Model Conceptualization: a Critical Review

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Abstract

Model Conceptualization is the most important activity in the development of a system dynamics model. Since Randers' classic paper 23 years ago, researchers in the field have worked in the development and refinement of tools and methods to improve the process. Although progress has been made, we still lack understanding of the process itself. The purpose of the paper is to review the progress in the model conceptualization area, and concludes with initial ideas for a research program.

Key words: model conceptualization, system dynamics, systems thinking.

Model Conceptualization: a Critical Review

"Conceptualization is at once the most important and least understood of all modeling activities. Conceptualization is really jargon for the mysterious process of creating a new idea, a word designed to make the creative act sound scientific, scholarly and repeatable" (John Sterman, 1986).[1]

Abstract

Model Conceptualization is the most important activity in the development of a system dynamics model. Since Randers' classic paper 23 years ago, researchers in the field have worked in the development and refinement of tools and methods to improve the process. Although progress has been made, we still lack understanding of the process itself. The purpose of the paper is to review the progress in the model conceptualization area, and concludes with initial ideas for a research program.

Introduction

Conceptualization of a problem is the most important activity in the development of a system dynamics model. Given its importance, researchers and practitioners have been working in the development of several tools to aid analysts in this process. Randers' classical paper (1980) constitutes an important milestone in the understanding of the conceptualization process. Many of the descriptions on model conceptualization are based upon his seminal ideas of reference mode and dynamic hypothesis, many of the tools and methods developed elaborate on these basic ideas, and the main disagreements are also about the importance of each of this elements in the process.

A lot of work has been developed during this last 23 years in order to get a better understanding and to further develop the tools and skills required by this difficult process (Conceptualization of a system dynamics model). Some of these efforts intend to describe in more detail the process of problem articulation. Other line of research is related with the development of better reference

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1 A quotation from the presentation of the reprint of Mass (1986) introductory address to the Conceptualization table in the 1981 System Dynamics Conference.

modes to characterize the dynamics of a problem. Some practitioners have worked in the development of better diagramming tools to represent system structure. An important group of researches has explored ways to conceptualize dynamic problems when working with groups. Finally, some system dynamicists have explored ways in which our conceptualization process can be enriched by the use of the tools from other methods.

The present essay constitutes an attempt to review the developments, research, and practices in model conceptualization, considering Randers' classic view as the starting point of the analysis. The purpose is to describe the insights that have remained constant over the past 23 years, and significant advances in each of the areas described in the above paragraph. As a conclusion of this review, the paper finishes with some comments about the areas of disagreement and a preliminary working idea that can help to get a better understanding of the conceptualization process.

Common Themes

In his classical paper, Randers (1980) characterizes the conceptualization process as the "stage that establishes the focus of the study – the general perspective and the time horizon. The critical decisions are made on what part of reality to study and how to describe it" (p. 118). Among the main activities to develop during this step of the modeling process, Randers (1980) considers that the modeler should familiarize with the general problem area, define the main questions to be addressed, and the time horizon of the problem of interest. Additionally, he proposes as the basis for model conceptualization an understanding of the social system (structure) and the social process (behavior) involved in the problem. Although he recognizes that the final goal of system dynamics modeling is to get a better understanding of the relations between structure and behavior of the problem, he thinks that the behaviors observed over time are the guiding principle for the whole modeling process. This historical or hypothesized dynamic characterization of a problem (that he calls Reference Mode) is linked to a series of basic structural mechanisms that can be depicted as a causal-loop diagram to constitute the dynamic hypothesis of a system dynamics study.

Table 1. System Conceptualization across the classic literature

<table>
<tr><th>Randers (1980)</th><th>Richardson & Pugh (1981)</th><th>Roberts et al. (1983)</th><th>Wolstenholme (1990)</th><th>Sterman (2000)</th></tr>
<tr><td rowspan="2">Conceptualization</td><td>Problem Definition</td><td>Problem Definition</td><td rowspan="2">Diagram Construction and Analysis</td><td>Problem Articulation</td></tr>
<tr><td>System Conceptualization</td><td>System Conceptualization</td><td>Dynamic Hypothesis</td></tr>
</table>

This basic characterization of the conceptualization process as the identification of a problem and the formulation of a dynamic hypothesis has remained constant across the years (table 1). With a more pedagogical approach, Richardson & Pugh (1981) described in more detail the activities to develop during the Conceptualization process, which is actually separated in two different stages, Problem Definition and System Conceptualization. Using the same two steps in the conceptualization process, Roberts et al. (1983) followed a different approach, offering in their book a rich set of problems and small cases to help the reader to develop the basic skills to define problems dynamically (in terms of reference modes) and to build structural explanations (in form of diagrams) linked to those dynamics. Sterman (2000) renames the System Conceptualization stage, as described in the classical textbooks, maybe to stress the importance of the dynamic hypothesis in the modeling process.

“A well-defined problem is half solved” (Pidd, 1999). In order to offer helpful guidelines to help modelers during the conceptualization process, Richardson & Pugh (1981), Roberts et al. (1983), and Sterman (2000) emphasize the basic principles of modeling a problem instead of a system, and that any modeling effort should be guided by a clear purpose and a set of questions. On the other hand, they stress the importance to focus, since the early beginning of the process, not only in the audience of the modeling effort, but in the important policy options and implementation issues associated with this policy options. A basic assumption of system dynamics modeling is that problems can be characterized in a dynamic way. Given that for most people is much more easy to think in “static pictures“ of symptoms of a problem rather than a dynamic one, Mashayekhi (1992) offered a step-by-step process (and an example) to use the initial static picture and transform it into a dynamic problem.

A group of researches in Europe, however, have decided to follow a different approach. This alternative approach (Wolstenholme, 1990) gives less importance to the reference mode and focuses more in the processes and structural characteristics of the system (stocks, flows, feedback loops, delays, etc.). This approach differs from the classical view of system dynamics, which focuses in a specific problem (Randers, 1980; Richardson and Pugh, 1981; Roberts et al., 1983; Mashayekhi, 1992; Saeed, 1992; Sterman, 2000), and intends to help the actors in the system to get a better understanding of the complexity of the system much more similar to the Soft Systems methodologies like the ones developed by Checkland, Eden or Bryant (Wolstenholme, 1992).

Research and Tools in the Conceptualization Process

The common themes described in the basic literature have also served as a guide for many of the developments in the area of model conceptualization. Researchers in the field have worked around these basic ideas to generate better ways to formulate a problem in dynamic terms, and also on better tools to depict a dynamic hypothesis. Additionally, practitioners working with groups have developed several tools and methods to facilitate team work in the conceptualization process. Although not many, some researchers have explored the possibility to enrich the system dynamic method with the incorporation of analytical tools from other fields.

Reference Modes

Although most of the literature uses the term of reference mode to refer to either historical or idealized patterns of behavior over time, Saeed (1992, 1998) considers historical trends as complex patterns that represent the aggregated behavior or "multiple behavior modes" of several subsystems of the problem that may extend in three dimensions, patterns that occur simultaneously because of different components of a system in the same time-period, patterns that occur because of the same component in different time periods or patterns experienced in similar organizations separated geographically. From his point of view, a historical trend can be used as the starting point to create a reference mode, but using that pattern as the reference mode itself can be misleading to the modeling effort. Sterman (2000) includes in his book several examples of the use of statistical tools to smooth or to obtain trends from the historical data in order to eliminate "noise" and use them as reference modes. Saeed (1998) considers that the reference mode is an abstract concept to guide the conceptualization process, which is built by using multiple sources of historical evidence. Some examples of the information used to build reference modes are verbal descriptions, isolated time series or single events. He actually proposes to use this set of data to build the reference mode in an iterative way as a learning cycle. Another implication of the three-dimensional nature of the reference modes is that the reference mode should be decomposed and the problem "sliced" across one of these dimensions in order to be effectively analyzed.

Most of the literature stresses the importance of selecting the appropriate time-horizon for the analysis. Other boundary decisions are also associated with the definition of a problem in a dynamic way, such as the selection of variables and the decision of which of them will be endogenous or exogenous. Although some "rules of the thumb" are offered, there is no easy way to make these decisions yet.

Representing Structure

In order to represent the "organizing principles" or structural hypothesized explanations of the behaviors observed. Researchers in the field have developed a series of "mapping tools" to represent such structures (figure 1).

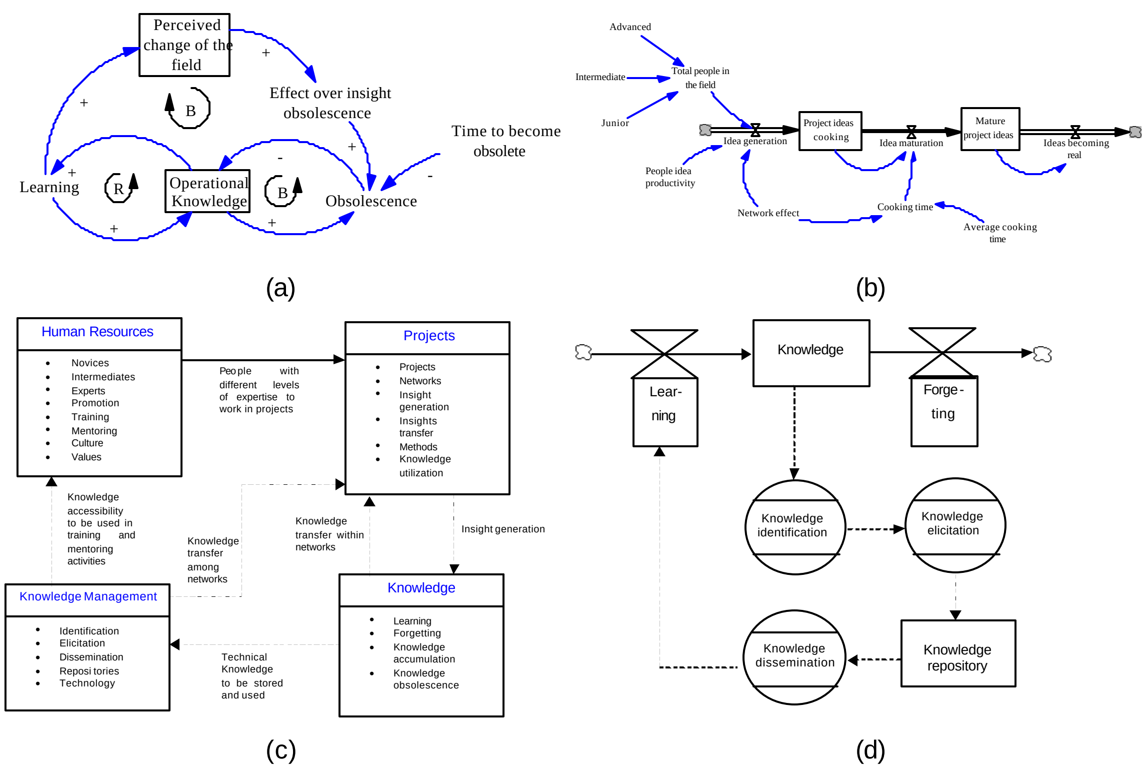

Figure 1. Examples of the mapping tools used in system dynamics conceptualization processes. (a) Hybrid diagram (b) stock-and-flow diagram (c) sector diagram (d) policy structure diagram.

In his classic paper, Randers (1980) uses causal loops to represent the system structure associated with the dynamic hypothesis in the examples he offered. According to Morecroft (1982), the use of this kind of maps was promoted by its use in Goodman's "Study Notes in System Dynamics". Nowadays, another important work that is behind the actual widespread use of causal-loop diagrams was Senge's "Fifth Discipline". Most of the main texts in the field

(Richardson & Pugh, 1981; Roberts et al., 1983; Sterman, 2000) contain detailed guidelines to build the most widely used mapping tools in system dynamics modeling, causal loop and stock-and-flow diagrams (figures 1a and 1b). Some of the basic recommendations associated with the construction of causal-loop diagrams are associated with the identification of the polarity of the links between variables, the selection of the variable names and the ways to phrase them (e.g. using nouns in positive ways). Richardson and Pugh (1981) emphasize the importance to use links associated with a single polarity and to disaggregate every link that need explanation. Sterman (2000) suggest to name the important loops in the causal map to express the main mechanisms associated with that main element in the causal theory. Morecroft (1982) and Richardson (1997) pointed out some problems associated with causal loop diagrams. Some examples of the problems of the use of causal loop diagrams are that they not make an explicit representation of decision-making processes, the lack of discrimination of the elements of the structure (stocks), and ambiguities associated with defining loop polarity.[2]

The classic texts mentioned above contain a good treatment and guidelines to build stock-and-flow diagrams too. This kind of diagrams was used in the field since Forrester's "Industrial Dynamics". Given the additional complexity associated with the interpretation of the stock-and-flow structures to the non-technical person, Richardson and Pugh (1981) proposed the use of "hybrid diagrams" (figure 1a), which are causal loops that distinguish the state variables from the rest of them. Morecroft (1982) proposed two alternative ways to create structural maps, (subsystem diagrams which evolve to become the actual sector diagrams – figure 1c) and policy structure diagrams (including levels, rates and processes recognized by the actors in the system represented by the circles in figure 1d).

A research developed by Martinez & Richardson (2001), suggest that the preferred mapping tools by the group of highly recognized experts in their sample are the stock-and-flow and causal-loop diagrams. The report reveals a disagreement among this group of experts about which of these tools is the most useful during the conceptualization process. On the other hand, a study conducted by Scholl in 1995 implied that these four mapping tools are frequently combined in system dynamics projects. From his sample, 82% of the projects utilized causal-loop diagrams, 70% of them used stock-and-flow diagrams, 41% included sector diagrams, and 19% employed policy structure diagrams.

[2] Some of the ambiguities associated with loop-polarity described by Morecroft in 1982 were discussed by Richardson in his 1997 paper and others in his 1995 "Loop Polarity, Loop Dominance, and the Concept of Dominant Polarity." *SDR* 11(1): 67-88.

Working with Groups

The challenge imposed by dealing with a group of clients is, without a doubt, an important catalyst in the creation of conversational and visual tools to define and conceptualize dynamic problems. On this way, the group of system dynamicists involved in this kind of projects have developed or imported a series of tools to be used during the process. The literature is very rich in this area. Thus, I will only point out some of the best examples of work in the area.

Vennix et al. (1990, 1992) and Lane (1993) recognized different ways of thinking along the modeling process, characterizing the problem definition and conceptualization stages as a divergent in nature. Additionally, they pointed out the differences in people's answers to questions when they (the questions) are formulated individually or in a group. On that line of thinking, they depicted a process in which the use of conceptual models was combined with a modification of the Delphi technique in the elicitation of a problem and its conceptualization. In his later book, Vennix (1996) stresses the importance of the facilitation processes and the design of the sessions in tackling "messy" problems with groups of people.

In another interesting example of the use of several tools to aid to the identification and conceptualization of problems, Reagan-Cirincione et al. (1992) pointed out, among other things, the importance to involve the decision makers in the modeling process and the ability to diagnose a real problem and to match the problem with an appropriate modeling technique. In the paper, they describe a way to tackle complex problems in decision conferences aided by several tools. Particularly, the group involved in the project combined System Assumptions Surfacing and testing (SAST), Multi-attribute Utility models and system dynamics in the conceptualization and policy analysis of a problem in NY State.

In his introductory address to the work table on Methods for conceptualization in the 1981 International System Dynamics Conference, Mass (1986) reflected over the implicit trade-off in most system dynamics interventions. The modeler has to depict the decision processes inside the system, but he needs to offer an outsider view of the system capable to produce some insight. As an interesting alternative to deal with that problem, Richardson & Andersen (1995) have designed 5 different roles during the group model building process. From the five roles described in their paper, the Facilitator and the Reflector are the ones mainly involved in this conflict. The Facilitator is "in the business of drawing out knowledge and insights from the group" (p. 114), while the Reflector "thinks and sketches independently, reflects information back to the group, restructures formulations, exposes unstated assumptions that need to be explicit, and in general serves to crystallize important aspects of structure and behavior" (p. 115).

Learning from other Fields

The relationship of the conceptualization process with other tools, techniques and methods has not been widely explored outside the group model building community. Some isolated examples constitute Fey's (1993) effort to build an Instructional Expert System to facilitate teaching and learning of the conceptualization stages, Lane & Oliva's (1998) proposal to use the methods of Soft Systems Methodology as a key tool in the conceptualization process, and Keating's (1998) effort to link the model building process with the System Development Life Cycle used mainly to develop information systems. Although the perceived potential of these efforts could vary depending on the observer, all of them are isolated efforts. I think that much more effort can be devoted to this area.

Conclusion

In the report of their work, Martinez and Richardson (2001) list the activities identified as best practices in the process of problem definition and system conceptualization. The statements in the paper, though very general, are very consistent with the developments of the last 20 years. Two main point of disagreement among the experts pinpoint two important areas of research associated with the conceptualization process. First, some modelers in the sample prefer to work on a specific problem, while others think that the modeling process should focus in a more generic kind of problem to which the particular case faced belongs. Additionally, modelers disagree in which kind of diagrams to use (stock-and-flow versus causal-loop).

In spite of the advances, common themes and potential disagreements, Sterman's statement is still true "conceptualization is the most important and least understood of all modeling activities". A recent discussion on the System Dynamics Listserv initiated with the idea of building a piece of software to create in an automatic fashion models from written text, Richardson (2002) suggested that "an interesting study would be to see if a sample of experienced system dynamics modelers or systems thinkers would produce the same map or model from a written textual description. Then maybe one could get them to say what they thought they were doing". This statement can be the motivation of a research program oriented to understand and get a better grasp of what is really going on in the modeler's head when he is facing a problem by himself, or when he is alone in the back (or front) of a room during a group modeling session listening to the group's conversations.

Some important questions to address on this research program could be, for example:

1. Which are the impacts of a preferred diagramming tool (causal-loop diagrams vs. stock-and-flow diagrams) on the conceptualization process, and on the characteristics of the final model?
2. What are the effects of the modeler's previous experience on the structure of the model?
3. What are the differences on the models and the modeling process when the modeler does not consider a reference mode to guide the process?
4. What are the differences on the models and the modeling process when the modeler focuses on a system instead of a problem, or in a generic problem instead of a specific one?
5. Are there relationships between modeling practices and software tools used by different modelers (ithink vs. vensim vs. powersim)?

The nature of the research program will require to use a rich set of qualitative methods such as interviews or direct observation in both controlled and uncontrolled environments. Additionally, the program can be enriched with the participation of reflective system dynamicists documenting their practices and offering methodological considerations.

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