QUALITATIVE AND QUANTITATIVE MODELLING IN SYSTEM DYNAMICS

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This article is a revised version of a paper that appeared in System Dynamics Review, January 2001, and of the author's Keynote Address to the conference of the System Dynamics Society, Wellington, New Zealand, July, 1999.

Keywords: methodology, qualitative models, quantitative models, influence diagrams, causal loop diagrams, research in system dynamics

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Summary

The tradition, one might call it the orthodoxy, in system dynamics is that a problem can only be analyzed, and policy guidance given, through the aegis of a fully quantified model. Since the mid-1980s, however, a number of purely qualitative models have been described, and criticized, in the literature. This article briefly reviews that debate and then discusses some of the problems and risks sometimes involved in quantification. Those problems are exemplified by an analysis of a particular model, which turned out to bear little relation to the real problem it purported to analyze. Some qualitative models are then reviewed to show that they can, indeed, lead to policy insights, and five roles for qualitative models are identified. Finally, a research agenda is proposed to determine the wise balance between qualitative and quantitative models.

1. Introduction

The discipline of system dynamics has long been based on the building of fully specified quantitative models of strategic problems in all manner of domains. (See *System Dynamics: Systemic Feedback Modeling for Policy Analysis*.) Such models were, and are, seen as the essential means by which the dynamics of a problem could be simulated and from which insights might be generated into policies to improve system behavior. Jay W. Forrester, in the originating text in the field, defined this theme, which was followed without hesitation in subsequent textbooks

A cardinal point in this *genre* was that the dynamics of a system cannot be inferred simply by reasoning from an influence or causal loop diagram, and that quantified simulation is the *sine qua non* of policy analysis. It is, however, worth recalling that Edward Roberts, in one of the earlier system dynamics texts, included numerous exercises in which the reader was asked to reason about the dynamic behavior of fairly complex systems.

By contrast to the original emphasis on quantification, the early 1980s witnessed the development of purely qualitative modeling in which only an influence diagram was drawn and there was no simulation. Several sources emerged practically simultaneously but Wolstenholme and Coyle took the view that there could be value simply in rigorous approaches to system description. Description of the system might be a precursor to simulation, in which case it would be valuable for the description to have been rigorous and disciplined. However, the case example, that of the nomads of the Sahel, seemed to them to involve so much uncertainty and doubt about the values of the parameters that simulation might be of questionable value. This theme of qualitative work has been developed in further refereed papers. It has been expounded in textbooks that also deal with quantification.

In none of this work was it stated or implied that dynamic behavior can reliably be inferred from a complex diagram; it has simply been argued that describing a system is, in itself, a useful thing to do which might lead to better understanding of the problem in question. It has, on the other hand, been implied that, *in some cases*, quantification might be fraught with so many uncertainties that the model's outputs could be so misleading that the policy inferences drawn from them might be illusory. The issue is that there are circumstances in which the uncertainties of simulation are so large that the results are likely to be seriously misleading to the analyst and the client. In consultancy the client's existence is clear, but there is also a "client" for purely academic work: the rest of the academic community.

This stream of work has attracted some adverse comment. George P. Richardson, in an important paper on problems in the future of system dynamics, reviews the qualitative work and argues, citing other work, that dynamic behavior cannot be inferred from qualitative models, though the qualitative authors never said that it could. He poses the question of "what are the wise uses of qualitative modeling?" Later in the paper he rephrases it as 'when to map and when to model?" Richardson revisits the same theme later and calls for rigorous research into the limitations of qualitative models. His stance is thus that a quantified simulation model is always superior to a qualitative model. This article supports Richardson's identification of the need for research, and will propose an agenda, but places the emphasis on the *relative* limitations of quantitative *versus* qualitative models.

In short, the theme of this article is that there is a serious need for very high-quality research into the problem of the respective roles of quantified and diagrammatic modeling. Are we, as Conrad Nuthmann remarks, in danger of producing "plausible nonsense from our [quantified] models." Where does the wise balance lie?

The authors most active in the qualitative work have had decades of experience of quantified modeling and continue to practice the art. One should not speak for colleagues but the present author has no doubt that, in the right circumstances, quantified models are often valuable tools of policy analysis. It is, however, also his view that qualitative modeling can be useful in its own right and that quantification may be unwise if it is pushed beyond reasonable limits. In short, there is a proper balance to be struck between qualitative and quantitative modeling and it is the purpose of this article to develop that theme.

2. Problems of Quantification

When modeling purely "hard" variables such as production, cash flow, and so forth, there are few difficulties in quantification. System dynamics however, and rightly, is strategic in orientation and it is often seen as necessary to introduce "soft" variables such as consumer satisfaction as an influence on, say, new order inflow rate. There are several ways in which that can be done, typically:

new_order_inflow_rate=basic_inflow*satisfaction_multiplier

in which the satisfaction_multiplier is a variable, ranging from, perhaps, 0 to an upper limit, which may exceed 1, and having a non-linear relationship with consumer satisfaction. This involves two uncertainties: one is whether consumer satisfaction is indeed a determinant of orders, the second is the shape of the non-linearity. Since the latter is a real function, it has infinitely many possible values so, strictly, the uncertainties are non-denumerably infinite. That will be ignored for the purposes of this article.

In system dynamics practice the uncertainties are usually justified by the argument that one is concerned with general patterns of behavior rather than with precise numbers. That might be reasonable in many cases. It may not be so in consultancy work, where the client may want precise answers, or believe that they are being provided when, in fact, they are not.

The problem becomes more severe when several multipliers are used. For example:

new_order_inflow_rate=basic_inflow*satisfaction_multiplier*quality_multiplier*price_multiplier*etc.

The number of uncertainties in the combination of relationships is now very large and there is an *extremely* strong additional assumption that the multipliers are, indeed, multiplicative. The effects can be dramatic. If, for example, three multipliers each have the value 0.5 their net effect is a multiplier of 0.125. If, however, the real causal process is that the worst factor dominates the others, as opposed to the factors multiplying together, the effect should be 0.5, or 4 times as much as 0.125. One has seen some cases involving as many as 10 multipliers, which one can only describe as being absurd, 0.5^{10}

being equal to 0.000977 which is 500 times too small if the process should have been a minimization. With more than one multiplier, there is, as in this example, a serious risk of double counting (there are means of avoiding that).

The difficulties are compounded further by the consequence of the money generated from those orders affecting the spending on, say, quality, which in turn affects the quality multiplier. If the uncertainties combine and compound in such ways, it may be hard to believe that the dynamics of the model, *and the policy inferences made from it*, are more "correct" than can be achieved from a qualitative model.

Having considered some principles, one may now turn to a case example. It is deliberately an old one, so that no one can feel that they are being personally criticized. (The modeler in question, a truly delightful person, died tragically young. One apologizes to his shade).

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Biographical Sketch

Professor Geoff Coyle has been active in system dynamics for 32 years, his contributions to the field being recognized in 1998 by the first Lifetime Achievement Award of the System Dynamics Society. He established the first system dynamics group in the UK in 1972 at the University of Bradford, where he directed the development of the first machine-independent system dynamics simulation language. Professor Coyle has written some 40 academic papers on system dynamics and two textbooks, *Management System Dynamics* (1977) and *System Dynamics Modeling* (1996). He is also the author of *Equations for Systems*, which deals with advanced modeling, and *System Dynamics Problems*, for student use. His academic career includes a Fellowship at Harvard and MIT, and posts at the London Business School, Bradford Management Centre, the Royal Military College of Science/Cranfield University, the University of the South Bank, and the University of Bath. He was commissioned in the Royal Engineers (TA).