System Dynamics

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INTRODUCTION

System dynamics (SD) is one of computer simulation methods especially for social science fields, such as management, economics, and politics. Elements in social science fields are mutually related, and the relationships can make circulated dependencies, called "feedbacks." In addition, information flows are often delayed. Making mathematical models of such systems directly means making dynamic system models using differential equations. Moreover, such systems are often difficult to be formularized and solved. Nevertheless, we, humans face the necessity of solving problems in these kinds of systems. Furthermore, this kind of complex systems' behaviour is often counter-intuitive. Roberts (1978, p. 562) notes that people's understanding of social systems is often wrong. One would often try to find a problem's cause outside of their systems, while the real cause is inside. In addition, Sterman (1989) says that people inside of feedback systems overlook the fact that temporary improvement causes other problems later. Thus, we often misunderstand the nature of complex systems and fail to manage situations.

SD models can easily express feedbacks and delays with a human-friendly interface. Therefore, SD can help humans understand reality and make reasonable decisions.

The main part of SD has three steps: drawing diagrams, giving parameters and equations, and running simulations. Detailed information is shown in following the Modelling Procedure section.

BACKGROUND

Objects in social science consist of many elements, and the relationships between them are generally complicated. It is natural and reasonable to employ dynamic simulation modelling in order to solve social science problems. Nevertheless, social science models have been expressed in static ways or have been unrealistically simplified, mainly because of difficulties in handling dynamics equations. However, it is still important to make social science models as dynamic systems. The reason is that elements in societies are mutually connected in complicated way, and the nature of social systems is dynamic; besides, people fail to understand dynamics (Booth Sweeney & Sterman, 2000).

In this situation, J. Forrester developed interface and procedures to make dynamic models in social science fields. This is "system dynamics."

The first appearance of SD in academic papers was in the Harvard Business Review in 1958 (Forrester, 1958). Since SD is a method of simulation, both theoretical enquiries and practical applications are shown in various journals. The journal of SD, "System Dynamics Review" started in 1985[1], and System Dynamics Society holds "International Conference of System Dynamics Society" every year[2].

There are seminal books of SD fundamentals. Sterman (2000) contains almost all of knowledge to build and test SD models. This book shows many detailed SCM models. Because many people can easily imagine material flow, SCM models would be good examples not only for SCM researchers but also for all practitioners and learners to introduce ideas of a stock-flow structure and feedback loops. This book also has detailed explanations about validation procedures. Validation is also discussed in Qudrat-Ullah (2005) which leads to agent-based simulation models' validation. Ford and Flynn (2005) present how to find key inputs.

Coyle (1996) describes important functions with mathematical background. This is useful to know precise numerical backgrounds.

Ford (1999) has many model examples from environment study field. This also explains SD modelling process concisely. Maani and Cavana (2000) show many business and economics models using SD. Included models are relatively simple so that this would be a good start point to learn. The models' parameters and equations are fully clarified; therefore, learners

DOI: 10.4018/978-1-4666-5888-2.ch120

can follow the modelling processes. More complex but practical models are shown in Morecroft (2007) and Warren (2008). Implementations of SD elements described in these books are helpful for practitioners and researchers.

Vennix (1996) recommends "group model building." Modelling not alone but en masse can stimulate self-learning and promote team cooperation atmosphere. Lyneis (1999) explains how to use SD for business strategy planning.

RELATED WORKS

As SD is a simulation method or means of forecasting, application examples are widespread. The most famous one is "The limits of Growth" in the Roma Club report (Meadows et al., 1972). Their presentation had a significant impact. Fortunately, people and governments all over the world considered the issue seriously; therefore, their tragic consequences were not realised.

After that, there have been many subsequent pieces of research in publications.

Angerhofer and Angelides (2000) refer to pioneering studies in various fields. Their reference tends to long term issues. However, Lyneis (2000) indicates that SD can carry out short and mid time period forecasts better than statistical methods.

The one of the most active fields of SD application is SCM. Recently, not only focusing on SCM itself, there are also researches that contains the global or environmental issues. Vlachos et al (2007) shows that SD models can be used to evaluate alternative long-term capacity planning policies around supply chains. In addition, Kamath and Roy (2007) present how to manage short lifecycle product supply chains.

There are models not only for forecasting but also for finding effective leverages, which are elements having significant effect when changing their values. For example, Weber and Schwaninger (2002) show what kind of interventions is effective when agricultural organizations cope with new challenges, such as opening the domestic market to foreign organization. Lyneis et al. (2001) shows a practical use of SD for a complex project management.

Environmental issue is also one of active fields of SD use. Georgiadis (2013) explains how to manage paper recycling network using SD models.

Society and community can be expressed in SD models. Magidson (1992) shows community volunteers' role in SD models and explain how to help their activities. Ethics in small organization is taken up in Takahashi and Tanaka (2010).

STRUCTURE OF SYSTEM DYNAMICS MODELS

Two Types of Diagrams

SD has two types of diagrams: "causal loop diagrams" (Figure 1) and "stock flow diagrams" (Figure 2).

Causal loop diagrams indicate relationships between variables. A "+" or "s" sign next to arrowheads indicates that a variable to which an arrow points increases (decreases) when a variable which is the arrow's root increases (decreases) and when all other variables do not change. The "-" or "o" sign means the opposite. If there is a delay in information transmission or material move, double lines are attached on an arrow.

When arrows on a causal loop diagram consist of a circulation, the circulation is called a "feedback loop." When a feedback loop has an odd number of "-" signs, the feedback loop can work as an engine of goal seeking behaviour and is called a "negative feedback loop" or "balancing loop." In order to indicate that a loop is a negative feedback loop, causal loop diagrams often indicate a symbol of "-," "B," or an image of "balance" near the loop structures (Figure 1). When a feedback loop has an even number of "-" signs, the feedback loop can work as an engine of exponential growth or decay and is called a "positive feedback loop" or "reinforcing loop." Positive feedback loops on causal loop diagrams are often indicated with a symbol of "+," "R," or an image of "snowball" Figure 1).

However, the behaviour of each variable cannot be precisely forecasted without numerical simulation, because most systems have multiple feedback loops and they influence each other. To make numerical simulation models, one need stock flow diagrams. Practically, SD software requires users to draw stock flow diagrams, not causal loop diagrams.

It used to be necessary to draw a diagram by hand, and then it was mentally translated to a program called "DYNAMO equations" by the modeller. Nowadays, one simply draws a diagram, then SD computer software[3]

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