

History of Systems Science

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This article is part of the Systems Science knowledge area (KA). It describes some of the important multidisciplinary fields of research comprising systems science in historical context.

Systems science is an integrative discipline which brings together ideas from a wide range of sources which share a common systems theme. Some fundamental concepts now used in systems science have been present in other disciplines for many centuries, while equally fundamental concepts have independently emerged as recently as 40 years ago (Flood and Carson 1993).



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The “Systems Problem”

Questions about the nature of systems, organization, and complexity are not specific to the modern age. As International Council on Systems Engineering (INCOSE) pioneer and former International Society for System Sciences (ISSS) President John Warfield put it, “Virtually every important concept that backs up the key ideas emergent in systems literature is found in ancient literature and in the centuries that follow.” (Warfield 2006.) It was not until around the middle of the 20th Century, however, that there was a growing sense of a need for, and possibility of a scientific approach to problems of organization and complexity in a “science of systems” per se.

The explosion of knowledge in the natural and physical sciences during the 18th and 19th centuries had made the creation of specialist disciplines inevitable: in order for science to advance, there was a need for scientists to become expert in a narrow field of study. The creation of educational structures to pass on this knowledge to the next generation of specialists perpetuated the fragmentation of knowledge (M’Pherson 1973).

This increasing specialization of knowledge and education proved to be a strength rather than a weakness for problems which were suited to the prevailing scientific methods of experimental isolation and analytic reduction. However, there were areas of both basic and applied science that were not adequately served by those methods alone. The systems movement has its roots in two such areas of science: the biological-social sciences, and a mathematical-managerial base stemming first from cybernetics and operations research, and later from organizational theory.

Biologist Ludwig von Bertalanffy was one of the first to argue for and develop a broadly applicable scientific research approach based on **Open System Theory** (Bertalanffy 1950). He explained the scientific need for systems research in terms of the limitations of analytical procedures in science.

These limitations, often expressed as emergent evolution

or "the whole is more than a sum of its parts," are based on the idea that an entity can be resolved into and reconstituted from its parts, either material or conceptual:

This is the basic principle of "classical" science, which can be circumscribed in different ways: resolution into isolable causal trains or seeking for "atomic" units in the various fields of science, etc.

He stated that while the progress of "classical" science has shown that these principles, first enunciated by Galileo and Descartes, are highly successful in a wide realm of phenomena, but two conditions are required for these principles to apply:

The first is that interactions between "parts" be non-existent or weak enough to be neglected for certain research purposes. Only under this condition, can the parts be "worked out," actually, logically, and mathematically, and then be "put together." The second condition is that the relations describing the behavior of parts be linear; only then is the condition of summativity given, i.e., an equation describing the behavior of the total is of the same form as the equations describing the behavior of the parts.

These conditions are not fulfilled in the entities called systems, i.e. consisting of parts "in interaction" and description by nonlinear mathematics. These system entities describe many real world situations: populations, eco systems, organizations and complex man made technologies. The methodological problem of systems theory is to provide for problems beyond the analytical-summative ones of classical science. (Bertalanffy 1968, 18-19)

Bertalanffy also cited a similar argument by mathematician and co-founder of information theory Warren Weaver in a 1948 American Scientist article on

“Science and Complexity.” Weaver had served as Chief of the Applied Mathematics Panel at the U.S. Office of Scientific Research and Development during WWII. Based on those experiences, he proposed an agenda for what he termed a new “science of problems of organized complexity.”

Weaver explained how the mathematical methods which had led to great successes of science to date were limited to problems where appropriate simplifying assumptions could be made. What he termed “problems of simplicity” could be adequately addressed by the mathematics of mechanics, while “problems of disorganized complexity” could be successfully addressed by the mathematics of statistical mechanics. But with other problems, making the simplifying assumptions in order to use the methods would not lead to helpful solutions. Weaver placed in this category problems such as, *how the genetic constitution of an organism expresses itself in the characteristics of the adult, and to what extent it is safe to rely on the free interplay of market forces if one wants to avoid wide swings from prosperity to depression.* He noted that these were complex problems which involved “analyzing systems which are organic wholes, with their parts in close interrelation.”

These problems-and a wide range of similar problems in the biological, medical, psychological, economic, and political sciences-are just too complicated to yield to the old nineteenth century techniques which were so dramatically successful on two-, three-, or four-variable problems of simplicity. These new problems, moreover, cannot be handled with the statistical techniques so effective in describing average behavior in problems of disorganized complexity [problems with elements exhibiting random or unpredictable behavior].

These new critical global problems require science to make a third great advance,

An advance that must be even greater than the nineteenth-century conquest of problems of simplicity or the twentieth-century victory over problems of disorganized complexity. Science must,

over the next 50 years, learn to deal with these problems of organized complexity [problems for which complexity “emerges” from the coordinated interaction between its parts]. (Weaver 1948.)

Weaver identified two grounds for optimism in taking on this great challenge: 1.) developments in mathematical modeling and digital simulation, and 2.) the success during WWII of the “mixed team” approach of operations analysis, where individuals from across disciplines brought their skills and insights together to solve critical, complex problems.

The importance of modeling and simulation and the importance of working across disciplinary boundaries have been the key recurring themes in development of this “third way” science for systems problems of organized complexity.

The Development of Systems Research

The following overview of the evolution of systems science is broadly chronological, but also follows the evolution of different paradigms in system theory.

Open Systems and General Systems Theory

General system theory (GST) attempts to formulate principles relevant to all open systems (Bertalanffy 1968). GST is based on the idea that correspondence relationships (homologies) exist between systems from different disciplines. Thus, knowledge about one system should allow us to reason about other systems. Many of the generic system concepts come from the investigation of GST.

In 1954, Bertalanffy co-founded, along with Kenneth Boulding (economist), Ralph Gerard (physiologist) and Anatol Rapoport (mathematician), the Society for General System Theory (renamed in 1956 to the Society for General Systems Research, and in 1988 to the International Society for the Systems Sciences).

The initial purpose of the society was *"to encourage the development of theoretical systems which are applicable to more than one of the traditional departments of knowledge ... and promote the unity of science through*

improving the communication among specialists."
(Bertalanffy 1968.)

This group is considered by many to be the founders of **System Age Thinking** (Flood 1999).

Cybernetics

Cybernetics was defined by Wiener, Ashby and others as the study and modeling of communication, regulation, and control in systems (Ashby 1956; Wiener 1948). Cybernetics studies the flow of information through a system and how information is used by the system to control itself through feedback mechanisms. Early work in cybernetics in the 1940s was applied to electronic and mechanical networks, and was one of the disciplines used in the formation of early systems theory. It has since been used as a set of founding principles for all of the significant system disciplines.

Some of the key concepts of feedback and control from Cybernetics are expanded in the Concepts of Systems Thinking article.

Operations Research

Operations Research (OR) considers the use of technology by an organization. It is based on the use of mathematical modeling and statistical analysis to optimize decisions on the deployment of the resources under an organization's control. An interdisciplinary approach based on scientific methods, OR arose from military planning techniques developed during World War II.

Operations Research and Management Science (ORMS) was formalized in 1950 by Ackoff and Churchman applying the ideas and techniques of OR to organizations and organizational decisions (Churchman et. al. 1950).

Systems Analysis

Systems analysis was developed by RAND Corporation in 1948. It borrowed from and extended OR, including using black boxes and feedback loops from cybernetics to construct block diagrams and flow graphs. In 1961, the Kennedy Administration decreed that systems analysis techniques should be used throughout the government to provide a quantitative basis for broad

decision-making problems, combining OR with cost analysis (Ryan 2008).

Systems Dynamics

Systems dynamics (SD) uses some of the ideas of cybernetics to consider the behavior of systems as a whole in their environment. SD was developed by Jay Forrester in the 1960's (Forrester 1961). He was interested in modeling the dynamic behavior of systems such as populations in cities and industrial supply chains. See Systems Approaches for more details.

SD is also used by Senge (1990) in his influential book *The Fifth Discipline*. This book advocates a systems thinking approach to organization and also makes extensive use of SD notions of feedback and control.

Organizational Cybernetics

Stafford Beer was one of the first to take a cybernetics approach to organizations (Beer 1959). For Beer, the techniques of ORMS are best applied in the context of an understanding of the whole system. Beer also developed a **Viable Systems Model** (Beer 1979), which encapsulates the effective organization needed for a system to be viable (to survive and adapt in its environment).

Works in cybernetics and ORMS consider the mechanism for communication and control in complex systems, and particularly in organizations and management sciences. They provide useful approaches for dealing with operational and tactical problems within a system, but do not allow consideration of more strategic organizational problems (Flood 1999).

Hard and Soft Systems Thinking

Action research is an approach, first described by Kurt Lewin, as a reflective process of progressive problem solving in which reflection on action leads to a deeper understanding of what is going on and to further investigation (Lewin 1958).

Peter Checkland's action research program in the 1980's led to an Interpretative-Based Systemic Theory which seeks to understand organizations by not only observing the actions of people, but also by building understandings of the cultural context, intentions and

perceptions of the individuals involved. Checkland, himself starting from a systems engineering (SE) perspective, successively observed the problems in applying a SE approach to the more fuzzy, ill-defined problems found in the social and political arenas (Checkland 1978). Thus, he introduced a distinction between hard systems and soft systems - see also Systems Approaches.

Hard systems views of the world are characterized by the ability to define purposes, goals, and missions that can be addressed via engineering methodologies in an attempt to, in some sense, "optimize" a solution.

In hard system approaches, the problems may be complex and difficult but they are known and can be fully expressed by the investigator. Such problems can be solved by selecting from the best available solutions (possibly with some modification or integration to create an optimum solution). In this context, the term "systems" is used to describe real world things; a solution system is selected, created and then deployed to solve the problem.

Soft systems views of the world are characterized by complex, problematical, and often mysterious phenomena for which concrete goals cannot be established and which require learning in order to make improvement. Such systems are not limited to the social and political arenas and also exist within and amongst enterprises where complex, often ill-defined patterns of behavior are observed that are limiting the enterprise's ability to improve.

Soft system approaches reject the idea of a single problem and consider **problematic** situations in which different people will perceive different issues depending upon their own viewpoint and experience. These problematic situations are not solved but managed through interventions which seek to reduce "discomfort" among the participants. The term system is used to describe systems of ideas, conceptual systems which guide our understanding of the situation, or help in the selection of intervention strategies.

These three ideas of "problem vs. problematic situation," "solution vs. discomfort reduction," and "the system vs. systems understanding" encapsulate the differences between hard and soft approaches (Flood and Carson 1993).

Critical Systems Thinking

The development of a range of hard and soft methods naturally leads to the question of which method to apply in what circumstances (Jackson 1989). Critical systems thinking (CST), or **critical management science** (Jackson 1985), attempts to deal with this question.

The word **critical** is used in two ways. Firstly, critical thinking considers the limits of knowledge and investigates the limits and assumptions of hard and soft systems, as discussed in the above sections. The second aspect of critical thinking considers the ethical, political and coercive dimension and the role of system thinking in society; see also Systems Approaches.

Service Science and Service Systems Engineering

The world economies have transitioned over the past few decades from manufacturing economies that provide goods, to service based economies. Harry Katzan defined the newly emerging field of service science: "Service science is defined as the application of scientific, engineering, and management competencies that a service-provider organization performs that creates value for the benefit of the client or customer" (Katzan 2008, vii).

The disciplines of service science and service engineering have developed to support this expansion and are built on principles of systems thinking but applied to the development and delivery of service systems.

Service Systems Engineering is described more fully in the Service Systems Engineering KA in Part 4 of the SEBoK.

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