CHAPTER 1

SYSTEMS

1.1 The Ubiquity of Systems

Man lives and works within social systems. His scientific research is exposing the structure of nature's systems. His technology has produced complex physical systems. But even so, the principles governing the behavior of systems are not widely understood.

As used here a "system" means a grouping of parts that operate together for a common purpose. An automobile is a system of components that work together to provide transportation. An autopilot and an airplane form a system for flying at a specified altitude. A warehouse and loading platform is a system for delivering goods into trucks.

A system may include people as well as physical parts. The stock clerk and office workers are part of the warehouse system. Management is a system of people for allocating resources and regulating the activity of a business. A family is a system for living and raising children.

If systems are so pervasive, why do not the concepts and principles of systems appear more clearly in our literature and in education? Is it because there has been no need for understanding the basic nature of systems? Or have systems seemed to possess no general theory and meaning? Or is it because the principles of systems, while sought after, have been so obscure that they have evaded detection? The answer seems to have been each of these three in turn.

In a primitive society, the existing systems were those arising in nature and their characteristics were accepted as divinely given and as being beyond man's comprehension or control. Man simply adjusted himself to the natural systems around him and to the family and tribal social systems which were created by gradual evolution rather than by design. Man adapted to systems without feeling compelled to understand them.

As industrial societies emerged, systems began to dominate life as they manifested themselves in economic cycles, political turmoil, recurring financial panics, fluctuating employment, and unstable prices. But these social systems suddenly became so complex and their behavior so confusing that no general theory seemed possible. A search for orderly structure, for cause and effect relationships, and for a theory to explain system behavior gave way at times to a belief in random, irrational causes.

Gradually over the last hundred years it has become clear that the barrier to understanding systems has been, not the absence of important general concepts, but only the difficulty in identifying and expressing the body of universal principles that explain the successes and failures of the systems of which we are a part. Economics has identified many basic relationships within our industrial system. Psychology and religion have described some of the interactions between systems of people. Medicine has treated biological systems. Political science has explored governmental and international systems. But most such analysis has been verbal and qualitative. Mere description has not been sufficient to expose the true nature of systems. Mathematics, which has been used to structure knowledge in science, has not been adequate for handling the essential realities of our important social systems. We have been overwhelmed by fragments of knowledge but have had no way to structure this knowledge.

(See Section W1.1 of the accompanying Workbook)

1.2 System Principles as the Structure of Knowledge

A structure (or theory) is essential if we are to effectively interrelate and interpret our observations in any field of knowledge. Without an integrating structure, information remains a hodge-podge of fragments. Without an organizing structure, knowledge is a mere collection of observations, practices and conflicting incidents.

Such a state of unrelated facts describes much of our knowledge about managerial and economic systems. Our separate and often conflicting impressions have not yet been brought into focus by being assembled into a unified structure. Without a structure to interrelate facts and observations, it is difficult to learn from experience, it is difficult to use the past to educate for the future.

The importance of structure in education is well argued by Jerome S. Bruner of Harvard.[1] He says, "Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully. To learn structure, in short, is to learn how things are related.....good teaching that emphasizes the structure of a subject is probably even more valuable for the less able student than for the gifted one, for it is the former rather than the latter who is most easily thrown off the track.....There are two ways in which learning serves the future. One is through its specific applicability to tasks that are highly similar to those originally learned.....A second way is through the transfer of principles or attitudes.....the continuity of learning that is produced by the second type of transfer, transfer of principles, is dependent upon mastery of the structure of the subject matter.....Inherent in the preceding discussions are at least four general claims that can be made for teaching the fundamental structure of a subject. The first is that understanding fundamentals makes a subject more comprehensible.....The second relates to human memory. Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten.....Third, an understanding of fundamental principles and ideas, as noted earlier, appears to be the main road to adequate 'transfer of training.' To understand something as a specific instance of a more general case--which is what understanding a more fundamental principle or structure means--is to have learned not only a specific thing but also a model for understanding other things like it that one may encounter.....The fourth claim for emphasis on structure and principles in teaching is that by constantly reexamining material one is able to narrow the gap between 'advanced' knowledge and 'elementary' knowledge."

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[1] Bruner, Jerome S., <u>The Process of Education</u>, Harvard University Press, 1960. A short book and well worth reading.

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The laws of physics form a structure to interrelate our many observations about nature. This structure of physical knowledge is the foundation for today's technology.

But in management systems, such a basic structure of principles is only now being developed. Managers and educators have long searched for a structure to unify the diverse manifestations of psychological, industrial, and economic processes. Management education has been criticized as being merely descriptive without a unifying structure. Indeed, structure has long been pursued, even though the nature of a suitable structure was elusive.

But now the concepts of "feedback" systems seem to be emerging as the long-sought basis for structuring our observations of social systems. Over the last century the theory of systems has slowly been developed to apply to mechanical and electrical systems. However, physical systems are far simpler than social and biological systems and it is only in the last decade that the principles of dynamic interactions in systems have been developed far enough to become practical and useful in dealing with systems of people.

Around the system principles discussed in this book it should be possible to structure our confusing observations about political and business systems. When a structure and governing principles for systems have been accepted, they should go far to explain the contradictions, clarify the ambiguities, and resolve the controversies in the social sciences. A systems structure should give to education in human affairs the same impetus that the structure of physical laws has given to technology. The social sciences should become easier to teach if they can rest on a body of principles that are common to all systems, be they human systems or technical systems. In the concepts of systems we should find a common foundation that underlies and unites the "two cultures" of the sciences and humanities. Education in many areas should be accelerated. As Bruner says, "structure.....is able to narrow the gap between 'advanced' knowledge and 'elementary' knowledge."

This book deals with the structure and principles of systems giving special emphasis to systems in economics and industrial organization and assembled into a unified structure. Without a structure to interrelate facts and observations, it is difficult to learn from experience, it is difficult to use the past to educate for the future.

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to systems that combine people, finance, and technology.

(See Section W1.2 of the accompanying Workbook)

1.3 Systems--Open and Feedback

Systems can be classified as "open" systems or "feedback" systems.

An open system is one characterized by outputs that respond to inputs but where the outputs are isolated from and have no influence on the inputs. An open system is not aware of its own performance. In an open system, past action does not control future action. An open system does not observe and react to its own performance. An automobile is an open system which by itself is not governed by where it has gone in the past nor does it have a goal of where to go in the future. A watch, taken by itself, does not observe its own inaccuracy and adjust itself--it is an open system.

A feedback system, which is sometimes called a "closed" system, is influenced by its own past behavior. A feedback system has a closed loop structure that brings results from past action of the system back to control future action. One class of feedback system--negative feedback--seeks a goal and responds as a consequence of failing to achieve the goal. A second class of feedback system--positive feedback--generates growth processes wherein action builds a result that generates still greater action.

A feedback system controls action based on the results from previous action. The heating system of a house is controlled by a thermostat which responds to the heat previously produced by the furnace. Because the heat already produced by the system controls the forthcoming generation of heat, the heating system represents a negative feedback system that seeks the goal of proper temperature. A watch and its owner form a negative feedback system when the watch is compared with the correct time as a goal and is adjusted to eliminate errors. An engine with a governor senses its own speed and adjusts the throttle to achieve the preset speed goal--it is a negative feedback system. Bacteria multiply to produce more bacteria which increase the rate at which new bacteria are generated. In this positive feedback system the generation rate of new bacteria depends on the bacteria accumulated from past growth of bacteria.

Whether a system should be classified as an open system or a feedback system is not intrinsic to the particular assembly of parts but depends on the observer's viewpoint in defining the purpose of the system.

The way in which the purpose of the system determines whether it is an open or a feedback system can be illustrated by considering a gasoline engine in terms of a series of viewpoints.

1. The engine, operating without a governor, has no goal for speed. It is an open system in terms of speed regulation. Changing the throttle will change the speed but the speed has no effect on the throttle. Furthermore, changes in load will change the speed without causing a throttle adjustment.

2. Adding a governor produces a feedback system in terms of a constant-speed goal. Changes in load cause changes in speed which produce a compensating change in throttle setting as the governor tries to hold the speed for which it has been set.

3. But suppose the engine is part of a lawn mower and we change the goal from constant-speed operation to a goal of mowing the lawn. Now, from the broader purpose of cutting grass, the lawn mower is an open system because it has no awareness of what grass has been cut or where to cut next.

4. By adding the person operating the lawn mower, we again see a feedback system in terms of the goal of cutting a particular lawn. The operator and mower form a feedback system (that is, a goal seeking system) rather than an open system (that is, one not striving for an objective) because the guidance of the mower is in accordance with the pattern of grass already cut.

5. But if the viewpoint is broadened again to that of the owner of a lawn-care enterprise with a goal of meeting his customer demands, the operator and his lawn mower are properly considered a component of a larger management system. As such, the operator and his equipment represent an open system that is undirected in its sequence of separate tasks.

6. By adding the management function, instructions arising from customer requirements are introduced as a guide. In terms of the goal of properly scheduled work, the operator, equipment, and owner must be taken together to form a feedback system for the purpose of serving customer lawn-care needs.

A broad purpose may imply a feedback system having many components. But each component can itself be a feedback system in terms of some subordinate purpose. One must then recognize a hierarchy of feedback structures where the broadest purpose of interest determines the scope of the pertinent system.

This book is devoted to the theory, principles, and behavior of feedback systems. It is in the positive feedback form of system structure that one finds the forces of growth. It is in the negative feedback, or goal-seeking, structure of systems that one finds the causes of fluctuation and instability.

(See Section W1.3 of the accompanying Workbook)

1.4 The Feedback Loop

The basic structure of a feedback loop appears in Figure 1.4a. The feedback loop is a closed path connecting in sequence a decision that controls action, the level* of the system, and information about the level of the system, the latter returning to the decision-making point.

*The term "level" is used in this book to mean a state or condition of the system.

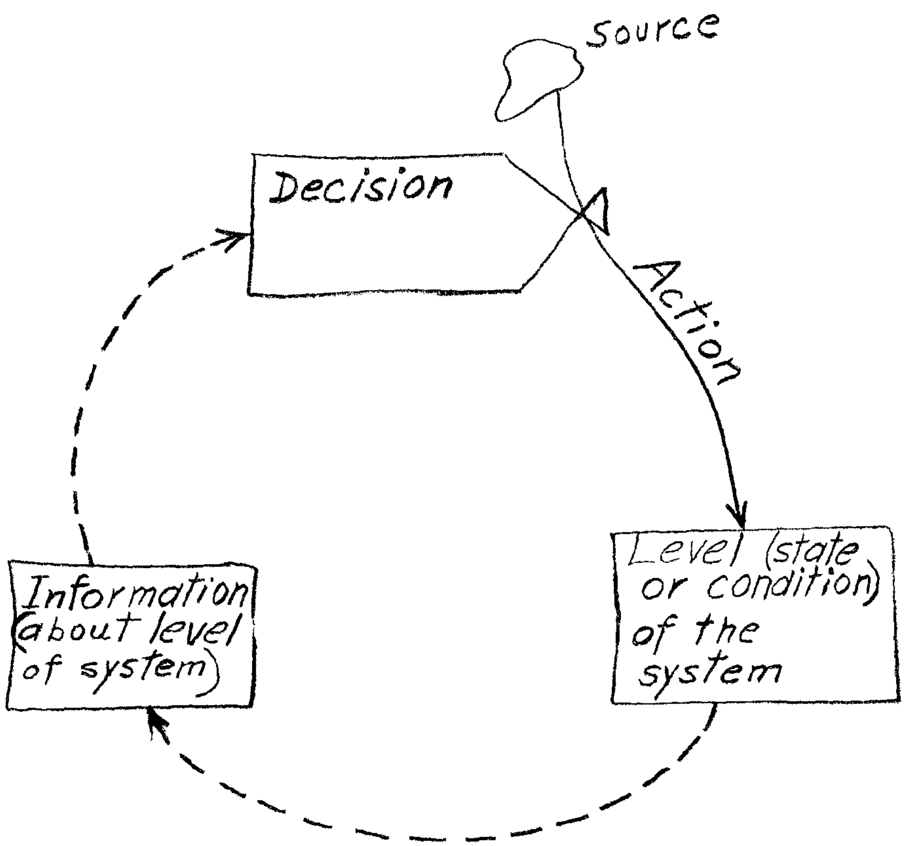

Figure 1.4a Feedback loop.

The available information, as it exists at any moment, is the basis for the current decision that controls the action stream. The action alters the level of the system. The level (true level) of the system is the generator of information about the system, but the information itself may be late or erroneous. The information is the apparent level of the system which may differ from the true level. It is the information (apparent level), not the true level, that is the basis for the decision process.

The single-loop structure of Figure 1.4a is the simplest form of feedback system. There may be additional delays and distortions appearing sequentially in the loop. There may be many loops that interconnect.

Ordering replacement goods to maintain an inventory in a warehouse illustrates the circular cause-and-effect structure of the feedback loop as in Figure 1.4b.

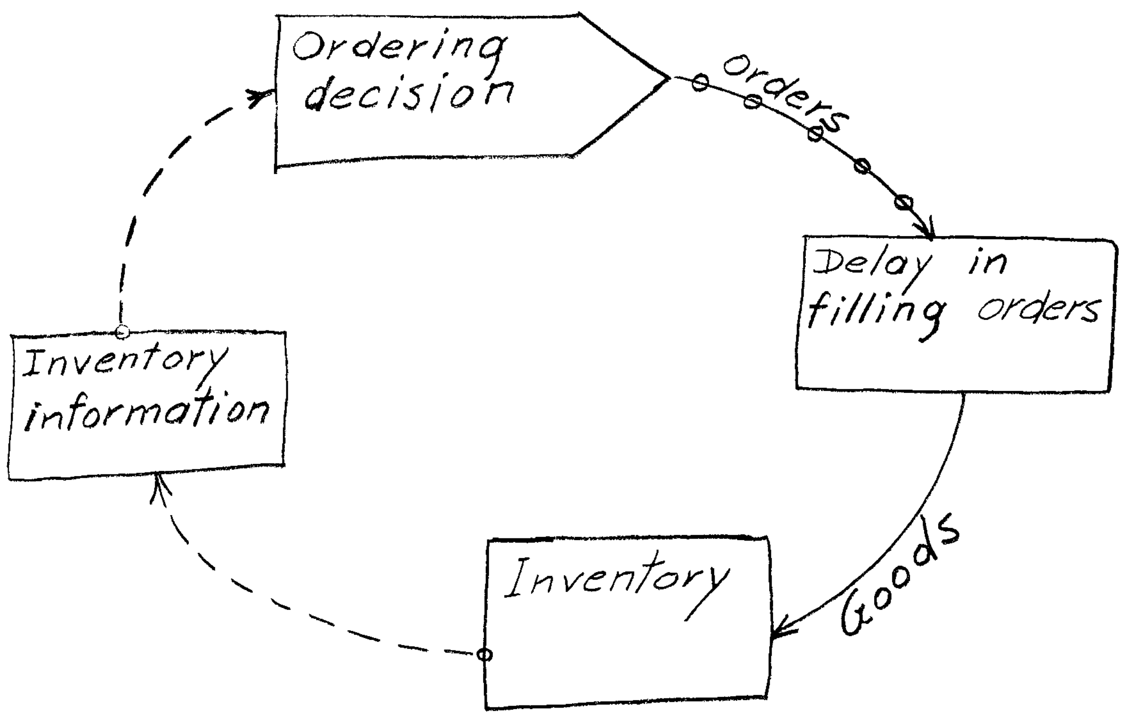

Figure 1.4b Inventory ordering loop.

Here the ordering decision generates a stream of orders to the supplier. The supplier, after a delay to ship or to manufacture, delivers the goods to the inventory. The inventory is the source of information about the inventory, but that information may contain errors and may be delayed so that it does not always reflect the true present level of the inventory. The information about inventory is the input on which the ordering decision is based. (In a more complete system there can, of course, be other inputs to the ordering decision.) The inventory-control loop is in continuous operation. Changes can be occurring at all times at each point around the loop.

The present action stream corresponds to the present decision that in turn depends on the present information. However, the present level of the system does not depend on the present action but is instead an accumulation from all past actions. For example, consider a tank that is being filled with water. The height of the water is the system level. The level depends on the accumulation produced by the past flow of water but the level is not determined by how fast water is being added at the present instant. A large stream into an empty tank does not imply a full tank, an already filled tank is not affected if the flow ceases entirely.

Information is itself one of the levels of the system (referred to earlier as apparent level). The information changes as it becomes evident that the information differs from the true variable that it is presumed to represent. Information is not determined by the present true condition, which is not instantaneously nor exactly available, but instead by the past conditions that have been observed, transmitted, analyzed and digested. The discrepancy between a true system level and the information level that governs decisions always exists in principle. As a practical matter, the information is sometimes good enough that no distinction is necessary between true and apparent level.

(See Section W1.4 of the accompanying Workbook)