Process Analysis

We use the phrase "process analysis" to mean the construction and use of systems models (Checkland 1981) to support the analysis of material and energy transformation processes and the socioeconomic structures that control and influence these processes. The socioeconomic resource systems of interest can be globally, regionally, nationally, subnationally, plant or unit operation specific in nature. The underlying processes can be either naturally occurring or man-made. In particular, process analysis aims at explicating the evolution of the patterns of physical flow-physical stock in socioeconomic resource systems. At the unit operation level, process analysis is used to support design and construction of components that are physically viable systems, that is, systems that are feasible because they are consistent with the physical laws of nature. These uhit operations use some form of stock, appropriately controlled, to transform a set of flows of energy and material to another set. At the plant level, process analysis supports the design and construction of uBit operations which can be coordinated for a specific purpose, that is, the production of some object or objects. At the corporate or company level, process analysis is used to support ongoing decision making concerning the operation of extant plant and additions to the corporate portfolio. At the subnational level, process analysis is used to support decisions concerning the coordination of regional development with all its concerns about zoning, tax base, employment and environmental impact. At the national level, process analysis is used to guide planning and policy as it partly represents the relationship of socioeconomic activity to the national resource base of a nation. At this level the concern with the resource base is both in its passive aspect as a source of materials and in its reactive aspect as a set of naturally occurring processes that must be used to ameliorate wastes. At the regional and global level, process analysis is used to examine potential trade patterns involving flows of materials, energy and service. This analysis supports decision making at the national level concerning trade agreements and industrial development strategy.

Process analysis is dynamic. It is dynamic in two senses: one is that it links levels, and the second is that the process-based systems models evolve in time as they are used. This dynamic time dependence of process analysis has two aspects: one is involutionary (i.e., how to exercise control) and the other is evolutionary (i.e., how to plan for development). The dynamic level linking of process analysis brings into relief an important distinction in the levels at which it is applied. That distinction can be cast as the ratio of involutionary to evolutionary concern of the decision making at each level. This ratio is low at the unit operation level, high at the plant and corporate level and decreasing through the remainder of the higher levels.

1. *What is a Process?*

The concept of a process (Jantsch 1981) is primordial. It can be defined as that which transforms one set of flows of material, energy and information into another. This implies that a process exists in an environment from which these flows arise and to which they go. What distinguishes a process from its environment is an arbitrarily chosen boundary. Although the choice of boundary is arbitrary, the wisdom of that choice will render analysis in a given context simple or difficult.

Networks of processes are again processes. This leads to concepts of process hierarchy, aggregation and embed ability. For example, a unit operation can be considered to be a set of basic physical processes coordinated in some way. In turn, a plant can be seen as a set of unit processes, an economic sector as a set of plants, a nation as a set of economic sectors, and so on. In fact, societal decision-making processes are related to this process hierarchy, as is shown in Fig. 1.

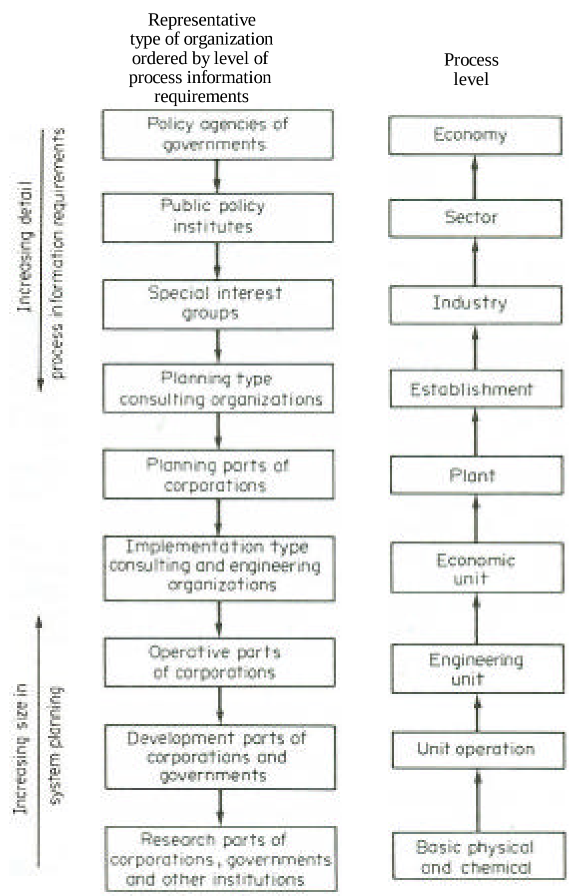

Figure 1
Hierarchy of processes

Depending on the time horizon over which an analysis is required, some processes operate so slowly that there appear to be objects, which, for our purposes, we shall refer to as funds. These funds, however, themselves undergo change and are simply networks (perhaps very complex) of processes. These networks or funds often provide a composite flow of information and energy to a process and such a flow is often referred to as a service. The importance of distinguishing these networks of slow-acting processes from the more active ones is that it simplifies analysis. The introduction of the concept of a fund is simply the addition of another boundary: thus the appropriate selection of boundaries for a given analysis becomes of prime importance in simplifying a system sufficiently so that tractable analysis can be carried out. The distinction of service (energy or information) flows from materials flows is important in process analysis because the principle of mass balance is an important consistency constraint on the correctness of any process description. The distinction of energy and information is also important since the second law of thermodynamics imposes an important consistency c0nstraint on entropy generation. This leaves information flows identified, and that in itself is useful because of the relation of information to the notion of control and the notion of control to that of planning.

To make the above more explicit, consider a chemical reaction

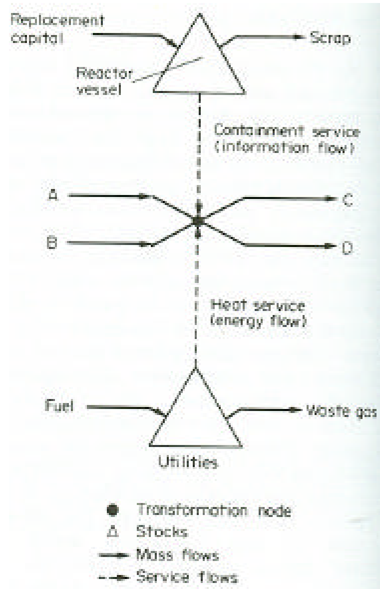

Figure 2
Example of a process topography

A+B--+C+D

being carried out in a reactor vessel. The input flows of materials A and B are transformed by the process represented pictorially by the process node in Fig. 2 into output flows of materials C and D. The process receives an informational input flow from the reactor vessel expressed in the form of containment in space and the input flow of heat energy. The reactor vessel is shown as a fund in Fig. 2 by the triangle. Now the reactor vessel itself is changing slowly by corrosion and thus is essentially replaced. If the analysis in which this process was involved was of short enough duration that reactor vessel corrosion and the subsequent processes of replacement and/or repair were irrelevant, no flow lines of mass would be shown going to the fund. If not, then one would have input and output mass flows to the reactor vessel.

2. *Quantification of a Process*

Organized coordinated quantification of processes is an important prerequisite to process analysis. In order to carry out process analysis one requires a well-defined set of processes and an operational model of a connected set of processes. These are what may be called the systems components of the system under consideration in a particular process analysis and are the outcome of process quantification. Two largely independent structures are required for process quantification. These, their interrelation and relationship to process models (process analysis) are depicted schematically in Fig. 3. First is what may be called the topography of a process. This is simply a definition of the connective structure of the flows in a process. It may be thought of as a named diagraph or simply a conventional flowchart or blueprint of the process. It names the flows, denotes their composition and characteristics and indicates their origin and destination. In the construction of a topography an implicit boundary is formed which separates the process from its environment. This topography may be used as a framework to record observations of a process. However, a process description requires information on "how the process works" or a theory of operation of the process. The theory is in practice a model of the operation of the process. A model description consists of the specification of relationships, the definition and the quantification of parameters of the model.

Experience shows that many processes operate similarly from a generic perspective, thus the second structure required for process quantification is a generic model of the process. When a generic model of a process is brought into confluence with a topography of a specific process the result is a data structure appropriate for storing a measurement (calibration) of the process. The data take the form of values for parameters, the connection between the variables in the

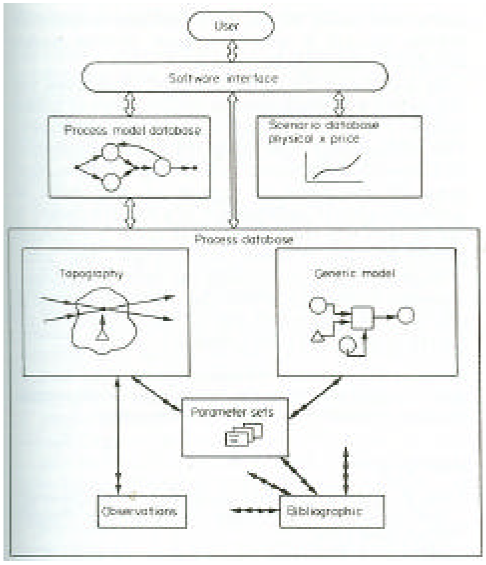

Figure 3
A database approach to process modelling

generic model and the flows in the process topography, and the names of variables and parameters.

3. *Process-Based Systems Modelling*

The data mentioned in Sect. 2 can be considered to constitute realized generic models, or simply models, of processes. These models can be used as the theory of the process in carrying out specific process analysis. Since generic models also represent a theory of operation for a process, the concepts of control and control variables are brought naturally into the process analysis. In most process analyses, realized generic models are coupled together through various linking rules and these resulting networks become the fundamental tools. These networks of realized generic models are referred to as process-based systems models. It should be noted that the linking rules themselves can be considered to be generic models and again have control variables associated with them. In this way two levels of control can be distinguished, the lower at the level of the process and represented in the generic model of the process, and the higher at the level of the linking rules. This allows process models, at one level of the hierarchy mentioned in Sect. 1, to become the "theory of the machine" at the next higher level and allows for the development of hierarchically coordinated systems models (Mesarovic et al. 1970). It also allows the definition of levels of aggregation for representing processes that are appropriate at different levels in the organizational hierarchy.

Process models, like other model types, come in various subtypes, each suited to its own purpose. Four dimensions of these subtypes that are useful to distinguish in applying the art of choosing a particular subtype for a particular application are:
(a) theory versus data rich,
(b) degree and type of feedback, (c)
degree of buffering, and
(d) optimization versus simulation.

Theory-rich process models are models in which the behavior of the component is taken as *a priori* from some lower level "theory of the machine," whereas data-rich models are those whose component's behavior is estimated from observation. Theory-rich might also be called the white-box approach while data-rich could be termed the black-box approach.

The degree of feedback depends on the openness and complexity of the process model whereas the type of feedback can be user interactive or analytic at one level and integrative or differential at another level.

The degree of buffering is related to the amount of memory less behavior of various process components in the model, that is, instantaneous communication via flows as opposed to communication via inventories.

Optimization process models are those that contain a large degree of decision making via internal programmed optimization routines as opposed to simulation process models whose decision making is a mix of heuristic and user-interactive.

At this point it is important to observe that a particular process model subtype is not equally useful at all levels of the organizational hierarchy. It is important to recognize this relation between process model subtype and organizational hierarchy as it can be a useful guide in allocating resources for process modelling efforts. As one moves up the hierarchy, one finds that increasing usefulness is obtained by moving to theory-rich, user-interactive, open, highly buffered simulation process models. In a word, one can describe this type of process model as loose compared with the tight models used in the lower reaches of the organizational hierarchy. Of course, this rule of thumb applies only generally and in any specific context may be overridden by other issues~

4. *Examples of Process Analysis*

There are five broad areas where process modelling has been extensively applied. These are: (a)
investment decision analysis, (b)
residuals management analysis, (c)
resource extraction analysis, (d) process
design, and
(e) process control.

In the first area, a detailed production function is derived from an engineering-based process model capable of articulating the investment decision in some prelimited space of decisions. In other words, questions as wide as portfolio decisions are not being addressed here. Extensive exposition of this area is given by Smith (1966), who addresses both input substitution and market penetration capability. Investment decisions can also be viewed from a broader policy perspective. In this area, process analysis has not been as widely used; however, Ayres (1978) provides an overview of it and a good reading list. The questions addressed here are materials substitution at the macroeconomic level and the degree to which certain technologies should be fostered.

In the area of residuals management, significant work was done in the early 1970s using process analysis. Russell (1973) and Russell and Spofford (1972) both give good overviews and specific examples. The former study deals with a specific technology while the latter deals with economic activity in a geographical region. The use of process analysis here is required by the need to relate economic activity to residual analysis. The importance of the corl1mon property character of the environment as it relates to its ability to ameliorate the waste streams of economic activity is at issue here.

In the area of resource extraction analysis, process analysis has long been used to address the question of the relation of economic activity and resource-base (in the sense of supplying materials) adequacy in a dynamic context. Examples of this are given by Kopp and Smith (1982) and Kydes and Rabinowitz (1981). There is an overlap here between investment decision analysis and resource extraction analysis in that models capable of contributing to one area also may contribute to the other.

In the more traditional area of process design, process analysis has long been used by the engineering profession to find physically feasible and least-cost solutions for the production of goods and services. Many works such as Peters and Timmerhaus (1968) may be referred to in this area. An important development since the 1960s in this area has been the advent of interactive computer-based and data-based tools to support this activity of process design. Other areas using process analysis can learn much from this development. The effect of this development is to significantly reduce the cost of process design, thereby allowing engineers to search a much larger portion of the physically feasible space of processes. This in turn contributes significantly to the overall productivity of an economy.

The last area is again an engineering area but is much newer than process design. Here a process model of an already designed process is used in a computer to aid in the control of that process. A discussion of this application is given by Rosenbrock (1974). There is again much that can be learned by social sciences in studying this area and transposing both the methods and certain results. Productivity rises very steeply when process control is aided by good process models encoded in control computers.

By looking at the commonality of these areas, one can discern a certain pattern or methodology of process analysis which is independent of the area of application. This methodology, once emancipated from its application-dependent manifestations, has significant implications for the mode of storage of, and mode of communication of, information in a modern society. It can be seen that the methodology forms a significant connecting link between the physical and social sciences. This link could, with the help of developing computer technology, enable the sciences in general to take a more responsible role in the guidance of the society in which they are embedded.

See also: Input-Output Analysis; Input-Output Analysis: Applications; Productivity and Technological Improvements: Managerial Evaluations; Residuals Management

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