Representing Reasoning/Logic in System Dynamics Models

G. W. Komanapalli

Department of Accounting & Finance, Faculty of Business, Computing and Information Management,
103 Borough Road
London South Bank University, London –SE1 0AA, England.
Email: komanaga@lsbu.ac.uk Phone: ++44(0)-20-7815 8239

Abstract

This paper intends to fuel a thought about representing and extracting reasoning in System Dynamics models. A perspective on the flow of information as policies in the system and also flow of information as logic or reasoning in the model is discussed. It also discusses how influences in the model are implemented as rate equations and challenges the impossibility in deriving these rate equations from the qualitative model. This paper raises concerns that the qualitative SD model normally describes the principle behaviour of the system in dual mode whether a growth or decline and omits the structure of reasoning in the model. Finally this paper argues that the logical structure of policies, if effectively represented at the formulation stage would open a channel for a revived and renewed process of developing SD models

Key Words: Flow of Information, Logic, Modelling, System Dynamics, Reasoning,

1.0 Introduction

Majority of the research and literature on System Dynamics(SD) is focused on analysing a model. The focus is on accurate abstraction of the system. A comparatively small proportion of literature is available on the implementation of the model (Keating, 1998). SD has been embracing relevant disciplines which supported and enhanced its adaptability. For example Systems Thinking (ST) is adopted to study and to formulate qualitative SD model. ST helps to gain understanding of the system behaviour at analysis and formulation stage. At this stage in the model building process, the modeller focuses on conceptual understanding of the behavioural dynamics of the system. ST helps to identify feedback loops and leverage points or policies in the system (Senge, 1990). Qualitative model represents fundamental direction of changes and behaviour of the system. Qualitative model helps to analyse effects of influences and lists out the influencing factors. However in SD qualitative model, whether a stock-flow model or influence diagrams does not give structure to the patterns of influences. In other words behavioural dynamics in levels (stocks) are effectively represented in qualitative SD model but the pattern of influence on the levels (or stocks) is not represented hence it is not possible to analyse pattern of behaviour at formulation stage. The following sections discuss about influences as policies in the system. To lay foundation for the discussion, first a perspective of information flow as policies of the system is presented. The discussion further looks at how policies are can give structure to the logic in the model. Finally concludes that is logical pattern is present it can guide the modeller as a trasaltion code from qualitative model to quantitative model.

2.0 Flow of information: Policy of the system and reasoning of the model

This section lays a foundation for the rest of the discussion of the paper. In doing so, it visits fundamental aspects of SD models and the expectations of SD.

2.1 Flow of information as policy of the system

Application of SD is more appropriate in policy making and it is not intended to model decision making scenarios (Forrester, 1973). SD model implements policy and tests the existing policy of the system and enables the users of the model to create various conditions and observe the effectiveness of the policy in those expected conditions. The fundamental difference between policy making and decision making process is that implementing a new policy requires various decisions either or both managerial and strategic decisions be made. Fig 1 shows SD “information –action-consequences” as described by Coyle (1996). This paradigm helps to understand that information flows in the system and therefore produces actions and consequences.

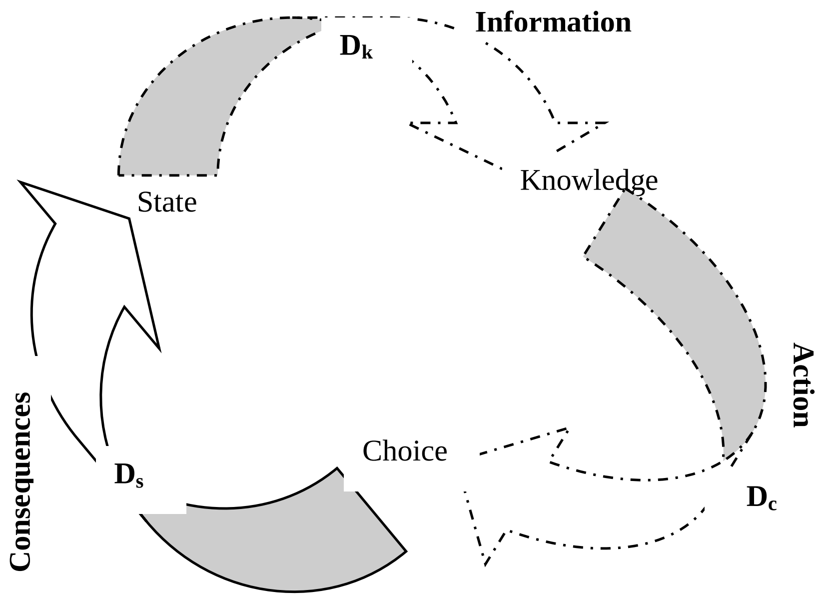


Fig 1: The information/action/consequences paradigm of system dynamics(Coyle,1996)

The dotted arrows for information and action represent that these parts of the system are capable of being changed. To put this paradigm in the current context, policies of the system is the source of information and applying these policies is parallel to actions and thus choices and consequences are changes that are caused in the system as time progresses.

When a system is modelled, its actual behaviour is implemented and policies are tested. When the behaviour of system is modelled current policy of the system that controls the behaviour is also implemented. This allows testing a policy of the system against various conditions. Testing a policy enables to make a decision or take an action. This policy is sometimes a principle or fundamental fact of a system.

2.2 Flow of information as the reasoning of the model

Processing of the flow of information is the core part of the model implementation. At the formulation stage a modeller tries to capture the network of influences and relationships in the system, in other words, captures the flow of information in the system. To understand the behaviour of a system, modeller adopts the systems approach. Systems approach assumes that world is collection of parts of system and individual parts exhibit certain general principles of wholeness (Checkland, 1981). This approach helps to carryout a qualitative analysis of system. This approach changes when quantitative model is implemented. Here the modeller adopts scientific approach. The scientific approach considers world as characterised by natural phenomena and investigates laws- of-nature (Checkland, 1981). Implementation of model requires a modeller to find suitable integration techniques and mathematical tools. A simulation model is thus is a set of mathematical equations representing the behaviour of the system. Mathematical constructs can be used for dual purposes. They can be used to model real world situations and events and they can also be used as objects of reasoning (Staub and Stern, 1997). Thus I would like to infer that SD simulation model represents structures of reasoning that support the network of relationships in the system.

Logic as defined in Collins English Dictionary is a pattern of reasoning representing relationships and interdependencies of a series of events, facts etc. As mentioned above at implementation stage mathematical deduction of logic represents a pattern of reasoning that encapsulates the flow of information in the system. Therefore a mathematical construct as an object of reasoning represents a mathematical deduction of logical structure of system. In the next section we will see how the logic is formulated and implemented in system dynamics modelling.

3.0 Extracting logic In the system

Keating (1998) presents a brief list of guidelines that could be used to formulate and implement the model. Identifying and implementing feedback behaviour is central to SD modelling. Feedback structures capture the dynamic behaviour of a system (Coyle, 1996). As mentioned earlier in the introduction ST helps to develop conceptual model of the system. This conceptual model represents a network of relationships among the internal and external forces of the system.

3.1 Formulating logic in the system

Essential element of formulating logic is to understand the network of relationships in the system and develop a qualitative SD model. Original emphasis of SD modelling was to simulate a completely quantifiable model (Forrester 1961). However, qualitative simulation of SD modelling is growing in popularity and has been accepted as it enables to simulate both quantifiable and non-quantifiable variables of the system. Qualitative SD model helps to communicate the behaviour and observations of the model. It also can be used as a tool to educate the users/audience of a system (Wolstenholme and Coyle,1983; Coyle 1983; 1984a; 1984b; 1996,2000).

Qualitative SD has many types of representations: Causal Loop diagrams(CLD), Stock-flow diagrams, Influence Diagrams, or combinations of these. Each of these representations captures flow of information using different techniques. Stock-flow diagrams effectively capture accumulations of physical quantities(Pidd, 1992). CLD capture feedback loops. Influence diagrams are similar to CLD but are more rigorous in representing information flows and physical flows.

3.2 Implementing logic through equations

Modeller commences implementation of model having identified key variables, leverage points and drawn the conceptual diagram. As the modeller moves further from formulation to implementation stage, the modeller begins to deduce logic that is found in the relationships among the variables. An SD modeller would agree that there is a shift in the attitude of mind at implementation stage and that it is nontrivial. Having analysed the system by parsing into individual variables and influences, modeller tries again to aggregate the logic so that the behaviour of the model can be simulated. This process may be considered as re-construction of the model.

Equations of the model represent various behavioural aspects of the system. Forrester (1961) identifies three fundamental types of equations: level, rate and auxiliary. Physical state of variables is mathematically represented through level equations. Influences that act on variables are represented as rate equations (Pidd, 1996). Thus an equation in a model represents the application of policy on the level (stock) variable or the policy it self. The changes in a level (stock) variable are defined by the sum of previous value of the variable and the net flows through the level variable (Pidd, 1992). These inflows and outflows are controlled in a prescribed way through rate equations, or a policy of the system control the net flows. Some changes in the system are discrete and occur repeatedly falling into a pattern of continuous behaviour. These can be implemented through rate equations. Some changes are progressively continuous and these can be implemented through level equations.

Execution of a single feedback loop depends on repeated decision making process within the loop satisfying the conditions imposed by the policy that is driving the loop as the model moves along time. In other words, a loop makes a decision having reasoned the logic in the policy. A simple loop in model represents dynamic changes in a level variable(s). The current state of level (stock) variable is defined by a policy (Fig 2). It is this policy that is formulated in rate/ auxiliary equations.

Rate equations represent continuous stream of information and a functional structure of policy in the model/system. This is shown in Fig 2. It shows policy as the input to the level variable and resulted state of level variables as the output of policy. Hence a level variable is the output of policy that is applied on it.

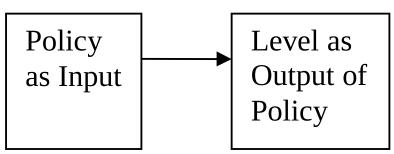


Fig 2: Function of Policy

4.0 Concerns

In this section I would like to raise few concerns on representing the logic at formulation stage. In the above sections we have seen how information flows in the system. Flow of information that causes dynamics behaviour is captured through feedback loops in causal loop diagrams or accumulations as in stock-flow diagrams. In either practice focus is on changes in physical quantities (level or stocks). Richardson (1973) identifies inadequacy in causal loop diagrams that, CLD does not distinguish between information flow links and non-information flow links. Yet Coyle

(1996) and Richardson (1973) agree that the simplicity of CLD is its own strength. The logical structure of stock (level) variables is well defined in stock flow diagram. This enables stock equations to be derived from the stock-flow diagram (Pidd, 1992). Even though a model shows continuous change in the system, it also should be able to represent the real behaviour of the variables that cause these changes which fall into continuous pattern of behaviour. For this reason, a rate equation consists of discrete functions to model discrete events in the system. This logical relationship should be effectively formulated in rate equations. The structure of this logic is not represented in the diagram. This leads to the impossibility in deriving flow (rates) equations from the diagram.

Coyle(1996) says ID can represent complexity of the system at various levels. ID show the polarities of variables which help to derive the structure of the relationships among the variables. There are still problems with ID. ID does not give information about what proportion of variable is flowing in the information link and how each factor is related to the other influencing factors. Their individual relation with level variable alone is represented in ID. When the influence of the variable is represented as positive or negative, this raises the question whether the behaviour of the model is just binary? Whether a growth or decline? However, we know that these positive or negative influences are a cumulative of influences that are feeding in and out of a level variable. It is this pattern of cumulative influence that is missing from the qualitative models. Coyle (1996) says that these details could defeat the purpose ID and its simplicity.

4.1 Discussion

Below are the examples of SFD, CLD and ID. These diagrams point out various factors that cause change in the system and the variables that change over time. There is a certain level of complexity in understanding these diagrams as they depict relationships among the variables. However, it is not possible to derive quantitative model from qualitative model. Quantitative model is independent of qualitative representation of the system. This paper is addressing this missing dependency in SD modelling process.

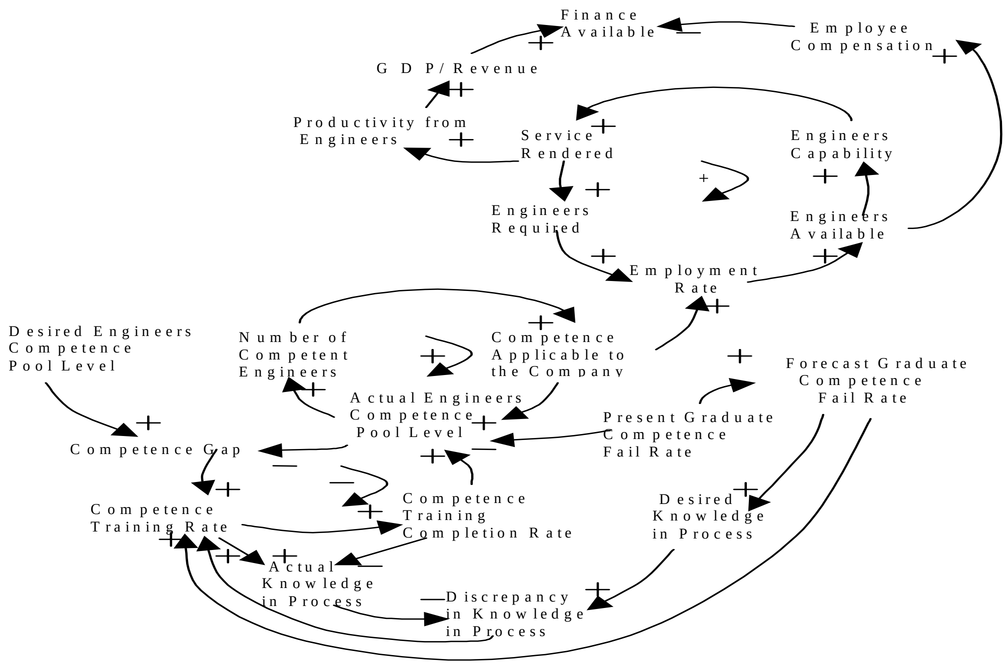


Fig 4: Example of CLD (Rodrigues, Martis ,2004)

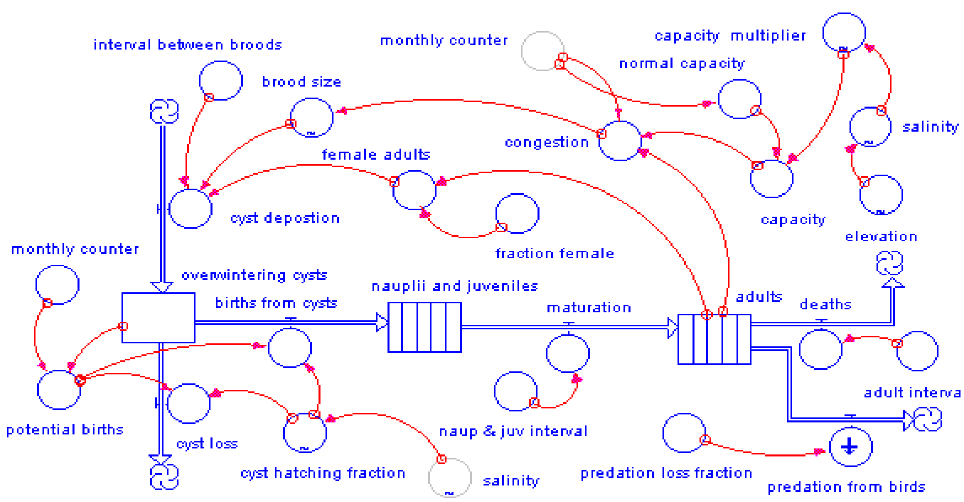
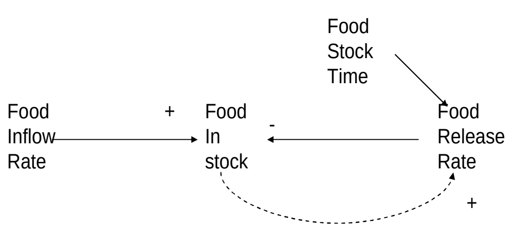


Fig 3: Example of SFD (Ford, 1999)



Equations:

r finra.kl = step (100,10) + step (stepht,steptm)
c stepht = 0
c steptm = 120
l food.k = food.j + dt * (finra.jk - foutr.jk)
n food = 0
r foutr.kl = food/fst

Finra = Food Inflow Rate

Food = Food in Stock

Foutr = Food release rate

FST = Food stock time

Fig 5 Example of ID (Coyle, 1996)

Fig 5 is an example of ID and gives both qualitative and quantitative diagram of a food stock problem. ID shows food coming to the stock and going out of the stock. However, *how* food is coming in and going out is not shown in the diagram but is shown in the mathematical model. This is where ambiguity arises for the beginner of SD. In addition, to write a mathematical equation modeller depends heavily on the software tool being used as a standard procedure to derive a quantitative model from the qualitative model is not available.

5.0 Conclusions

Modelling information flow is one of the strengths of SD. Information has more than one dimension. Not only the flow of information causes ripple effect in a system, it contributes to this ripple effect in various forms. For example, qualitative models show growth or decline in the value of a variable, a dual or binary behaviour. This is effectively represented with the symbols + or – for increase and decrease respectively. However that influences on the variable come in different measures. This measure or the proportion of the influence is what that needs to be presented on the diagrams. This is a major deficiency in the qualitative SD models. Measure of influences or the pattern of influences is a vital component of a model.

So far, our SD qualitative model represents relations. It is though a valid representation as the science began to analyse the systems in terms of networks of relationships. However, SD goes further from analysing the relations to implementing the reasoning in the model by deducing the logic of the system. Finally it is beneficial to represent the logic in diagrams and bridge the gaps of knowledge in the representation of the model. More importantly it would enable extracting quantitative SD model from qualitative SD model. I believe that this gives rise to a revolutionary modelling practice in SD as Software tools provide the modeller with a fully implemented model, without the modeller writing the equations.

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