Increasing User Confidence in System Dynamics Models Through Use of an Established Set of Logic Rules to Enhance Forrester and Senge's Validation Tests.

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Abstract

System dynamics modelling is an approach to policy analysis and design that is founded upon the development of causal loop influence diagrams and dynamic simulation models. Forrester and Senge (1980) discuss the need for building confidence in system dynamics models via use of a set of validation tests. Forrester and Senge claim that the validation process should extend to include persons not directly involved with constructing the model. They also state that unless the modeller's confidence in a model can be transferred, the potential of a model to enhance understanding and lead to more effective policies will not be realised. This objective can be achieved by using a set of logic rules, normally employed to validate the "tree" structures used within the Theory of Constraints "Thinking Processes". The logic rules, known as the Categories of Legitimate Reservation (CLR), can be used to validate system dynamics models, providing an enhancement to the use of the validation tests promoted by Forrester and Senge. The use of the CLR within the validation process is a means of achieving the goal of transferring confidence in the model, from model builders to the model users. Such involvement aid in gaining user "buy-in" to the system dynamics model as a source of information for policy and strategy formulation.

Introduction

System dynamics simulation models are a sophisticated tool designed to provide information to decision-makers charged with formulating policy and strategy, and to increase their knowledge of the behaviours of complex systems. The accuracy of the simulation model will have an influence on the quality of the information supplied to model users. Increasing user confidence in the information supplied by SD models may lead to greater levels of acceptance of SD as a decision support system for policy and strategy formulation and analysis. This paper makes two major assertions: Firstly, that user confidence in the information provided by SD simulation models will be enhanced by the use of a new approach to model validation: Secondly, heightened user confidence will increase the extent to which an SD model is actually used as a source of information for policy and strategy formulation. A new approach to model validation is proposed as a supplement to, not replacement for, the established tests for SD model validation promoted by Senge and Forrester (1980).

What is SD Modelling?

Jay Forrester is widely recognised as the father of the Systems Dynamics movement. Who better to provide us with an understanding of SD, and SD modelling. "System dynamics combines theory, methods, and philosophy for analysing the behaviour of systems" (Forrester, 1998: 3). We are surrounded by a wide range of complex systems. These systems can be social, political, economic, biological, meteorological. SD is a philosophically based discipline concerned with understanding the dynamic behaviour of these systems. SD simulation modelling is a sub-set of SD which provides tools for modelling complex systems. "System dynamics uses concepts from the field of feedback control to organise information into a computer simulation model. A computers acts out the roles of people (or other variables) in the real system. The resulting simulation reveals behavioural implications of the system represented by the model" (Forrester, 1998: 3).

The Use of SD Models

The widespread availability of powerful computer technology has meant that practitioners from a wide range of disciplines have access to SD modelling tools. SD models have been built to gain an understanding of such diverse systems as fish numbers in deep-sea fisheries, to opposum numbers and their affect on productivity of a pine plantation, to "flight simulators" which represent businesses enterprises, to the economic environments those businesses operate within. These diverse systems have one common element: They are all "complex" systems, systems that have a multitude of variables influencing their behaviour. Many elements of a complex system may be understood well by people with an expert knowledge of the system. However, the bounded rationality, or cognitive limitations of human decision-makers, constrains the extent to which even experts can understand behaviours within a complex system. Consequently, SD simulation can play a useful role, by broadening understanding of system behaviour and lessening the bounded rationality of those involved. SD simulation can extend expert user understanding of the system by identifying such system phenomena as counter intuitive feed back loops, non-linear behaviour, and general trends.

Not surprisingly, it is important that expert users have faith in the model that is supplying them with information. If the users do not have confidence in the information provided, it is unlikely that such information will be incorporated in their policy and strategy formulation decisions.

Confidence in SD Models

A member of the strategic policy unit within a major Australasian telecommunications company recently provided an insight to managerial perception of their own SD market model. The strategist claimed that most managers in the strategy unit viewed the SD model as little more than a curiosity. He stated that managers seldom took the information outflow from the model seriously in their strategy formulation activities. He felt that many of the strategists simply did not understand the model, and furthermore he speculated that as a result of this lack of understanding, the managers did not trust the information produced by the model.

We can only speculate about the extent to which established SD models are actually used by decision-makers. It seems reasonable to conclude that the telecommunications scenario just described is not a totally isolated example. If this assertion is correct, there may be potential benefits to be derived from improving user confidence in SD models. The following discussion relates a means to achieve enhanced user confidence in SD simulation models.

SD simulation models are a complex and sophisticated tool designed to capture the behaviour of dynamic systems over time. In order to provide an accurate representation of the systems they model, SD simulations must be validated in order to remove any errors in the representation of relationships and behaviours. This validation process is typically conducted by use of Senge and Forrester's established tests, which are discussed briefly below. It is significant that model builders are the prime participants in the validation process. The modellers may be the party with expert knowledge of SD modelling, but may not necessarily be the party with expert knowledge of the system being modelled. Thus, it can be argued that some degree of system expert and user participation in the validation process is necessary.

Senge and Forrester (1980) themselves claim that the validation process should extend to include persons not directly involved with constructing the model. The traditional validation process may be successful in producing a degree of confidence in the model, for those deeply involved in the validation process. However, if the proposed users of the model do not have a significant involvement in validation, then it is more likely that they will not acquire the same level of confidence, as acquired by the model builders. This point is emphasised by Senge and Forrester (1980) who claim that unless the modeller's confidence in a model can be transferred, the potential of a model to enhance understanding and lead to more effective policies will not be realised.

It is also significant that in many instances the decision-makers who use the information from a SD model will be responsible for the consequences of their decision. The converse may hold for the model builder(s), who are less likely to be responsible for consequences resulting from decision based on information flowing from an SD model. Thus, model builders and decision-makers are likely to have entirely different risk perceptions in relation to the model, further emphasising the need to gain user trust and confidence in the model.

Forrester and Senge's Validation Process

A complex approach to validation SD models is promoted by Forrester and Senge in their 1980 paper *Tests for Building Confidence in System Dynamics Models.* The authors define what they mean by testing SD models: "By testing, we mean comparison of a model to empirical reality for the purpose of corroborating or refuting the model" (1980: 210). Forrester and Senge propose a model validation process via the use of a range of tests to "establish confidence in the soundness and usefulness of a model" (1980, 210).

The tests Forrester and Senge propose can be categorised under three different headings. Firstly, a group of five tests assess the structure of the SD model. Secondly, a group of eight tests are employed to assess the behaviour of the model. Lastly, four tests designed to assess the policy implications of the model are presented. When combined, these tests form a rigorous validation process.

The approach to using these tests in a validation process is described by Forrester and Senge: "Validation beings as the model builder accumulates confidence that a model behaves plausibly and generates problem symptom or modes of behaviour seen in the real system. Validation then extends to include persons not directly involved in constructing the model" (1980: 210). It has been previously been stated in this paper that model users have an important role in model validation. Users are an important group of "persons not directly involved in constructing the model". The following section will introduce an approach to incorporating users into the validation process.

Models as Cognitive Representations

System Dynamic models are a cognitive representation[1] of the model builder's perception of the interrelationship of variables in a system. There are several types of cognitive representation familiar to those in the systems community. The cognitive maps of Strategic Options Development and Analysis (SODA), causal loop influence diagrams as used in the development of SD models, and the tree diagrams of the Theory of Constraints' Thinking Processes to name just a few. Such cognitive representations have similarities and differences. The similarities include an attempt to link variables (statements) in a manner to relate causality. The linkages in each of these forms of cognitive representation reflect the modeller's belief of the nature, direction, and magnitude of influence or causality evident in the actual system.

The differences between the various forms of cognitive representation are less important than the similarities, for purposes of the current argument. However, it can be said that cognitive maps and Thinking Processes tree diagrams attempt to model a problem situation that exists within a complex system. Whereas, causal loop influence diagrams are generally used to model whole systems, rather than just problematic situations that exist within them.

The relevance of this discussion comes from recognising that a qualitative validation process has been developed for one of these forms of cognitive representation. The Theory of Constraints (TOC) is a complex management system developed by Israeli physicist, turned management guru, Dr Eliyahu M. Goldratt. The TOC Thinking Processes are founded upon a positivistic epistemology, indicating a belief in the ability to identify clear causal relationships in a system. The positivistic rigour of this methodology comes from a set of logic rules used to validate the tree diagrams which form the Theory of Constraint's system improvement / problem structuring methodology. This set of logic rules is known as the Categories of Legitimate Reservation (CLR).

The CLR are used to verify and validate the causal relationships identified by tree builders using the Thinking Processes methodology. The rigorous analysis of the

[1] Pers Comm: a label proposed by Professor John Brocklesby, VUW.

connections between statements in tree diagrams greatly enhances the accuracy and validity of the methodology in practice (Dettmer, 1997). When using the CLR the tree builders must scrutinise linkages between statements one by one, systematically working their way throughout the whole tree diagram.

A validation process that has proven successful for use with one form of cognitive representation has relevance to other, similar, forms of cognitive representation. Therefore, this paper proposes the use of the CLR as a means to validate firstly the causal loop influence diagrams that provide a foundation for the development of the SD simulation model. Secondly, the CLR can be applied to the SD simulation model, and used as an aid to implementing Forrester and Senge's validation tests, as detailed in their 1980 paper.

The Categories of Legitimate Reservation (CLR)

CLR consist of a group of eight rules of logic that must be adhered to by the model builder(s) and model user(s). Forrester and Senge clearly state that unless user confidence in a SD model can be developed, more effective policies will not be realised (1980: 210). Ensuring user participation in the validation process is a means of developing user confidence in the SD model. Participation is a means of increasing user understanding of the model. The CLR are a validation technique useful to facilitate user participation. The CLR don't require an in-depth knowledge of SD as a methodology, but do require a degree of knowledge about the system being modelled. In many instances this is knowledge that model users will possess.

Inter-personal communication is at the heart of a user participation validation process. Model builders and users must communicate about the model, about the inherent relationships between its components, and about the resulting model behaviour. The CLR can be used to facilitate and structure that communication process. The CLR allow a user to critically analyse a model in a way that allows them to contribute their knowledge of the system being modelled. The approach also ensures that the relationship between model builder and model user remains tenable. Any criticism the user has about the model is expressed as a specific form of "reservation". Legitimate reservations represent valid arguments about a specific element of the model. The logic rules of the CLR are a set of valid arguments, or legitimate reservations. Each of the rules of the CLR is described below.

The Components of the Categories of Legitimate Reservation

- **Clarity:** This component is an exception to the statement that CLR are logic based. Clarity is a practical rule used to ensure "any misunderstandings resulting from inaccurate or incomplete communication of an idea are eliminated before the logic is examined". The meaning of a statement or linkage must be understood before it can be assessed for logical validity. The parties to the communication must verify they understand the concepts being related. Therefore, the meaning, significance, and context of the concepts communicated must be understood by all participants. Additional explanation may be needed to ensure clarity is achieved.

- **Entity Existence:** Dettmer states an entity is a complete idea. In terms of a SD model an entity can be considered to be a variable in the model. Entity existence is a reservation raised, by a listener, about an idea or variable under consideration. These reservations result from one of three conditions: An incomplete idea, structurally unsound, or a statement / variable / relationship that does not seem valid. Structural unsoundness occurs when multiple ideas are captured in a single relationship.

- **Causality Existence:** This component of the CLR arises when a participant expresses concern that a stated cause does not lead to a stated effect. So the validity of the connection between variables is challenged. Verbalising the relationship between variables is useful in assessing validity, but participants must only verbalise the relationship exactly as related in the model, and not read more into the relationship between variables. Valid cause and effect relationships have an element of tangibility about them. A cause must be measurable and observable.

- **Cause Insufficiency:** This is said to be the most common deficiency found in logical cognitive relationships. Few effects are likely to have a single cause. Therefore most effects will be caused by multiple dependent factors. Dettmer claims "cause insufficiency" is raised as a reservation when a participant doesn't believe a single cause is enough by itself to produce the stated effect. Some other factor is needed to explain the existence of the effect. The "oxygen" concept is often used when relating cause insufficiency. A missing element of causality will not allow the effect to occur. For example oxygen is needed along with heat and fuel for fire to result. Remove oxygen and fire won't result. Clearly when assessing the validity of a cause insufficiency the participants must ensure that the components claimed to be missing must be essential for the effect to result.

- **Additional Cause:** this reservation arises when a participant points out that a cause is not the only cause that can produce an observed or predicted change in a variable. In this situation the participant is not disagreeing with the model builder that the original cause is a valid cause of the stated effect. However there is an additional cause which must be acknowledged as having possible responsibility for the effect. The issue of the magnitude of the influence of the possible causes must also be addressed.

- **Cause-Effect Reversal:** Dettmer (1997) clarifies this reservation by asking the question "Is the cause the source of the effect or is the effect really the cause?" Scrutinisers of the model must ask themselves if the direction of the causal relationship can be reversed. The question why an effect exists versus how we know it exists must be considered.

- **Predicted Effect Existence:** is a tool used to support or refute the existence of a relationship. The idea of supporting evidence is central to predicted effect existence. It means that if the proposed cause and effect relationship is valid, another observable effect would also be expected. One can check whether the stated cause exists by observing whether the effect exists.

- **Tautology:** or circular logic as it is known, is likely to arise when causality existence is questioned and the cause is intangible. Examples of tautology are instances where the effect does not arise from the claimed cause. Just because a result occurs doesn't mean it occurred because of a particular reason.

Use of the CLR to Validate Models

The CLR are employed in a very specific manner, by those scrutinising an SD model. Firstly, the user(s) participating in the validation process must be made aware of, and develop a familiarity of the rules of the CLR. The model user has access to definitions of the CLR rules when communicating with the model builder. Any model scrutiniser can use the CLR in a very specific manner, as follows:

Scrutinisers examine each connection between variables in the model. When noticing an aspect of the model, with which they have concerns, the user refers to the CLR definitions and identifies the nature of their reservations. The user then communicates their reservations about the validity of the specific aspect of the model in a very particular manner: For instance, "I have an Additional Cause reservation about *this observed effect* in *this particular variable* in the model. This reservation arises because I believe another variable has an influence on the behaviour of this other variable". The scrutiniser then goes on to explain the nature of the additional cause reservation. Once the particular reservation has been verbalised and consensus reached about any incremental adjustment to the model, the scrutiniser(s) proceed to examine other linkages in the model. Such an approach to using the CLR is a highly iterative process.

The use of the CLR allows scrutinisers to constructively criticise a relationship in the model without offending the model builder. It is unacceptable for model users to state that the model is "just plain wrong". Participants in the validation process must adhere to the CLR as a set of rules of communication.

Applying the CLR enables users to structure their own opinions about the system, and to contribute this knowledge in a manner that specifically indicates the nature of their reservations. Adhering to such rules captures user knowledge of the real system and their perspective of the area of divergence between the model and the real system. Thus, the CLR provide a means of assessing causal validity, in a positive manner, to expedite the development of accurate and useful modelling activities. Such an approach is likely to reduce the incidence of conflict among the participants in the modelling exercise.

Advantages of Using the CLR to Validate SD Models

There are several advantages that can be derived from use of the CLR. These advantages are summarised as follows:

1. The CLR approach is a means of increasing model user or system expert participation in the validation process. Achieving increased user involvement in the validation process will help realise the enhanced understanding and lead to more effective policies, as desired by Forrester and Senge (1980). More effective policies may emerge from a greater level of user reliance on valid SD models.

2. The use of the CLR approach to increase participation in the validation process would also help ensure that sufficient information about the system is available. The provision of a higher degree of system information may mean that the model builders are less likely to be forced to make assumptions about the real system. The need to make fewer assumptions is likely to lead to improved model quality. The CLR approach can help overcome a shortage of expertise, by helping to ensure that the knowledge of users and experts is exploited to good effect, by encouraging them to critique a model in a very structured manner.

3. Greater user / expert participation in the validation processes is a means of identifying and overcoming the impact of personal bias and blind spots in the model. The CLR are a means of increasing participation in validation, thereby promoting synergy in the creative, model building and validation, process.

4. Dettmer (1997) claims that using the CLR with a group of people scrutinising a cognitive representation engenders a sense of cohesiveness, teamwork, unified commitment toward the task.

5. Dettmer also claims that the CLR provide a basis for communicating disagreement that averts conflict. Avoiding conflict, while providing avenues for critical evaluation of the model, is a means of smoothing the relationship between model builders and model users.

Concluding Discussion

SD simulation models are a very valuable strategy and policy analysis tool, that can now be readily accessed because of the proliferation of powerful computer technology. The use of such a tool is a means of overcoming the cognitive limitations faced by even expert policy and strategy decision-makers. However, SD models will be viewed as little more than a curiosity unless decision-makers and managers have confidence in their accuracy and predictive powers. The established validation tests promoted by Forrester and Senge in their 1980 paper provide a rigorous process for validating SD models. An application of such a validation process is likely to create high levels of model builder confidence. It is important that users of the model have sufficient faith in the information supplied from the model to incorporate this information in their policy formulation activities. Forrester and Senge emphasis this point. They claim it is necessary to transfer model builder confidence to model users. This paper argues that one approach to achieving user confidence is to involve users, and system experts, more intimately in the model validation process.

This involvement can occur in two stages. Initial involvement can take place at the time that causal loop influence diagrams of the system are developed. The second stage of involvement can take place when validating the SD simulation model. Both causal loop influence diagrams and SD simulations are cognitive representations of a real system. A simple validation process commonly used with another form of cognitive representation can be used to validate SD models. The Theory of Constraints' Thinking Processes tree diagrams are validated via use of a set of logic rules known as the Categories of Legitimate Reservation (CLR). The CLR provide a specific structure to the communication between model builders and users about the model. Scrutinisers of a model can use the CLR to verbalise their concerns about a certain aspect of the model, in a very specific manner. The CLR reduce conflict between parties to the validation process, and provide a basis for structuring and communicating the knowledge possessed by model users and system experts. The CLR provide a means of increasing the participation of non-model-builders in the validation of the model. Such increased participation may create the effect of transferring confidence in the model from the model builder to the model user. This transference of confidence is likely to enhance user "buy-in" and promote an increase in the use of SD model information in policy and strategy formulation. An increase in the reliance on SD models may achieve realisation of generating the "more effective policies" sort by Forrester and Senge in their 1980 paper.

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