Journal of MultiDisciplinary Evaluation
Volume 12, Issue 26, 2016

JMDE
Journal of MultiDisciplinary Evaluation

ISSN 1556-8180
http://www.jmde.com

Using Graphical Perception Principles to Improve the Systems Thinking Tools' Data Visualization: Revisiting the Systems Dynamics Model

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Background: Systems Thinking (ST) is the new paradigm in Evaluation. It represents a significant mind-set shift for the evaluation field and it is a powerful tool to tackle complex environments.

Heir to the systems concepts of the engineering field, and especially regarding the hard systems tools, ST in evaluation uses the same visual tools that were created many years ago. All these tools already incorporate data visualization features: they depict ideas, relationships and concepts relying in shapes and figures more than a textual explanation.

Revisiting these tools and applying the latest data visualization principles, they could be optimised in order to provide with more information within the same concept.

Purpose: To provide ST practitioners with more informative tools in order to facilitate:

- ST experts and users can optimise the application of the tools to real life models beyond the initial set up of their visual representations.
- Audiences of evaluations using ST as part of the toolkit can find the outputs more apprehensible and easy to understand .

Setting: Not applicable.

Intervention: Not applicable.

Research Design: Not applicable.

Data Collection and Analysis: Not applicable.

Findings: Improving ST representations of reality and systems can help both enhance ST applications and make it more accessible and comprehensible for evaluation practitioners' and users.

Six ways for improving the understanding of the current stock and flow diagrams were identified. The tools proposed consist of: customizing the colours and shape of the variables and their relationships to make them more informative; highlighting the existing subsystems within the model; and providing the specific sequence for reading the main causal chains.

Keywords: *systems thinking; data visualization; systems dynamics; visual tools; stock and flow diagrams.*

Introduction

Systems approach is growing in interest and use since it is perceived as a great promise due to its ability to think and understand differently (Cabrera et al., 2008). The advantage of systems approaches relies on the acknowledgement of the emergent properties within a system (Jackson, 1991; Kay, 2006), that never can be found splitting the system in its parts (Sherwood, 2002).

Although systems thinking can be yet ambiguous at some points (Cabrera et al., 2008), there is an agreement upon considering system thinking as the conjunction of (1) an understanding of interrelationships, (2) a commitment to multiple perspectives and (3) an awareness of boundaries defining the system (Williams and Hummelbrunner, 2010). Williams and van 't Hof (2014) precise what these three key concepts —interrelationships, perspectives and boundaries— mean: Interrelationships relates to how the specific items within a situation connect with each other and the implications for the different agents. Perspectives means to deal with the different ways in which a situation could be framed and understood, as well as with the effects of it in the behaviour of the different agents. Last but not least, boundaries refer to the conscious or unconscious decisions about what is in and what is out our system, as well as the ethical, political and practical implications of these decisions.

Dyehouse et al. (2009) showed how system-based processes: (1) produced better and more effective solutions than logic or linear causal models; (2) prevented erroneous relations which might manipulate the results of an analysis; and (3) helped to foresight issues and effects of an intervention in a more effective way. The use of systems tools allows to carry out actions intending to improve the system from the understanding of patterns, structures and mental models driving the behaviour of the system that we see, instead of from how we perceive that the system works. This is relevant in order to identify the leverage points of the system; those parts in which a small shift can produce strong changes—differently to other points in which big changes could have no effect—(Meadows, 1999; Senge, 2006).

Regarding the use of systems thinking within the evaluation field, systems thinking has been identified as especially relevant when dealing with dynamic and non-linear aspects, entangled interrelationships, context sensitivity, different ways in which a situation can be understood and power issues among others (Williams and Hummelbrunner, 2010). Since the late 1980s, attempts to wed the systems and the evaluation field have been made, and according to Cabrera et al. (2008) many things are now widespread at this regard. The following are some examples: (1) the idea of systems as the evaluand; (2) the design and implementation of evaluation systems; and (3) the use of systems concepts as the stakeholders' perspectives or the analysis from different levels of scale. Cabrera et al. (2008) claimed that "system thinking is not necessarily a matter of drawing an entirely new skill-set out of the intellectual ether; rather, it is a unique perspective that transforms the approach [taken to analyse any intervention]" (p. 300).

Systems Thinking Most Relevant (Visual) Tools

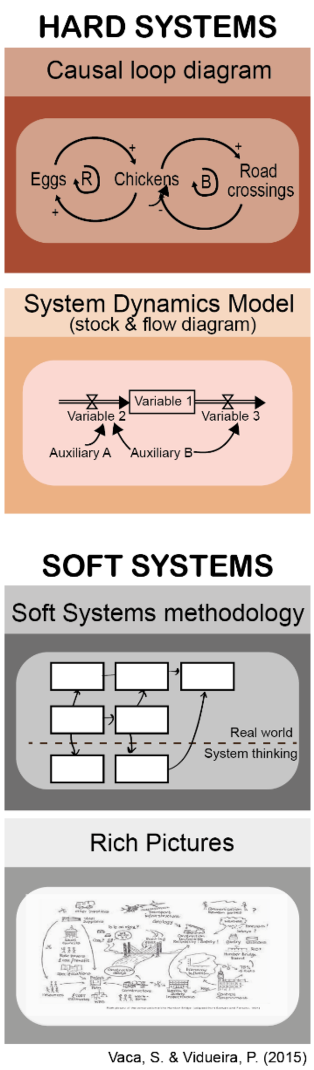
Among the wealth of tools, concepts and approaches within the systems field, a first raw classification would be dividing hard and soft systems approaches. Within the soft systems approaches, the Rich Pictures and the Soft Systems Methodology are among those widespread used. In the hard systems side, the Stock and Flow Diagrams are used in order to express any System Dynamics (SD) model. Causal Loop Diagrams are also used sometimes as a first step in the modelling process. This broad general perspective is reflected on figure 1.

Within the systems approach, system dynamics was conceived as a modelling tool for the management of big industries in order to provide support to the decision-making and optimization processes (Forrester, 1993). The development of system dynamics was greatly influenced by the development of technology and computer based simulations methods in the 1950s (Wolstenholme, 1999; Gil-García, 2008).

Since then, system dynamics has been used in a broad range of fields and situations in order to get a comprehensive view on cause-effect chains and dynamic relationships in complex scenarios (Forrester, 1993) by exploring the consequences of nonlinear relationships and delays within a system. Among the different uses of system dynamics some of them can be highlighted: programme and policy planning at the public and private level (Makoto & Suetake, 2005; Arango et al., 2009; Klaus, 2011); project management (Rodrigues, 1996); development of organizational networks (Akkermans and

Vennix, 1997); and innovation management (Milling, 2002). It is relevant also the use of system dynamics as a method to support the impact assessment in programs with social, economic, environmental and political variables involved (Bryden, 2009) as well as its use within a group model building process (Vennix, 1996) with more prominent relevance of participation within a mixed methods approach by authors such as Makoto & Suetake (2005) and McRoberts (2010).

Figure 1. Broad classification of systems approaches and some examples



Systems Dynamics Model: The Stock and Flow Diagram

One of the most common ways to formulate and visualize a system dynamics model is through the stock and flow diagrams. This is the way that system dynamics models are built and also the tool used to work and communicate relationships and concepts represented by the model through shapes, figures and letters. The basic structure of stock and flow diagrams is showed on figure 2.

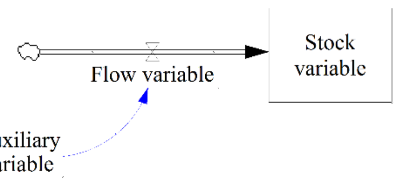


Figure 2. Basic structure of stock and flow diagrams

Stock and flow diagrams represent how the different variables involved in the system are connected. This is also represented by other systems tools such as causal loop diagrams (CLD). There are two main differences between causal loop diagrams and stock and flow diagrams (also known as Forrester diagrams).

The first difference is that stock and flow diagrams represent three different types of variables – stock, flow and auxiliary, as it is shown on figure 2 – while causal loop diagrams only represent only one type of variables.

The three types of variables in the stock and flow diagrams are (1) stock variables – accumulates or depletes over time; (2) flow variables – rate of change in a stock; and (3) auxiliary variables. In the results section, a more detailed analysis of some of the most common conventions followed for the stock and flow diagrams is presented.

The second difference relies on the relationships between variables. While in the causal loop diagrams these relationships are qualitative, in the stock and flow diagrams, relationships are represented by a formula that quantifies that connection. This allows simulating the modelled system with actual quantitative values. It is important to notice that often these models are more useful for insights than for real predictions of variables' values.

Stock and flow diagrams, as many other ST tools, use data visualization for depicting variables –through different squares and other forms displayed within a space- and their relationships –represented usually through arrows-. However within the diagram, other visual features could be exploited.

According to research, there are limited set of visual properties that are detected very rapidly and accurately by the low-level visual system. For many years vision researchers have been investigating how the human visual system analyses images. An important initial result was the discovery of a limited set of visual properties that are detected very rapidly and accurately by the low-level visual system. These properties were initially called *preattentive*, since their detection seemed to precede focused attention, occurring within the brief period of a single fixation. We now know that attention plays a critical role in what we see, even at this early stage of vision. The term *preattentive* continues to be used, however, for its intuitive notion of the speed and ease with which these properties are identified.

Some of the visual features that have been identified as *preattentive* are: orientation, length, width, closure, size, curvature, density, contrast, number, estimation, color, hue, among others.

Stock and flow diagrams in their original form are not fully taking advantage of the *preattentive* features' potential to communicate information. There are also findings form experiments in the psychology field that reveal relevant information at this regard. We will highlight three results from Healey and Enns (2012) research: (1) Viewers detect a target element with a unique visual feature within a field of distractor elements; (2) viewers detect a texture boundary between two groups of elements, where all of the elements in each group have a common visual property, and (3) viewers count the number of elements with a unique visual feature. These results provide guidance for the visual improvement of stock and flow diagrams, what is the main goal of this research.

Limitations to perception in stock and flow diagrams

As was mentioned before, stock and flow diagrams represent variables - of three types: stock, flow and auxiliary, and their relationships. However, they do not provide with any information about:

a) Which variable/s is/are the most relevant one/s
b) Which relationships are showing the highest causal relation
c) Which is the sense (positive or negative) among the variables.

On the contrary, all variables of the same type and relationships look the same in the diagram without further distinction between them.

Objectives and Methodology

Our contribution will be experimenting and testing *preattentive* graphic perception features such as position, width, colour and others to include more information within the same space, in a digestible understandable way.

We have chosen the Systems dynamics model because is one of the most widely used tools that provides an overall picture of the system. We have first analysed and compared the most relevant symbols conventions (see figure 3). We have based our work in some examples taken from the book "Systems dynamics: Systems thinking and modelling for a complex world" (Sterman, 2000). Then we have iterated with graphic perception features such as colours, position, width, hue, size, until we have reached to an improved version of the initial model.

Here you will find the results of all these steps.

Revisiting the Tool: The Systems Dynamics Model

Present Icons Conventions in SDM

As it was already mentioned, a system dynamics model comprises three types of variables – level, flow and auxiliary. Besides the variables, the model contains relevant information about the existing relationships among the variables and the values that the variables get through the simulation of the model.

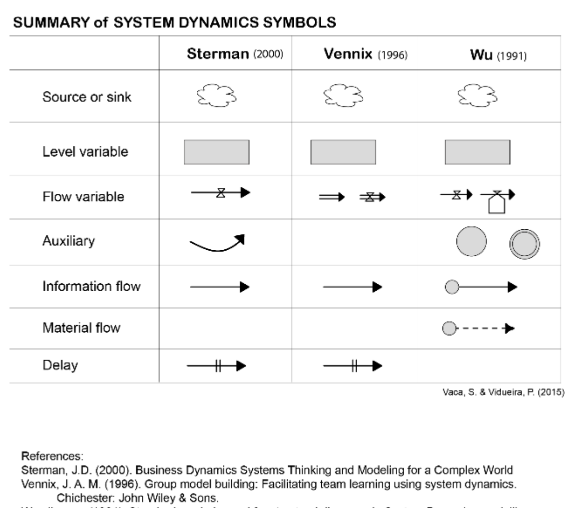


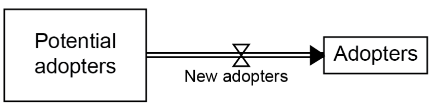
Figure 3. Synthesis of some of the more widely used conventions for building a stock and flow diagram — as the way for expressing a system dynamics model.

Our Contribution to Visual Standards in SDM

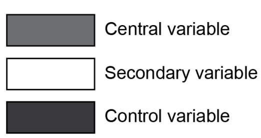
For the present tool – Systems dynamics representations, we have found that new features can be added resulting in a more useful informative scheme of the system. We have developed six different alternatives, grouped in three categories:

1) The importance of the variables

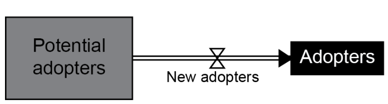
a. Can be represented making the box containing them proportional to their dimension. Bigger boxes contain more relevant ones.



b. When using different colours or hues in the background of the variables these colours should have a meaning and be clearly identifiable. A legend explaining the codes should be included. For example, adopting the following color code:

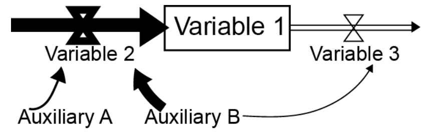


We could represent our model adding extra information:



2) The details of the relationships

a. In the same spirit, size and colours of the arrows could represent importance and type of relationships. We suggest dark grey for positive effects and light grey for negative, varying the width of the arrow according to the effect importance.

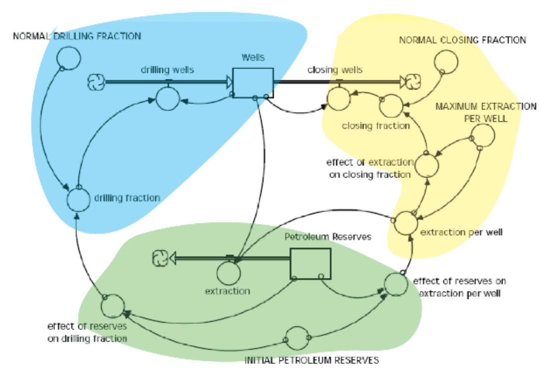


b. Arrows could also be representing the flow positive or negative that links that two variables. This could be represented with different colours, the most typical being green for positive and red for negative.

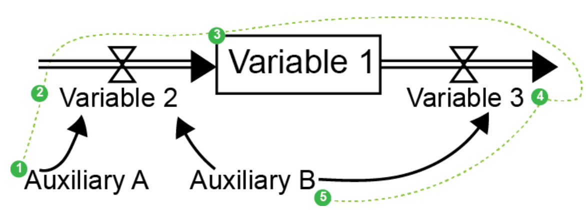
3) Mapping the system to assist in the overall understanding

a. Variables can be sorted within the diagram by colours, grouping them by types and making it easy to locate and interpret them.

Different colours can help identify subsystems.



b. Adding a path made by numbered steps to interprete the graph could help to walk the reader through the model using a logic interpretation:



Conclusions

By including some very simple and feasible improvements to the systems dynamics representations and ideally making these suggestions generally used, reading this type of visual displays would be much easier both for the outsiders and even for the people involved in the process.

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