A Methodology for Qualitative System Dynamics

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ABSTRACT

This paper is based on the premise that there is a need to formalise the procedures used in system dynamics, outside the area of computer simulation analysis, to create a stepwise procedure for systemic analysis. This need arises within the subject when applications encroach on areas where quantification is difficult or unacceptable or when a full qualified analysis is not an economic proposition or limited by time factors.

The paper suggests that qualitative system dynamics should be propogated through the medium of a general framework for system enquiry. The need for general systemic methodologies is examined and the major elements of system dynamics are used to formulate the basis of such a methodology. This formulation presents a means for qualitative problem analysis in terms of the organisational structure and process control structure of systems using generally proven results developed from quantitative system dynamics models.

INTRODUCTION

Whilst there is no clear dividing line between qualitative and quantitative system dynamics, in that models must always be constructed bearing in mind the order of magnitude of the variables specified and the underlying time horizon considered, qualitative system dynamics (Q.S.D.) is taken here to represent system dynamics without specific quantification of variables and computer simulation analysis.

It is suggested that all system dynamics practitioners practice Q.S.D. to some extent and that there appears to be a need for such an approach for four genuine reasons. Firstly, full quantification of all variables is feasible on only a small number of studies on which analysis is needed and hence the application of the full system dynamics method is restricted to a very small part of the full spectrum of systemic problems. Secondly, the people who perhaps need an appreciation of systemic methods most are rarely the ones who find highly quantitative approaches very compatible with their own philosophy. Hence, a persistance with full system dynamics studies is a strategy which does not penetrate the whole market of potential users. Thirdly, even given its speed and ease of application relative to many other methods, a full system dynamics study is often, in all but the most experience hands, too slow a method of facilitating change in many types of system. Consequently, it can be argued that application of the full system dynamics method is sometimes also restricted to longer term background problems. Fourthly, even where time is not too limited, it is often considered that the value added from developing a full computer simulation model might not be worthwhile.

It is the premise of this paper that much more thought must be given to specific methods of conducting Q.S.D. and that progress here could reap vast benefits by improving communication of the underlying attributes of system dynamics models to other fields and hence expanding its breath and rate of application.

System dynamics is undoubtably a powerful tool for providing insight into the behaviour and evolution of complex systems, which is somewhat unique in encompassing the adaptive nature or feedback effects of such systems. However, those adept at practising this method often adopt a blinkered approach to the process which they use. The procedure employed primarily represents a direct search for a model structure capable of providing a feedback hypothesis for observed system behaviour, and its ultimate objective is to move as quickly as possible to designing system policies by which to improve behaviour. Whilst this is a commendable procedure it often leads to the impression in other field of enquiry that the subject is totally self-contained and independent and concerned only with developing highly sophisticated and quantitative control. It is felt that this perception is a major factor in its current state of isolationism, which has been observed by numerous analysts in recent years (for example Fey 1981). An alternative use of system dynamics, as put forward here, would be to aim for introducing a much lower level of control into a much wider range of systems and to concentrate on breaking down the procedures used into a form more compatible with those used in other fields.

There are already some steps being taken within system dynamics along these lines, but these do not go far enough. For example there is already much work being undertaken in the qualitative use of influence and casual loop diagrams (Robert N. et al 1982) for explaining system behaviour. However, this tends to be carried at within the self contained framework referred to above and it is felt that the key to unlocking the door to system dynamics lies in presenting it within a more open and accessible framework.

Such frameworks exist in many fields and are created to facilitate stepwise procedures for structuring complex issues. These frameworks are usually qualitative since they must appeal to the full breath of the fields involved, but they often contain optional quantitative components. A good example of such frameworks are those used in business policy (Gluck 1976, Porter 1980) for strategic assessment of companies. Here, the subsumed quantitative component is usually a hard technique area for assessing alternative strategies, after their generation, and before the implementation stage. The use of system dynamics as an alternative to existing frameworks in the business policy field is currently being explored. (Morecroft 1985).

The ultimate extension of the framework concept leads to the idea of the possibility of creating a general methodology for system enquiry, applicable across all fields. The search for such a general methodology for system enquiry has, in fact, been in existance for some time, with very limited success. It is the premise of this paper that it is at this totally general level of enquiry that the concept of system dynamics as a framework for analysis should be aimed. It is suggested that the procedures of system dynamics provide an ideal basis around which to create a general system enquiry methodology and that Q.S.D. should be developed for this purpose. This view requires an open mind. It requires an understanding of the need to perhaps breakdown the existing system dynamics method in to what may sometimes appear, to current practitioners, to be trivial components. It also requires an acceptance of the fact that the complete stages of the system dynamics method (even in qualitative form) may not be carried out in all cases. The purpose of the paper is, therefore, to briefly review progress within the general systems field towards the development of methodologies and to provide a personal view as to how the major elements of system dynamics might be used to form the basis of such a methodology.

SYSTEMS ENQUIRY AND SYSTEMS METHODOLOGIES

System enquiry is used here to define the whole field of investigation concerning the understanding and design of change in complex human activity systems. This field is extremely vast and although much attention has been increasingly focussed on it in recent years, there remains a dearth of methods available to provide frameworks for analysis.

A belief in the need for holistic thinking has existed for a very long time and its advantages over reductionist attitudes has been well expounded (Von Bertalanffy 1968,Popper 1957,Churchman,1968). However, the development of meaningful methods by which to apply holistic ideas has so far proved very difficult, certainly in any practical rather than theoretical sense, although the literature is well sprinkled with attempts. These attempts come from a wide variety of disciplines. Discounting for a moment the methods of system dynamics there are those arising out of the isomorphic elements of systems theory (Churchman 1971, Hall 1982, Jenkins 1969); those resulting from attempts to expand and elevate mathematical problem based techniques (Ackoff 1978); those concerned with the wider interpretations of cybernetics (Beer 1972); those based on the method of computer systems analysis (De Neufville and Stafford 1980); those based on highly sophisticated structural modelling ideas (Linstone 1979) and those based on purely qualitative diagrammatic and verbal procedures (Checkland 1982).

The difficulties in generating useful methods centre on the compromise required between the vagueness necessary to be sufficiently general and the precision needed to produce specific results. In terms of problem analysis this dilemma takes the form of a need to have a wide and flexible approach to facilitate structuring of symptoms and problem identification whilst simultaneously requiring a narrow rigid approach to facilitate the creation and testing of remedies.

Consequently, there continues to be extensive research into compromise approaches for system enquiry, based on a mixture of hard result orientated technqiues and soft subjective methods, and current systems work is characterised by the search for improved methodologies. Methodology is defined here as the overall process of investigation usually stepwise and iterative, by which concepts philosophies and theories can be expressed independently of the subject matter of the investigation and independently of the problem type to be considered. This use of the word methodology is not be confused with its use in a specific technique sense where it simply implies a list of steps necessary for the application of that technique for example, the linear programming methodology. The ideal methodology according to Checkland must avoid the content free methodologies derived from General Systems Theory and the ever precise goal orientated formulation stemming from system analysis.

SYSTEM DYNAMICS AS A SYSTEM METHODOLOGY

The credentials of system dynamics as a system methodology have been explored elsewhere (Wolstenholme 1982 and 1984) and a stepwise procedure put forward for system description and problem exploration. The basic points which were made concerning the credentials of the system dynamics method as a systems methodology were twofold. Firstly, that the building blocks of rates and levels provided an excellent compromise between generality and usefullness for structuring systems and secondly that the concept of control and its effect on system evolution over time was addressed. On the limitations side it was firstly, suggested that there was a need to overcome the almost total emphasis placed on system processes in system dynamics and that there exists a great need to recognise the role of the organisational structure of systems in determining system performance. This need is, in fact, becoming more widely recognised (Morecroft 1984). Secondly, that there was a strong case for divorcing the system description and systems analysis phases of system dynamics to comply with methodological practice in the systems field. In other words system description should be carried out as an essentially static function, which is, in fact, often the case in practice when a reference mode of system behaviour is not available and primary structuring of a system is the aim. It was with these ideas in mind that the following definition of system dynamics as a systems methodology was suggested

> "A rigorous method for problem identification, system description, qualitative modelling and analysis of change in complex systems; which facilitates and can lead to quantitative modelling and dynamic analysis for the design of system structure and control."

and the stepwise procedure for its system description phase (Appendix A) formulated. This procedure essentially restates the process of model conceptualisation used in system dynamics; however, it places more emphasis on the early recognition of system levels and orientates the process towards a more convential methodological form. The purpose of the procedure is to focuss on influence diagramming for system description as a stand alone method, and to contrast its attributes relative to many of the less rigorous methods currently used in the system field. In the context of the whole spectrum of system enquiry these description methods range from poetry at one end to totally explicit computer based algorithm at the other. The use of influence diagrams, which are almost independent of system behaviour considerations, is not totally unique in the system enquiry field (Eden 1978). The main characterised of the procedure is that it starts at a high level of aggregation, and is aimed at facilitating both the elmination and introduction of resource states, as well as attempting to focus on the right level of resolution for the diagram. The overall objective of the procedure is to produce the simplest diagram structure, capable of relating the key variables associated with the cause for concern specified. The procedure is close to that recommended by a number of system dynamics practitioners for use in initial problem structuring, where both knowledge of the system is poor and a basic feedback hypothesis does not exist. In other words its final objective is to uncover any feedback loop structure.

The second stage of the procedure relates to the qualitative analysis of the derived diagrams and the remainder of this paper will be devoted to suggesting procedures for this.

QUALITATIVE ANALYSIS USING SYSTEM DYNAMICS

The definition of the steps for qualitative analysis suggested here may be viewed essentially as an attempt to replicate the basic procedures of system dynamics policy design, but without resorting to computer simulation. The important differences are that more attention is paid to the organisational implications of the system and that the whole process of the analysis is slowed down and the degree of resultion of the analysis is increased. This is aimed at increasing communication and understanding of the system to assist the role of the system actors and owners in designing and implmenting change for themselves.

A four phase procedure is suggested for qualitative analysis and these phases together with the main steps involved in each are summarised in Appendix II. The major phases consist of static analysis, the identification of control issues, the dynamic implications of the existing system structure and the indentification of factors for improving system performance. Many of the steps are self explicit and are laid out to facilitate the application of the methodology by people who are not familiar with system dynamics. The details of each step will not be repeated here in the text, but discussion will be made of the general structuring of the procedure.

The first three phases are designed to make analysts' stop and think about the system as is, rather than jump headlong into system redesign. The first of these stages focusses on creating a static feel for the process/organisational balance of the system and is geared to focussing the system actors attention on the process perspective. The second tries to examine the existance or otherwise of control in the system and to categorise control, where present, by its variables, mechanisms and frequency of application. Only during the third phase is it suggested that true dynamic analysis and hand simulation of the structure be attempted.

The fourth and final phase of the procedure is concerned with changing the system. It is at this point that we are faced with the problem of how, in the absence of a quantitative test procedures, to objectively improve system performance and to overcome the original cause(s) for concern associated with a system. This problem is, of course, not unique to this particular approach and is a common difficulty encountered by all soft system methodologies. In fact, by having used system dynamics as a bases for structuring the system it could be argued that there exists a much stronger basis for analysis than in the case of many other system methodologies and that this is where system dynamics scoes an enourmous advantage over other methods. There are two reasons for this, both associated with the relatively high level of rigour attached to the diagramming procedure, which has arisen out of its simulation origins. Firstly, the level of communication facilitated by the diagrams is high and they are very orientated towards encouraging self-diagnosis and self-help amongst the system actors and owners. Secondly, there exists a whole body of proven general results for system dynamics structures which can be used as a basis for directing change in systems. Whilst it is not suggested that such results will have a relevance in all systems, and that there are, undoubtably, dangers in the indiscriminate use of them, it can be argued that there is, in the majority of practical systems, sufficient scope for improvement to justify their use. This idea of the identification and transfer of generic components and results between dissimiliar systems (isomorphism) is one of the most deeply established concepts associated with the development of system methodologies (Bertalanffy 1969) and is an area being strongly pursued at present in the system dynamic field (Morecroft 1985).

It is, no doubt, likely that all system dynamics practitioners would, if asked, be able to produce a good and useful breakdown of generalised results that could usefully be transferred between systems. The list identified in phase IV of the methodology here is neither claimed to be sufficient or definitive. Its main purpose is to draw attention to the fact that such a list does exist and should be communicated to the rest of the systems field as being a useful contribution to redesign throughout the system's spectrum. The list presented, in fact, concentrates on the fundementals of improving any mismatch between the organisation structure and process structure of the system; in highlighting the need for control; in defining how it may be designed or improved in terms of objectives and discrepancies and by reducing delays in information retrieval; and the implications of these factors on the information and hence monitoring needs of the system. It is further suggested that, a search is made within the diagrams developed for subconcious feedback. That is longer term feedback loops which often exist between system variables, but are not directly perceived as important by system actors because they perhaps exist at a different level of aggregation or on a different time scale to the loops under scrutiny. Finally, it is suggested reiteration takes place and that the dynamic implications of any new structures defined are examined as in phase III of the procedure.

CONCLUSIONS

This paper has attemtped to demonstrate that qualitative enquiry, is an important facet of the system dynamics field and that the current trends in qualitative system dynamics analysis currently taking place should be reinforced. It is suggested that the major elements of system dynamics when combined with some organisational analysis could form the basis for a more complete general system enquiry methodology than currently available in the systems enquiry field. The key to developing qualitative system dynamics is clearly seen to lie in parcelling this within a methodological framework, which is acceptable outside the field and which would significantly advance the utilisation of the concepts. The challenge to system dynamics practitioners is how to achieve this without too much perversion of established practices.

APPENDIX A

A STEPWISE METHODOLOGY FOR Q.S.D. (PROBLEM EXPLORATION/MODEL CREATION)

1. Recognise the key variables assocated with the perceived cause(s) of concern in the system and with the remit provided for the enquiry. Where possible, examine the behaviour of these variables over time and define a time horizon for the analysis.

2. Identify some of the initial system resources associated with the key variables.

3. Identify some of the initial states (levels) of each resource using a level of aggregation compatible relevant to the time horizon defined in 1.

4. Construct physical flow modules associated with each state of each resource, containing the physical processes or rates which affect these. (A module must contain at least one resource state and one rate).

5. If more than one state of a resource is involved cascade flow modules together to produce a chain of resource conversion or transfer.

6. For each module or set of cascaded modules identify the intra module behavioural information and control (policy) links by which the levels affect the rates.

7. Identify similar behavioural and control links between modules of different resource types. For complex situations this should be carried out for small groups of resources at a time within a defined theme and the resultant diagrams reduced to produce the simplest representation possible, consistent with relating the key variables of the investigation.

8. Identify any new states of existing resources, or new resources, which affect the rates of the modules created or new key variables, and add these to those recognised at 1 and 2. Reiterate if necessary.

APPENDIX B

A STEPWISE METHODOLOGY FOR Q.S.D. (MODEL ANALYSIS)

I. Static Analysis of the Model Structure

1. Confirm with the system actors that the model relates the major system variables associated with the original cause for concern.

2. Identify uncertain contentions or highly subjective relationships between defined variables.

3. Group variables into sets characterised by existing areas of functional responsibility (such as common accountability) and superimpose venn diagrams to delinate the boundaries of these.

4. Identify delays:
   Identify the order of magnitude of delays in both physical operations and in the retrieving or perceiving of information.

II. Identify Control Issues

1. Search for control frameworks: Classify information links as behavioural or control based. (Behavioural links are defined as the means by which systems adapt themselves in the long term if left to their own devices, whereas control mechanisms are defined to represent the actions of humans aimed at changing system performance).

2. Classify resources by their control functions: If control links exist, identify the resource stream which is being controlled (the controlled resource) and the resource stream which is acting as a controller (the controlling resource).

3. Identify the particular variables within the controlled resource, through which control is implemented and identify who is the controller (i.e. who has organisational responsibility) of each of these controlled variables.

4. Clarify the mechanisims of control, i.e. identify the range of control policies for each controlled variable; identify the sources of information feeding the policies and the intermediate processes through these data pass; identify the mechanisms by which the policies convert information into action.

5. Determine the frequency of control implementation; i.e. can control be instigated on a real-time continious basis or only at certain review points. Is the fequency of implementation of control restricted by the speed of information retreival or by organisational factors (e.g. committee meetings).

III Dynamic Implications of the Model Structure

1. Identify the major feedback loop structure of the model.

2. For each feedback loop carry out a hand simulation to assess its likely behaviour; firstly starting by changing each of the

controlled variables to extreme values of the policies defined for them and secondly by changing each of the uncontrolled (exogeneous) variables, again to the extreme range of values likely to be experienced for them.

3. Is there any evidence to suggest that the system will be subject to any well known counter inituitive or self regulating models of behaviour?

IV <u>Identify Factors likely to lead to Improved System Performance</u>

1. Can the organisation structure be changed to better match the process structure, or vice versa? For example, could one person be given responsibility for more than one controlled variable in a particular resource stream? If this is not possible can further control be designed to help resolve conflicts?

2. Do overall objectives exist for the whole or parts of the system defined and do these conflict?

3. Can control be designed for variables that are presently uncontrolled or only subject to behavioural control?

4. Does the concept of a desired state exist for each of the actual state variables in the system and are critical values defined for actual states? If so, are they themselves variables or constants? Does the concept of measuring discrepancies between actual and desired states exist?

5. For each controlled variable within each resource flow is account being taken, in its control policy, of the content of upstream and downstream states of the resource.

6. For each controlled variable are there any information flows that are very protracted and can these be short circuted; i.e. can the system be made more responsive and is this desireable? It may be that attributes of the controlled resource could be monitored whilst it is within the controllers sphere of responsibility rather than outside.

7. Examine the information retrieval and monitoring infrastructure of the system to make it compatable with the control requirements identified.

8. Examine the likely links which might exist between variables in the system which are currently perceived as being totally independent.

9. For each new defined policy, or change in system structure, created either intuitively or from the previous steps, repeat the process of defining its dynamic implications given in part III.

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