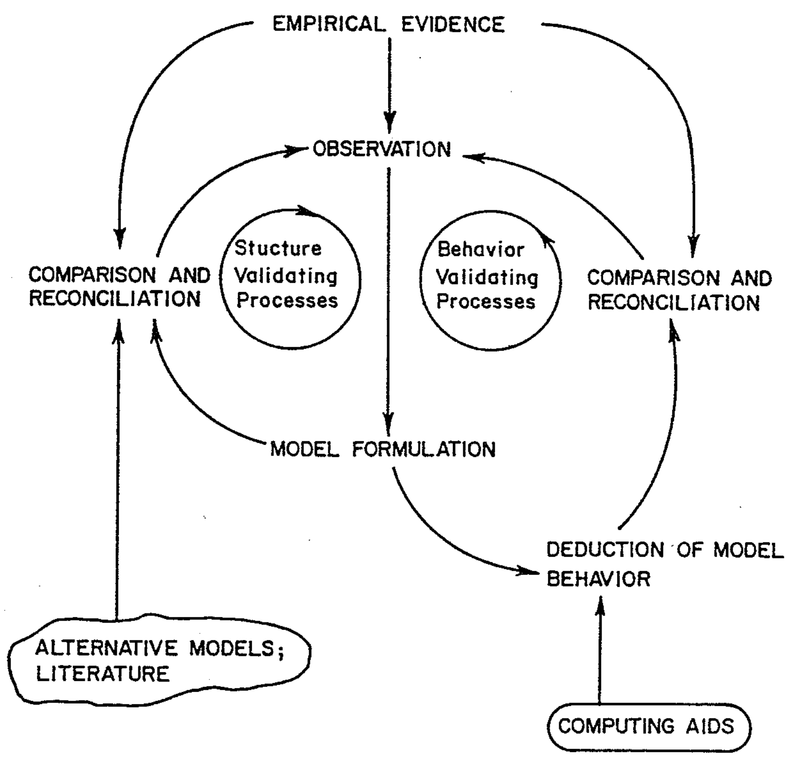

Figure 1 : System Dynamics Modelling Procedure

The first requirement of the method is to organize historical information into what is known in our jargon as "reference mode." The reference mode leads to the 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 in the system, and not on correlations between variables observed in the historical data.

A formal model is then constructed incorporating the dynamic hypothesis along with the other structural details 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 the real world consists both of theoretical expositions and experiential information. A model may undergo several iterations to arrive at an acceptable structure.

Once a satisfactory correspondance between the model and the real world structure has been reached, the model is subjected to behavior tests. Computer simulation is used to deduce the 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 the reference mode, the model structure is re-examined and, if necessary, modified. In rare cases, such testing might also unearth missing detail concerning the reference mode, leading to a restatement of it. In most cases, however, the reference mode delineated at the start of the modelling exercise must be held sacred.

When a close correspondance is simultaneously achieved between the structure of the model and the theoretical and experiential information on the system, and also between the behavior of the model and the emprical evidence on 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].

WHAT CAN GO WRONG WITH THE SYSTEM DYNAMICS MODELLING PROCEDURE?

The procedure described above for developing system dynamics models appears quite consistent with what has been proposed in the literature as the method of scientific enquiry, which seeks to ensure that all edifices of knowledge are empirically based. The first task of a scientific enquiry is to understand how real world behavior arises out of real world structure. However, since there is no direct way of knowing this, a model of the real world structure must be constructed and its behavior obtained through deductive logic. The structure of this model is obtained through a process of induction based on empirical knowledge of the real system. Repeated comparisons with the real world, both with respect to structure and behavior, establish confidence in the model as the basis for its validity [Kemeny 1959, Popper 1959].

Figure 2 illustrates the essence of the general verification procedure suggested by Popper, which requires that a model be compared and refuted through many points of contact with reality in terms of both its micro-structure and behavior, to ensure its existence in reality, its uniqueness, and its ability to be empirically identified. These are the requirements for it to be a valid piece of knowledge.

Provided the various steps incorporated into a scientific modelling procedure are not contrived, it should be possible, at least in theory, to create a model of a system which is not only internally consistent, but which also exists in reality, is unique and identifiable, and has been sufficiently refuted [Casti 1981]. The modelling heuristics of system dynamics, although informal, seem to adequately assure that the scientific procedure is followed in spirit [Bell & Bell 1980]. Unfortunately, a model created by following these heuristics, although quite valid from a theoretical standpoint, may be of little value for designing change.

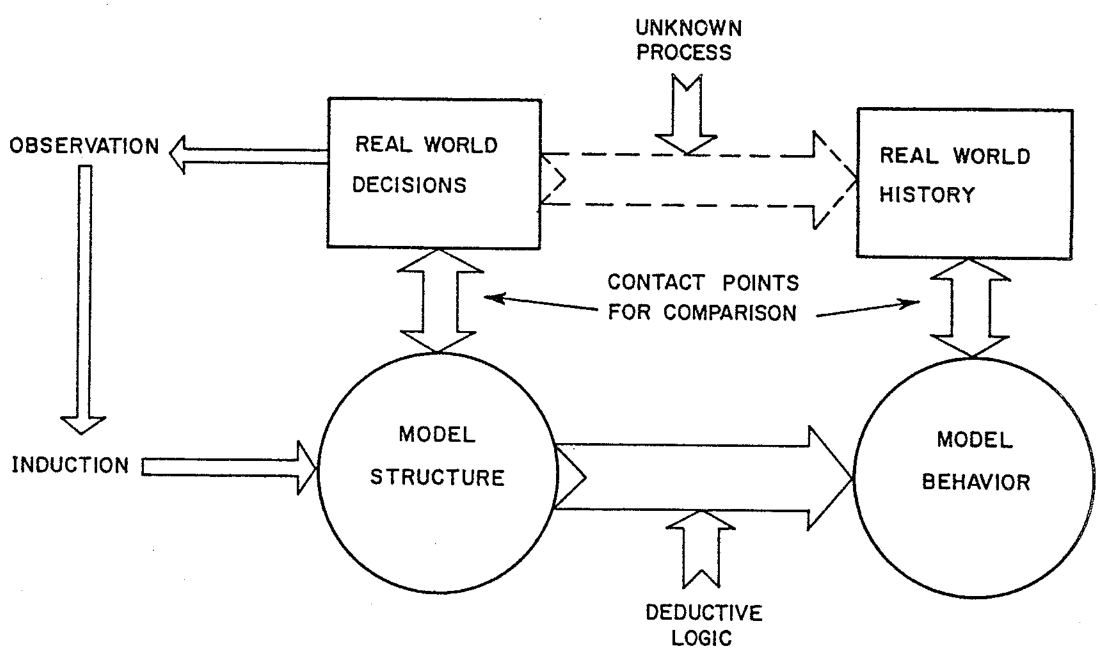

Figure 2 : Scientific Method

Three types of problems arising with the heuristical procedure of system dynamics modelling may depreciate the value of a model as an instrument for the design of change:

First, the informality of the procedure is both its biggest strength and biggest weakness since it leaves the modeller with a very high degree of freedom to determine what might be an adequate level of testing for a model and also the criteria for qualifying in a test, which produces a large variability in the quality of understanding of the modelled agenda. A poorly formulated and understood model can often be set up to replicate a historical pattern faithfully, but it may not provide any insight into the design of change. Very large models with overly complex structures may often fall into this category.

Second, even when the behavior of the model is well understood and it also has a high explanatory power on a phenomenon that was basis for delineating its structure, the model may be too local to that phenomenon and may lack entry points to mechanisms of evolutionary change from a given pattern to another. Very small models may often fall into this category. Highly complex large models that incorporate multiple modes of behavior existing simultaneously but that cannot subsume multiple patterns existing over various periods in history in a single organization or in various similar organizations, may also be of little value for the design of change.

Finally, a model may be quite cleverly constructed, may contain an appropriate policy space for entry points for evolutionary change and the model structure and behavior may be well understood. It may even point towards effective ways to change an existing pattern. However, unless the broad policy guidelines issued by the model are translated into an implementation strategy that is congnizant of the human organization in which implementation is to take place, the design of change may designate some imaginary entity like "We" as the agent of change, and "We" may have to be someone with the jurisdiction of a god and the mission of a saint to be able to intervene according to this design [Saeed forthcoming].

There is indeed no dearth of analyses making moral judgements about the responsiblity of an organizational leader, a government, the people at large, or even the world conscience, and implicitly designating these parties the agents of change, whether or not they are able and willing. Sometimes, such policy agenda may even fuel someone's ambition for power by justifying the centralization of decision making. Such centralization may not facilitate change but may only help to create machiavellian beings with no commitment to the objectives for which the design was originally conceived [Saeed 1986,1986a].

THE REQUIREMENTS OF A MODEL FOR THE DESIGN OF CHANGE

It is important for the design of change that the behavior of the model, which is a basis for design, and its empirical relevance are fully understood. Thus, the model may not be overly complex, although it must incorporate the essential ingredients of a general framework for affecting a system change.

This problem is not new and has classically been overcome by simplifying the models so that they are relevant to relatively simple patterns of behavior. For example, suggestions are made in the literature to develop special models for the design of economic development plans for developing countries, which are different from the models applied to the developed countries, although these models may lack the mechanisms for change from the under-developed country to the developed country pattern [Lewis 1974]. The designs thus created often disregard existing system and advocate massive intervention by the government as has been the case in the policy design for economic development [Saeed 1986].

It may also be possible to partition the system to be modelled into smaller sub-systems and prepare a design for change based on the many models representing these sub-systems. To be able to facilitate the design for change thus attempted, the model of each subsystem must subsume multiple modes of behavior so that it is possible to identify policies that may cause one mode to change to another. However, the term "multiple modes" is used rather loosely by system dynamists and not all classes of multiple modes may be relevant to the design of change. Thus, intuitively sensible schemes for partitioning a system may often create sub-models that do not incorporate policy space for the design of change.

In my observation, the term "multiple modes," as used by system dynamists, has two dictinctly different interpretations:

First, it may refer to simpler components of a complex pattern of behavior that is exhibited by a system over a given period. An example of multiple modes interpreted in this way 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 to change them [Mass 1975].

Second, it may mean multiple patterns experienced in history over different periods or over the same period by similar organizations separated geographically. Examples of multiple modes interpreted in this way are the many patterns of social class structure that can emerge from Forrester's Urban Dynamics model [Forrester 1969], the many levels of market share given by Forrester's Market Growth model [Forrester 1968], the many patterns of income distribution given by Saeed's Income Distribution model [Saeed forthcoming], and the many patterns of market penetration of an innovation given by Homer's Innovation Diffusion Model [Homer 1987].

A model that is suitable for designing 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 these may not provide any additional policy space, although they may enhance a model's ability to track history accurately.

Unfortunately, most commonly practiced functional partitioning schemes may often create sub-models which emphasize the replication of historical patterns containing simultaneously existing multiple modes so that model behavior tracks history accurately. However, for the sub-models to be useful for the design of change, the opposite of the above partitioning scheme is necessary. The system 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 to limit the complexity contained in a single model.

Partitioning a system into subsytems that produce behavior different from what might exist in historical data complicates the task of verifying the behavior of the sub-models as it may not replicate historical time series in a composite form but may concern only one of its components representing one of the trends in the system. Since composite historical data may not directly produce such a trend, it is necessary to analyse history carefully to be able to discern trends that are specific to the partitions. This requirement may also make it difficult to use automated procedures of parameter estimation for the model that require historical data as input.

If the reference mode has been adequately understood, leading to its decomposition into its simpler components either formally or intuititively, partitioning a system into models each of which relates to a specific component of the complex historical behavior may also not necessarily undermine the explanatory power of an analysis. Saeed's related models concerning social, political and environmental factors in the context of the design of change for the developing countries is an example of partitioning the system along the simultaneously existing multiple modes into separate modelling agenda [Saeed 1986a].

It would, of course, be ideal to incorporate into a model the structure underlying both the types of multiple modes described above and still be able to understand its behavior intuitively. This way, the model would have both the ability to track a historical time path accurately and also adequate policy space to facilitate the design of change. An exmaple of such a modelling exercise is Forrester's National Model, which not only incorporates both types of multiple modes, it also addresses many problem areas [Forrester et. al. 1976]. Unfortunately, the time and resources necessary for undertaking a modelling effort of that magnitude are rarely available.

Finally, the policy recommendations should not end with a moral statement about what should be done but should also identify the agents of change and discuss their motivation for undertaking the change. To avoid vagueness about these agents and their ability and willingness to implement the policies of change, their jurisdictions and interests must be carefully considered as part of the policy design effort.

HEURISTICS FOR MODELLING FOR THE DESIGN OF CHANGE

A model or a set of models which may serve as a useful instrument for the design of change must have a structure that is intuitively understandable with the help of simulation experiments, subsume the multiple modes of behavior the system may give when operating in different times and places, and be capable of providing clues to evolutionary change in the system. To meet these requirements, the heuristical procedure of system dynamics modelling needs to be supplemented by the principles described here.

a) The modelling objective should be to understand process, not generate a design

I strongly subscribe to the view that the burden of responsibility for designing a change must rest with the modeller as an individual and not his model. A model should be seen only as an instrument to assist with understanding a problem and identifying a general framework for the design of change. Such a model may not directly generate the details of the design since one capable of doing this may be too complex to understand and absolve designer from accountability for his design.

The objective of a modelling exercise, therefore, may not be to obtain policies of change from the model but to understand the mechanisms of change existing in a system so that a design for change can be attempted. This principle also creates the requirement for the model to be intuitively well understood.

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

Historical data in the form of a record 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 searching and organizing data to delineate the reference mode for a model to give clues about change. This refernce 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 the delineation of 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 may 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, based on isolated historical experience. Neither of these models can identify an evolutionary mechanism of change from one pattern to another without highly interventionist policies. 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 on how a given pattern may evolve into another [Saeed forthcoming].

Historical data also have to be decomposed, either informally or using formal spectral analysis algorithems, 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 seen in the social, political and technology related patterns in an organization or a 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 may be blank cells 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 to be addressed.

c) 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.

d) Each model developed as a part of the design effort should have the 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 conservative subsystems in the model that make possible the distribution of the contents of the relevant levels between functional and dysfunctional categories. A latent structure would thus 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 tenure in Saeed's Income Distribution model [Saeed forthcoming], 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 addressing the simultaneously existing multiple modes in separate models.

f) 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 the centralization of the power to make decisions by an outside autonomous hand is usually not feasible. 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 longer sympathise with the objectives of the design. Finally, centralization may go against a prevalent management ideology and may be unacceptable to the members of the organization in which the design is to be implemented, thus arousing destructive conflict. The design 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 the latent structure for the model suggested in para (e) above, the policies indicated for creating a desired pattern would usually translate into changing the 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 critical decisions [Forrester 1987].

If the model has a critical parameter, it may still lead to a policy design in terms of changing this parameter. In actual practice, however, such a change may require 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 either of 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.

The design guidelines thus conceived may still need considerable thinking before a workable implementation strategy can be worked out. The process of design for change should not, therefore, end with identifications of clever ways to change system behavior.

DESIGNING AN IMPLEMENTATION STRATEGY

The world view underlying a design for change will strongly influence whether the design can be realistically implemented or not.

If the design is based on the assumption of the existence of a social vacuum instead of a living society with a complex motivational pattern, it often calls for an autonomous outside hand to intervene as has often been the case. Such an intervention has little chance of success as it would be resisted by the actors affected while the motivations of the intervener may also change during implementation from the original purpose of the change.

If it is recognised that a system of roles already exists and that the design is to be implemented within this system, the design would be concerned with identifying mechanisms of intervention for an evolutionary change. These mechanisms might often lie outside the scope of the model that issued the functional design guidelines. The design of a strategy of change in such a case may be guided by the following principles.

a) Implementation roles should be identified, not left to leadership

The implementation of a design of change cannot be left to the leadership since a designated organizational leader may neither be willing to take unnecessary personal risk nor be sufficiently committed to the objectives of change. It should be recognised that the leaders of an organization must also work under the pressures of their own roles and their commitment to implementing a policy for change may not be independent of these roles.

b) Scope of existing organization and its leadership should be recognised

Means of intervention are to be usually explored within the framework of an existing organization and the scope of its existing leadership. The functional role of each agent of change is to be clearly stated. It may often be necessary to delineate the costs and benefits of the change to the various parties concerned with the implementation to undertstand their motivation to act.

c) Organizational change should be conceived as an evolutionary process

Sometimes, an organizational change may become part of the design of a functional change. Such an organizational change must also be conceived as an evolutionary process, except when the organization in question is small and agreement on changing its structure can be readily reached. Sometimes another model incorporating the organization of implementation might help to delineate such design details; it may often be possible to work these out intuitively.

The surface has only been scratched in the field of system dynamics on the design of implementation strategies. Examples of interesting implementation modelling include Mass's treatment of Self-Learning Revival Policies for implementing policy guidelines issued by Forrester's Urban Dynamics model [Mass 1974], Saeed's treatment of political pressures to understand the commitment of a government to public welfare in the context of the implementation of the development agenda issed by his income distribution model [Saeed 1986, Saeed forthcoming], and Homer's work on the diffusion of innovation in a market [Homer 1987].

To address the issue of implementation in any exercise concerning a design of change should be a requirement. System dynamics lends itself easily to the address of such issues. Important research agenda on this front include the investigation of the role of organizational leadership and its commitment to change, and the diffusion of a new functional process in an organization, a market or a society.

CONCLUSION

System dynamics is a powerful tool with which to create realistic designs of change. However, policies generated by this method are often as irrelevant to implementation as those based on any other type of modelling. It should be recognised that system dynamics, in spite of its power, will not create a better design for change if the implicit view underlying the preparation of the design continues to be that implementation can be undertaken by an autonomous hand which is able and willing and whose actions will be fully accepted by the actors of the system.

I have attempted in this paper to delineate modelling agenda for designing evolutionary change in an existing system of roles. According to this agenda, the role of the modelling exercise is not to issue a policy directly but to increase understanding of the problem so that policy design can be attempted. It is thus important that model is small enough to be understandable.

Although it is not advisable to make so many limiting assumptions that the behavior of a model is divorced from reality, sometimes, a complex problem may be partitioned into sub-problems and several models constructed to address the issue of design of change. Such partitioning, however, must create models that subsume patterns belonging to the same behavioral attribute but existing at different points in time or at different geographical/physical locations. On the other hand, multiple modes of behavior existing simultaneously in a system may be addressed in separate models. Historical data may often have to be decomposed into simpler components to delineate a reference mode for such models, while a search for historical patterns separated by time and geographic location is also necessary to identify multiple modes to be subsumed in a single model.

The implementation details of a functional design must be prepared keeping in view the limitations of the existing organization in which implementation is to occúr and its leadership. Sometimes separate models may be needed to address this issue.

The design of change must be distinguished from a scientific modelling exercise attempting to explain a phenomenon. A model that may give clues to evolutionary change must subsume multiple phenomenon separated by time and geographic space. Since system dynamics is capable of creating such models, the design for change is suggested as an appropriate agenda for its application.

REFERENCES

Bell, J. A., & Bell, J. F. 1980. System Dynamics and Scientific Method. In Elements of System Dynamics Method. J. Randers, ed. Cambridge, Mass.: MIT Press

Bell, J. A., & Senge, P. M. 1980. Methods for Enhancing Refutability in System Dynamics Modelling. In System Dynamics. Legasto et. al., eds. Amsterdam: North-Holland

Bertalanffy, L. V. 1968. General System Theory. New York: George Braziller

Blair, D. C. 1982. The Nature of Scientific Theory. Human Systems Management. 3: 279-288

Cairncross, A. 1985. Economics in Theory and Practice. American Economic Review. 75:1-14

Casti, J. 1981. Systemism, System Theory and Social System Modelling. Regional Science and Urban Economics. 11: 405-424

Forrester, J. W. 1968. Market Growth as Influenced by Capital Investment. Industrial Management Review. 9: 83-105

Forrester, J. W. 1969. Urban Dynamics. Cambridge, Mass.: MIT Press

Forrester, J. W. 1980. Information Sources for Modelling the National Economy. Journal of the American Statistical Association. 75: 555-566

Forrester, J. W. 1987. Nonlinearity in High Order Models of Social Systems. European Journal of Operations Research 30:104-109

Forrester, J. W. and Senge, P. M. 1980. Tests for Building Cofidence in System Dynamics Models. In System Dynamics. Legasto, A., et. al., eds. Amsterdam: North Holland

Forrester, J. W., et. al. 1976. The System Dynamics National Model: Understanding Sociio-Economic Behavior and Policy Alternatives. Technological Forecasting and Social Change. 9:51-68

Homer, J. B. 1987. A Diffusion Model with Application to Evolving Medical Technologies. Technological Forecasting and Social Change 31:197-218

Katz, D., & Kahn, R. 1978. The Social Psychology of Organizations 2ed, New York: John Wiley

Kemeny, J. G. 1959. A Philosopher Looks at Science. New York: D. van Nostrand

Lewis, A. 1984. The State of Development Theory. American Economic Review 74:1-10

Mass, N. J. 1974. Self-Learning Revival Policies in Urban Dynamics. In Reading in Urban Dynamics. Vol I. Cambridge, Mass: Wright-Allen Series, MIT Press

Mass, N. J. 1975. Economic Cycles: An Analysis of Underlying Causes. Cambridge, Mass: Wright-Allen Series, MIT Press

Mitroff, Ian I. 1984. Why Today's Universities are Irrelevant to Today's Problems: They've Been Designed for That Very Purpose; The Time for Cahnge is Way Overdue. Technological Forecasting and Social Change. 26:183-188

Popper, K. R. 1959. The Logic of Scientific Discovery. Part I. New York: Basic Books

Richardson, G. P., and Pugh III, A. L. 1981. Introduction to System Dynamics Modelling With DYNAMO, Cambridge, Mass.: MIT Press

Saeed, K. 1986. The Dynamics of Economic Growth and Political Instability in the Developing Countries. System Dynamics Review. 2: 20-35

Saeed. K. 1986a. Limits to National Development, Resources or Resource Allocation Processes. In Proceedings of the Conference of System Dynamics Society. Saville. 1: 537-563

Saeed, K. Wage Dtermination, Income Distribution, and the Design of Change. Behavioral Science. Forthcoming