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THE SYSTEM DYNAMICS APPROACH TO ANALYSIS OF COMPLEX INDUSTRIAL AND MANAGEMENT SYSTEMS

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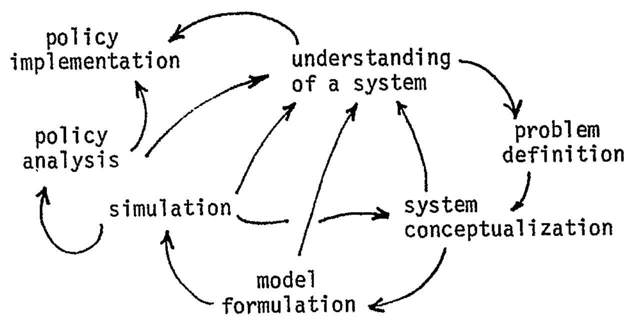
The tutorial is designed to expand a person's ability to understand and to model complex industrial and management systems. Modeling of physical systems such as aircraft flight or engineering design structures are not addressed. The system dynamics approach to examining, conceptualizing, and modeling complex systems is emphasized. Complex managerial and social systems are of special interest. The informational feedback characteristics of these systems are discussed and methods to focus on feedback structures are presented. Special attention is given to the dynamic interaction among structure, policy, and time delays in decision and actions that determine system behavior and performance.

1. INTRODUCTION

The system dynamics approach to problem-solving is based on the major premise that informational-feedback structures are the core frameworks in systems. The method of approaching system study is built around discovering, understanding, and modeling these feedback techniques. The chief objective of a study is to provide a device that may be used to suggest changes in policies or structure that will bring the behavior of a system into line with objectives. The purpose of the tutorial is discussion of the method, its strengths, and limitations. The material presented in this paper will serve as an outline for further discussion in the tutorial.

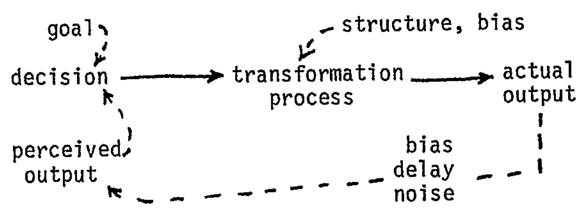
2. SYSTEM DYNAMICS IN SYSTEMS ANALYSIS

The System Dynamics paradigm was introduced by Forrester in the late 1950's and early 1960's at MIT. He based his analysis of corporate structure on principles of control theory stemming from his electrical engineering background. The approach is based on an iterative process of conceptualization, analysis and measurement, and parametric modeling that has been applied widely in various forms by system scientists of various backgrounds. The paradigm in general form is known as the systems science paradigm. It is clearly articulated by Schoderbek, Schoderbek, and Kefalas. The process of analysis was intended for use with systems that exhibit continuous behavior patterns. There are aspects, however, that may be powerfully applied in any systems study. The specific paradigm is articulated by Richardson and Pugh as:

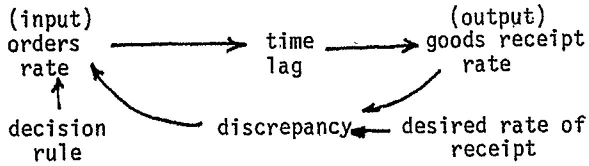


The first thing necessary in applying the process is developing a simple method of completing system conceptualization. One will be discussed in the next section.

The basic feedback structure of a system may be represented in several ways. Roberts shows the following general structure:



and Coyle the following for an inventory structure:



The major points are first, there is a goal; second, there is an output; third, there is information about the output; fourth, there is a difference in actual and perceived behavior that causes some action; and fifth, the resulting decision is implemented in some physical structure. These simple representations form the basis for applying a method of conceptualization known as causal loop diagramming.

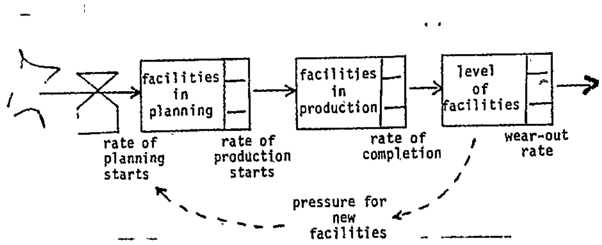
3. CAUSAL LOOP DIAGRAMMING

The first step in conceptualization typically has been causal loop diagramming. This step also has been termed impact analysis, influence diagramming, and causal analysis. It is a method of decomposing a system taking two elements one at a time and focusing upon decisional elements, variable measurement, behavioral consequences and hypotheses, and upon feedback mechanisms. Primary initial attention is given to the objective of a system, or its observable (or desired) output. The analysis is based on the relationship between any two elements taken one at a time. For example, in a production system as the quality of labor increases, productivity will increase, all other things equal. This would be represented as:

This modeling process continues until the system is specified to satisfaction. As an example, a simple production model for highway construction may appear as:

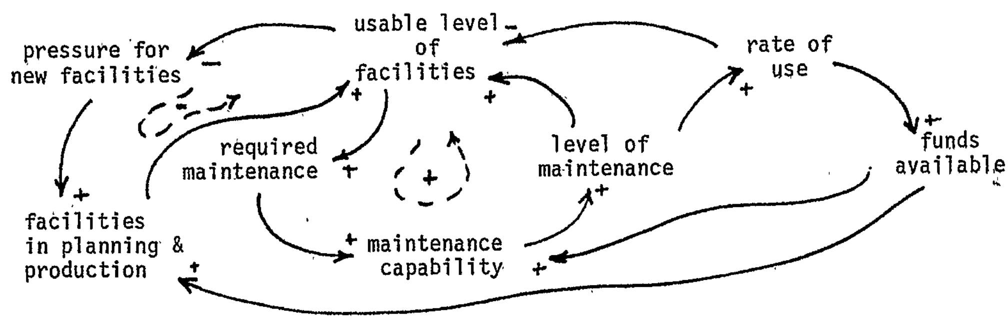
4. FLOW DIAGRAMMING

The next step in model development is to develop a flow diagram of the structure that translates the causal diagram to a form that is more amenable to parameterization and mathematization. The system is expressed as a set of state (or level) vectors and the rates of flow for them. In the example, the loop from usable facilities through pressure for facilities to new construction might appear as:



This simple (very simple) representation shows three levels or accumulations of facilities and the rates that control flow from one level to the next. The states of the system change as the rates increase and decrease. The output rates of the levels are represented as a function of, with some delay, the input rate. (The role of delays will be discussed in the tutorial.)

The system is represented as a continuous structure. Discrete input and output are not measured, but rather the shift of the rates and levels over time. Time is represented in some unit smaller than the smallest rate delay. The mathematical structure of a continuous system may be represented in either differential or difference equation form. In the first case the equation for the



The plus or minus sign at the head of each arrow is, in fact, a causal hypothesis about the behavior between the variables. For example, as the level of facilities increases, the required maintenance increases. There are several feedback loops shown in this simple model. Two of the major ones are shown by the dotted lines in the diagram. Negative loops are goal-seeking or stabilizing and positive loops are destabilizing in a system. This approach and its implications will be discussed more fully in the tutorial.

first level in our example would be represented as:

$$FIP = FIP_0 \int_0^t (RPS - ROPS)dt$$

where: FIP = facilities in planning
RPS = rate of planning starts
ROPS = rate of production starts

In the second case, the equation would be given in the form:

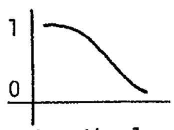
$$FIP_t = FIP_{t-1} + (RPS_{t-1,t} - TOPS_{t-1,t})$$

There are a number of simulation languages that deal with systems represented in this form. Perhaps the best known are SLAM, GASPIV, and DYNAMO. At least one of these is the subject of another tutorial, so these or other languages will not be addressed specifically.

The mathematical model is submitted to an appropriate language for solution. Typically, output is shown as a graph of variable movement over time. The initial objective is to provide a stable model that can be used in experimentation. Model stability and its implications will be discussed in the tutorial.

4. VERIFICATION AND VALIDATION IN DYNAMIC SYSTEM MODELS

The example of highway production illustrates one of the most criticized aspects of system dynamics analysis. One of the variables used was "pressure for new facilities." Measurement of such variables is difficult if not impossible, but managers often describe such variables as part of a complex decision process. Such a variable would be repeated in the model as a direct function of the "level of usable facilities" through some type of look-up table. The pressure might appear on some arbitrary scale from 0 to 1 as:



level of usable facilities

The greater the level of facilities, the lower the pressure to increase usable facilities. Models that contain such elements would obviously raise serious validity and verification issues. The form and range of such functions must be tested and related to actual decision structures. Methods for doing this will be discussed in the tutorial. Also, the various tests suggested by Forrester and Senge for verifying and validating models will be discussed.

5. SUMMARY

Application of the systems science paradigm has been outlined. The steps involved will be discussed in the tutorial. The use of such models in problem analysis and their place in the field of simulation also will be addressed.

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