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"Qualitative v. Quantitative Modelling: The Evolving Balance".

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Abstract

This paper addresses the issue of what are the wise uses of qualitative mapping and what are the conditions that require formal quantitative modelling within System Dynamics.

The background to the evolution of qualitative and quantitative system dynamics will be explored. This analysis will recognises that although the history of feedback thought repeatedly contains the assertion that formal, quantitative models are essential for understanding the dynamics of complex systems, the need for quantification is relative and depends on the purpose of analysis, which in turn is related to the methods used and the audience addressed.

The central theme of the paper will be to examine the strengths and weaknesses of qualitative and quantitative system dynamics and to relate these to their respective tool sets. The paper will also focus on evidence from the author's extensive recent use of qualitative and quantitative system dynamics in education, training, research and consultancy studies of the way in which qualitative and quantitative system dynamics can be linked together to consolidate management learning, both in projects and in organisations.

The paper concludes that both qualitative and quantitative system dynamics are important and related to the purpose of analysis. It is suggested that within studies the true power of system dynamics to address problem solving lies in a judicious blend and intertwining of both qualitative and quantitative ideas, aimed at addressing as broad an audience as possible whilst remaining sufficiently rigorous to be useful. Within organisations it is suggested that there is a need to cement together the use of qualitative system dynamics in management development and quantitative system dynamics modelling for strategic and operational learning in teams.

Introduction

System Dynamics as Quantitative Computer Simulation

In its original concept, the subject of system dynamics was purely a computer simulation method. The core idea being to bring the emerging power of computer simulation to the analysis of complex socioeconomic issues [1,2]. Stock-flow diagrams were used to capture the structure of systems and to keep a diagrammatic representation of the equations listing of the resultant system dynamics simulation model. Essentially, model creation centred around a preliminary diagram from which the initial simulation equations were written. However, the equations soon dominated the model development process and the diagram, as in most

systems analysis of the day, was often a retrospective attempt to monitor and communicate the development process.

Enter Causal Loop Diagrams

Given that system dynamics models were basically control feedback models, an early innovation was to introduce the idea of causal loop diagrams [3], later referred to in the U.K. as influence diagrams [4,5]. Causal loop diagrams provided a high level means of conceptualising models in terms of their feedback loop structure. These diagrams were then converted into stock flow diagrams for the purpose of simulation modelling.

Qualitative System Dynamics based on Causal Loops

It was later suggested by a number of authors [6,7,8,9], that causal loop diagrams could be used in a free standing mode without computer simulation to assist issue structuring and problem solving.

One strand of this work resulted in the development of cognitive mapping [10] and its associated software. The other resulted in the development of qualitative system dynamics, firstly as a prerequisite for quantitative system dynamics [11], then as a free standing concept referred to as systems thinking [12] aimed at providing some level of insight into managerial issues by inferring, rather than calculating, the behaviour of the system represented. Note that the use of the term systems thinking in this way should not be confused with its use in the UK to describe the systems approach to managerial problem solving represented by the various strands of soft OR [13].

This assertion that causal loop diagrams alone could add value to issue structuring and behaviour assessment was based on the fact that even in this mode such diagrams were sufficiently rigorous to provide a significant increase in assistance to thinking compared with other emergent diagrammatic tools. For example, the system problem solving approaches embedded in the methods of soft operational research and, in particular, the rich pictures of the soft systems methodology [14] .

Qualitative System Dynamics based on Stocks and Flows

At the same time the development of system dynamics simulation software turned towards the use of visual interactive components [15,16,17]. Such software allowed the development of models electronically by creating stock flow diagrams directly on the computer screen as icons which could be opened to insert data to create simulation models, without recourse to separate equation formulation. This method only allowed models to be changes via the diagram and hence ensured that diagrams were always a one-to one representation of the equation listing. These preliminary stock-flow diagrams were termed system maps to distinguish them from system dynamics models and such software was designed to operate either in mapping or modelling mode. Some software [17] now allows the mapping to be carried out in either stock flow of causal loop diagrams, although no way has yet been established to directly convert a causal loop representation directly to a simulation model.

System Archetypes

One of the cornerstones of qualitative system dynamics based on causal loop diagrams was the use of generic structures. Of particular significance was the use of generic structures in both diagramming formats. The stock-flow version of this was in the form of multiple stock flows or main chain structures and the causal loop version of this was in the form of system archetypes [12]. These were patterns of loops related to patterns of behaviours (for example, limits to growth and fixes that fail) which emerged from extensive cumulated simulation modelling experience. These archetypal structures have since been further categorised [18]. They have also been developed to include model boundaries and condensed into truly generic two loop combinations [19].

The current issue, addressed in this paper, centres on to what extent can qualitative mapping and quantitative modelling contribute to understanding the dynamics of complex systems?

Spectra of Quantification

The Context of Quantification

Before answering this question it is of interest to take a systems perspective by standing back and reflecting on the context of the issue. Two spectra are considered of relevance to this context. The first is the spectrum of the audience addressed by these methods and the second is the spectrum of the methods of problem solving available to shed light on complex issues. Both of these spectra range from the extremes of purely qualitative to purely quantitative.

The Audience Spectrum

Firstly, the audience. Many people need insights into complex systems who are towards the qualitative end of the audience spectrum. These include non-visual thinkers [20], non-quantitative thinkers or those who would never have an interest in the learning overhead associated with learning a modelling approach to problem solving. The non-quantitative audience is thought to be much larger than the quantitative and to include many busy and successful senior managers. There is strong evidence that people toward the quantitative end of the spectrum are more introverted and, whilst more capable of using the methods, would not have the same breadth of interest to became decision makers in influential positions.

Although this situation might suggest that the quantitative people (analysts) should help the non-quantitative, it is well established that insights cannot be transferred easily [21,22]. The implication here is that methods must be found to enable everyone to be involved in the modelling process and to learn these insights for themselves. In fact, one of the biggest problems in growing the field of system dynamics is that of finding people with the right blend of technical and managerial skills.

The Spectrum of Problem Solving Methodologies

Secondly, the methods of problem solving. These range from the extremes of total intuition and speculation at the qualitative end of the spectrum to rigorous algorithms at the quantitative end of the spectrum. Any way of assisting intuitive thinking involves some degree of formal and logical issue structuring and both systems thinking and system dynamics

can be thought of as tools for this purpose. An important point here is that system dynamics simulation is itself not particularly formal and neither is qualitative system dynamics particularly informal, relative to the extremes of this spectrum. Systems thinking and system dynamics might be thought about as map-supported and model-supported speculation respectively. No map or model is ever a complete analysis and there is always still a need for further speculation beyond the insights reached.

The important conclusion of this section of the paper is that any claims for the value of quantitative system dynamics simulation analysis over systems thinking is relative to where they lie on the spectrum of problem solving methods and the needs of the spectrum of audiences requiring assistance with their thinking. Further, that in applying any problem solving methods there is a need to create a balance between the need to remain sufficient quantitative to be applicable and sufficiently flexible to be relevant, in terms of both audience and method.

The Strengths and Weaknesses of Qualitative System Dynamics

Systems thinking undoubtably provides a significant level of assistance to thinking.

'Causal loop' systems thinking enhances linear and laundry list [16] thinking by introducing circular causality and provides a medium by which people can externalise mental models and assumption and enrich these by sharing them. Further, it facilitates inference of modes of behaviour by assisting mental simulation of maps. By identifying policy links in maps, it allows focussed speculation of how to intervene to redesigned systems. By using archetypal structures, particularly total generic two loop structures, involving policies, boundaries and delays, it enables potential unintended consequences to be anticipated and hence increases the chances of plans being achieved. The methods bring much needed tools to the strategic areas of management and allow a wide range of managers to access the power of feedback thinking.

'Stock-flow' systems thinking requires additional skills and learning than its causal loop counterpart, but adds the dimension of process representation into the analysis. It facilitates similar analysis to causal loops but, by depicting processes as flows rather than influences, it is not easy for the inexperienced to interpret feedback loop structures easily.

The dangers claimed for qualitative system dynamics is that it is easy to apply inappropriate insights to problems and that, although the methods overcome the quantification problems of simulation, they still require the strengths of feedback loops to be assessed (by at least considering in the order of magnitude of variables) and still require at element of visual thinking ability. One of the major criticisms is that the ability to become expert at causal loop mapping requires people to have undertaken much quantitative modelling and that this issue is never explained by its proponents.

The Strengths and Weaknesses of Quantitative System Dynamics

Quantitative system dynamics on the other hand adds the dimension of data to mapping structures and hence allows computer simulation of systems to ascertain their behaviours over time. Inferring behaviour of even the simplest of feedback structures is very difficult even for the trained since the human ability to consider any more than a very small number of variables at once is limited. Quantitative system dynamics brings together the best

combination of both people and their creative thinking ability and computers and their data manipulation ability.

Computer simulation modelling adds significant value to qualitative mapping by enabling deeper and more rigorous analysis. It allows a combination of soft and hard elements which is unique and powerful.

The problem with computer simulation is that data is often not available and hence models are still speculative. Further, they are often idealised representations of the world constrained by the restrictive nature of stock-flow diagrams. One of the major problems is that of how to produce simple, balanced and elegant models at an appropriate level of aggregation in time and space to be useful. There is always a tendency to produce models which are too detailed and complex and to insufficiently validate them against the mental models of their creators. Much skill is required in achieving good modelling practice both in terms of assembling the appropriate teams and the modelling process. The ideal is to create true 'modelling for learning' [23] where the process on taking part is as important an outcome as any predictive answers. Again the blend of skills for expert modelling competence is difficult to find.

Mixing Qualitative and Quantitative System Dynamics within projects

Since both qualitative and quantitative analysis are important to the success of any system dynamics study it is important to sequence the process of application of the method to capture both approaches. On such sequence being extensively and successfully used in practice by the author is referred to as 'intertwined project learning' and is shown in Figure 1. In practice this process is iterative at each stage, as implied by the circular arrows. Further each stage may be self contained and the process can be terminated at any point if required.

The first step is issue definition and exploration and the second, knowledge capture. Causal loop diagrams are used in both of these stages for the prime purpose of management engagement and knowledge extraction. These stages often involve the use of archetypal structures to stimulate the overall modelling process. The third stage is to develop the output from stages 1 and 2 into 'first pass' qualitative maps related to a consensus view of the issues of managerial concern and to feed back individual maps to managers in a group forum. These maps are then used to define the scope of a study in terms of its degree of resolution in time and space and its boundaries. They are also used as a basis for group speculation and hypotheses development of likely system behaviour, alternative policy generation and redesign of organisational boundaries and responsibilities.

The forth stage is to begin the process of serious data collection and quantification and the development of simulation models to substantiate the hypotheses created and test out organisational redesign ideas and plans.

At this point those people involved in the modelling process have usually developed numerous insights from the modelling experience and are keen to in implement their findings. However, the most serious factor effecting the success of implementation centres on conveying the insights to colleagues and, as previously intimated, it is very difficult to

transfer a learning to others. Stages five, six and seven of the modelling process therefore focus on the important area of disseminating the results and insights.

Stage five is involves returning to a qualitative mode of operation and is aimed at summarising the model in terms of an easy to understand archetypal structure. System dynamics models can easily become large and complex and the important causal loop structure generating the essential model behaviour can be lost in the detail. It is important therefore to maintain a causal loop map which summarises the structure of the model at any time. An excellent way of doing this and at the same time communicating the essence of the model is to collapse the model down to an archetypal representation.

Stage six is not aimed at summarising insights, but at creating a way of allowing other people to relive the experiential learning process that was undertaken by the modelling team. This is achieved by developing the model into an easy to use microworld by which people can use for constructive play, either individually of in a workshop setting, to investigate organisational redesign. Stage seven provides an enhancement of stage six by embedding the microworld into multimedia learning environments (LEs), which combines the model(s) with cognitive help routines which can be revealed at a controlled rate to facilitate the learning process.

Combining Qualitative and Quantitative System Dynamics within Organisations

The number of organisations now using qualitative system dynamics (in its guise as systems thinking) and quantitative system dynamics is growing rapidly. However, the tendency is still for these two (absolutely interdependent and complementary) approaches to be used in isolation.

Systems thinking is finding a home in management development programmes, where it is bringing clarity and rigour to a particularly abstract field. At the same time, system dynamics is being used to provide senior and middle managers with models for strategy and operational policy development at many different levels of an organisation. A number of large companies have over twenty different system dynamics modelling projects in existence at one time

The danger is that neither systems thinking or system dynamics, if used in isolation, will achieve their full potential. The systems thinking contribution to learning might still be too abstract and unrelated to the specific operational realities of organisations to make a lasting and meaningful co contribution to management development. And the specific learning and insights created from system dynamics modelling may be lost, without a formal process by which to capture and relate those insights back into general and top management development.

A method for consolidating learning from system thinking and system dynamics in large companies is to formalise a process which builds upon the interdependence of Systems Thinking for general management learning to a wide spectrum of managers and System Dynamics modelling for strategic and operational learning in small project teams. One such process develop by the author is referred to as Accelerated Business Learning (ABL) and is described in Figure 2.

The purpose of this process is to embed qualitative and quantitative system dynamics into the learning culture of the organisation.

ABL involves capturing the output and insights from system dynamics models at any level and sector of an organisation through the creation of reflection workshops. Here team leaders and members from different modelling projects can share model process and content experiences.

Further, these experiences can be captured and used as the basis for qualitative system dynamics inputs into management development programmes. In particular, the insights can be developed as system archetypes and the models into learning environments. The fact that these archetypes and LEs are constructed from real in-company situations rather than those imported from external situations provides a much more powerful impact on senior managers.

The introduction and communication of in-company modelling projects and their insights within general company training provides, in turn, a platform for managers to sponsor more detailed training in system dynamics modelling for their staff, and hence new modelling initiatives.

The outcome is a reinforcing process of learning in system dynamics.

Conclusions

This paper has sought to shed light on to how to best combine and balance the use of qualitative and quantitative system dynamics to bring the methods to a wider management audience, whilst focussing on enhancing the rigour of management thinking. It is concluded that both approaches have important contributions to make to management thinking and that there is a need for methods of applying them which judiciously blend and intertwine their best characteristics. A ‘within project process’ and a ‘within organisation process’ to achieve this have been introduced.

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Figure 1, Blending Qualitative & Quantitative System Dynamics within projects

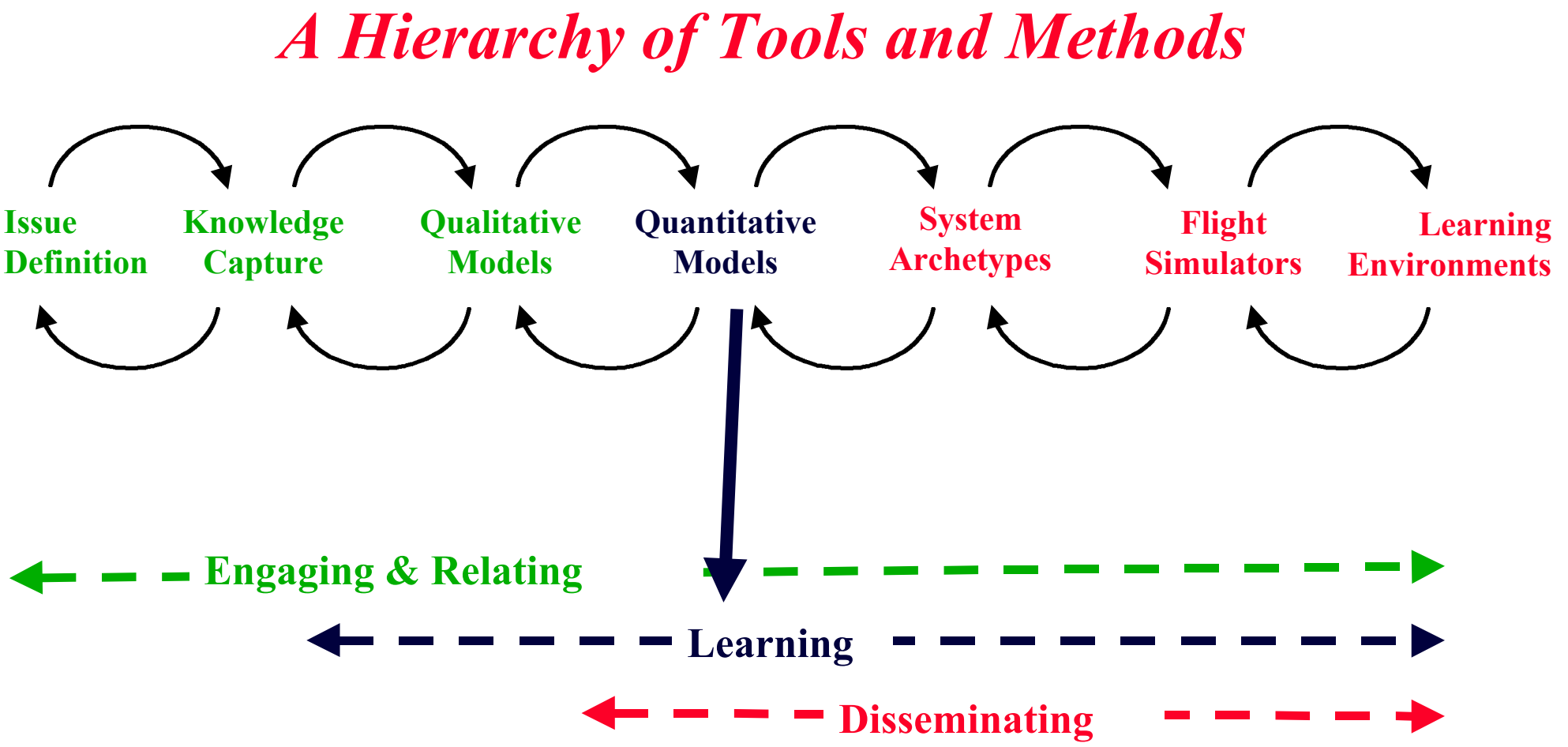

Figure 2, Blending Qualitative & Quantitative System Dynamics within projects