SYSTEMS ANALYSIS AND MODELING OF INTEGRATED WORLD SYSTEMS

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Keywords: Systems modeling, Systems analysis, Systems principle, Systems concept, Systems philosophy, Systems approach.

Contents

Organisms as systems exist in a state of constant change, resembling flames rather than crystals.

(L. Bertalanffy)

Summary

The problems of development in the modern world are important and complex. They need approaches that can provide plausible solutions. The systems approach to global problems holds much promise and may be used to gain an understanding of the global processes: social, economic, technical, ecological, and so on. Advances in systems philosophy, general systems theory, and systems analysis that occurred during the second half of the twentieth century, are useful for finding solutions to a wide range of important problems at a qualitative level.

Methods of mathematical modeling and computer simulation that were originally developed for studying physical processes and human-made systems are effective tools for the quantitative analysis of systems. Rapid advances in cybernetics, computing techniques, and the various subject fields are now allowing scientists to model highly sophisticated problems of regional and global development. Until recently this activity was limited to hypothesis testing, revealing hidden behavior, claims, and criticism. In future a theory should be developed dealing with understanding of models' similarity, and considerable efforts must be put into developing realistic models and to applying them to solve many of the pressing problems of development, and the need to protect ecosystems.

1. Introduction

In different spheres of modern life (production, culture, science, and so on), all of us have to confront various problems. In our efforts to handle and manage them, we must study their structure, gain insight into their behavior, and take appropriate decisions. In this process the keyword is "system." Notions (scientific concepts, disciplines, and associated tools) such as "general systems theory," "systems philosophy," "systems approach," "systems analysis," "systems synthesis," "systems studies," and "systems modeling" have been developed for the purpose. There are different views about their value with respect to their nature, role, significance, and relevance. According to some, they are of great importance, while others consider them trivial and doubt their usefulness. There are some who do not even recognize their existence, especially in the case of systems philosophy. The purpose of this article is to outline the essential concepts so as to provide an overall perspective of the subject, avoiding arguments on these diverse points of view.

2. Philosophical and General Theoretical Foundation of Systems Analysis

It is now possible to take decisions in unfamiliar situations, especially global ones, within the framework of systems thinking. Fundamental works in this field are: *General System Theory* by L. von Bertalanffy (1945), *Cybernetics* by N. Wiener (1948), and the work on 'Praxiology' done by T. Kotarbinski during the 1930s and 1940s.

First let us consider the concept of a system. A *system* is usually considered to be *a complex of interconnected components that forms a whole, or a set of objects in a state of interaction.* Depending on the nature of the objects included and a number of other factors, systems can be classified in various ways. Considering common features at a certain high level, systems are often divided as follows (depending on the basis chosen for classification):

- Natural (created by nature) and artificial (human-made)
- Closed (do not exchange energy, matter, or information with their environment) and open (exchange energy, matter, and information with their environment)
- Static (time invariant structure and characteristics) and dynamic (structure and characteristics can change over time)
- Manageable (where it is possible to change characteristics of the system on the whole or its components—subsystems, objects, elements—at the expense of artificially created impacts) and unmanageable
- Stable and unstable (depending on the behavior in the system caused by a disturbance).

However, a range of other classifications is also used. For example, systems may be termed technical, social, economic, and so on, according to the nature of their activity. They may be called simple or complex, depending on the quantity and character of inter-relations between the components, as well as with their environment.

General systems theory was developed between 1930 and 1960 by Ludwig von Bertalanffy in direct connection with his researches in biology. From a philosophical point of view he was not satisfied with the extreme approaches towards the end of the 1920s: *mechanism* because of its faulty logic in explaining natural phenomena, and *vitalism* because of what seemed to him an irrational world-view during the course of its study. Bertalanffy embarked on the formulation of theoretical biology on the basis of the ideas of organisms by combining the concept of wholeness (inherent in *vitalism*, too, but with a different meaning)—the priority of the integral properties of a system over the properties of its components—and the analytical apparatus of statistical thermodynamics (inherent in *mechanism*), thereby making it possible to describe and integrate properties of the aggregate of the objects. This approach permitted him first to formulate open systems theory in the 1930s and then, in the late 1940s and early 1950s, to come forward with a program for constructing a general theory of systems. Apart from pragmatically pursuing the goals of his study of biological objects, which was perhaps his primary interest, Bertalanffy paid considerable attention to philosophical comprehension of a new approach. *Systems philosophy* and *systems principle* form the core of this approach.

Systems philosophy: This term was introduced around the 1970s by E. Laszlo, a professor of philosophy at New York University. In his opinion the essence of systems philosophy is the recognition of, first, holism as methodology and ontology, second, integration of scientific knowledge as the ideal which ought to be aspired to, third, the unity of nature as a philosophical setting, and fourth, humanism as a goal of science. Sharing these ideas for the most part, Bertalanffy thought that systems philosophy consisted of three relatively independent parts: *systems ontology*, *systems gnosiology*, and *systems value theory*. By embracing nearly all essential scientific philosophical bases in this way he seems to have exaggerated the philosophical importance of the systems concept. Nevertheless, general systems theory, along with other significant scientific achievements of the same period such as cybernetics, information theory, modeling theory, and so on, has inspired fruitful research in practically all the most important directions of science, including in systems philosophy itself (by M.Bunge, A. Buhm, A.Rupoport, I. Blauberg, V.Sadovsky, and E. Yudin among others). It has also been effectively applied in all developed countries. As a result, despite the lack of universal acceptance of the scientific point of view and the absence of a uniform nomenclature, it is still possible nowadays to speak about the existence of a systems concept, because it provides useful solutions to problems in various spheres of human activity (scientific, socio-economic, ecological, etc.) and particularly in tasks related to energy supply, transport, rural economy, and other fields.

Systems concept. This contains several important elements of systems character. As it is still at a stage of intensive development many aspects are not defined fully. Their structure too is far from being robust and many questions are still debated. Nevertheless, based on an understanding of the essential sense of these elements, the following definitions can be made.

Systems principle (the principle of systemacity) is the core of systems philosophy. It suggests considering the set of objects (phenomena and processes) in question from the point of view of general systems theory, while reflecting, first of all, peculiarities of the ratio of the whole and parts within the limits of the systems, as well as their interaction with the environment.

The main aspects of the systems principle are the following:

- Focus on the wholeness of systems
- Interrelations of the whole and the parts within a system
- Primacy of the whole over the parts
- Hierarchical structure of complex systems
- Interactions of an object within the system with the others
- Availability of the whole environment and its influence on the system under study
- Dynamism of systems, their structure and features of their elements
- Possible ambiguity of the state and behavior of the environment and systems under consideration in future
- Stability of complex systems to the uncertainties
- Self orientation and self-regulation of systems towards high efficiency of performance through their functions.

Thus, systems principle, on the one hand, differs greatly from the well-known classical principles that form the basis of mechanism, physicalism, biologism, and others, in which it is peculiar to meet conditions of an exception of the above aspects prohibited by the appropriate laws (Roden's principle: cutting off all the unnecessary) and sufficiency of "pure experiments"—deduction can give the rest (the principle of local experiment). On the other hand, it proceeds from the possibility of development of systems, with an objective related to the improvement of their dynamic stability and efficiency in terms of uncertainty of changes in the environment that have a substantial influence on them. Dynamic resistance, a property of systems that preserves their ability to realize their main function efficiently (perhaps changing structure, parameters of the components, and so on), will also be implied. Efficiency is estimated with respect to "the cost" of the realization of a function and the total cost and results of the activity of the systems.

Systems approach. This is a methodological approach based on particular scientific cognition and social and economic practice. The approach considers the objects as systems and is based on the systems principle. In particular, it proceeds with the understanding that the properties of the whole, as a rule, differ from those of the aggregate of its components. It recognizes the existence, alongside direct (internal) and indirect (external) impacts in the systems, of synergetic effects of the interaction of the components (emergent effects, namely the impacts of integrity, effects of concentration, agglomeration, and so on). It also recognizes that the future state and behavior, especially of complex real world systems, are in any case unpredictable, thus giving ample opportunities for adaptive management, which is very important from a practical point of view. Certainly, along with all this, reasonable rules of optimization should be observed, in particular, W.R. Ashby's Law of Necessary Diversity, which provides a potential choice of rational managerial impact: "Diversity of a controlling object should be higher than that of the controlled one." From this point of view, Aurelio Peccei, a founder of the Club of Rome and its first President, characterized the systems approach succinctly: "A keen demand for systems approach is dictated by the complex character of the modern world itself, as interconnections of separate components are often more important than the components themselves."

Systems modeling: This is a description of a system under study with the help of a certain language, based on the requirements of the systems approach. Since mathematical language is very convenient for such description, in most cases we can speak about mathematical systems modeling.

Systems analysis: This is a branch of science whose goal is to use, on the basis of systems approach, the existing methodological means (and to elaborate new ones) of studying complex natural systems in order to understand how they function, and to analyze artificial systems for the purpose of development through effective solutions. In order to understand systems analysis and the specific methods of its application systems research, we can compare it with traditional scientific methods, such as those applied in natural sciences. It is well known that their validity is determined by the fact that in most cases they have the following premises:

- The possibility of accurate testing of the underlying assumptions
- The repeatability and strict recurrence of the results
- Objective and unambiguous conclusions, which are free from the personal prejudices and interests of the researcher.

In systems analysis, particularly applied to the tasks of social and economic character in which weakly structured elements and weakly formalized factors occur (for example, individuals, collectives, societies as a whole) those premises (as a rule) do not apply, for the following reasons: the information used may be incomplete or unreliable; the decision-makers may not fully understand the purposes or methods of the study; it may be impossible to take into account all influential factors because of their complexity, lack of knowledge and so on. Therefore, systems analysis takes account of the "human factor" as an important element. Factors such as human intuition and human–machine procedures in searching for optimal or rational decisions give rise to a system of "object and subject unity."

3. Methodological Fundamentals of Applied Systems Analysis

3.1. General Scheme of Applied Systems Analysis

Applied systems analysis: This is an application of systems analysis methodology for solving a variety of complex problems (political, technical, social, economic) of human activity. Often, in reality, the need to allocate resources for the implementation of decisions may somehow shift the emphasis from clearly defined purposes to simply achieving the most effective results. There is a need for a deeper systems study of the specificity of objects, consideration of possible alternatives of their behavior and development, valid models, estimates, and mechanisms for the implementation of decisions.

In conformity with the aims under consideration, general principles of carrying out systems analysis are being concretized to yield meaningful results. In this context the analysis has to meet the requirements set out below. To help gain an understanding of these requirements, consider for example the problem of providing normal life-supporting conditions at global, regional, and local levels by means of production and infrastructure systems (energy, transport, and so on):

- It is necessary to consider the complexity of infrastructural systems, which generally consist of a great number of interconnected net elements, of many different types. The interaction of individual subsystems among themselves, the presence of their own "interests," aims, and criteria of estimate, socio-economic mechanisms of functioning, etc. give rise to considerable synergetic effects. In such systems, too great a focus on local profits of the subsystem could result in unprofitable decisions for the whole system and, ultimately, for many people. Therefore, it is necessary to have an appropriate mechanism to co-ordinate "interests" whose parameters can be adjusted to provide a consensus and decisions profitable for all the participants.
- Consideration of the hierarchy (multilevel character) of infrastructural systems and subsystems, and its temporal and spatial consequences in various aspects, gives rise to the need for systems co-ordination in all aspects: appropriate aggregation and disaggregation of parameters and characteristics of functioning and development of infrastructural subsystems at different hierarchical levels, and the choice of criteria and efficiency indices that have a single hierarchical directivity.
- One must consider the manageability of infrastructural subsystems at all hierarchical levels in order to choose the path for the most efficient achievement of the stated aims. Taking decisions that provide movement along the most profitable trajectory can be aided simultaneously by the descriptive and prescriptive aspects of systems analysis, helping to change the state and behavior which exist to those which should exist.

- A dual approach to the analysis of the infrastructural systems is required. This means on the one hand, considering them as relatively independent dynamic systems, developing according to their own regularities, and on the other, as integral parts of a more general socio-economic system, which they serve.
- Systems analysis makes use of models both according to their internal description (i.e. when processes that take place in systems are studied directly, dynamic characteristics of these processes are determined by their structure and parameters), and according to their external description ("black box" models and causal "input–output" models).
- A comprehensive study is needed of the different (social, economic, and other) consequences of the decisions taken, not only in infrastructural systems themselves, but also in the other related systems such as supply of resources, product (services) consumers, accounting for the uncertainty of those consequences in future, due to the ambiguity of possible "states of nature," as well as to the "man-machine" character of the decision process, and even infrastructural systems themselves.

A more or less typical scheme of applied systems analysis includes the following stages.

- Problem exposure, statement, formulation and organization.
- Study of the specificity of the problem (process, object) in question, its internal and external connections in temporal, spatial, structural, and other necessary aspects.
- Analysis of the main structural elements of the problem at a qualitative level.
- Specification of the aims and criteria, determination of their hierarchical interconnections, and deciding on the possibilities of ranking and quantitative estimate.
- Determination of possible alternative ways to achieve the aims and the most important limitations and mechanisms necessary for stable functioning in unforeseen circumstances.
- Acquisition of initial data, evaluation of the data for completeness and authenticity, possibilities of data renewal and quality enhancement.
- Construction of models, quantitative analysis of the main structural elements, determination of characteristics connected with alternatives and related to the total (including not only direct and indirect components but also synergetic ones).
- Carrying out calculations according to the models, synthesis of quantitative and qualitative analysis results, introducing expert corrections and preparation of decisions and, if necessary, correction of the models, initial data, repeated calculations, and synthesis of the results.

From the given scheme it is clear that systems analysis procedure has an iterative character with multiple mutual co-ordination of the intermediate results according to systems considerations. In other words, during the process of systems analysis systems synthesis is also taking place.

Systems research: This is the study of various complex problems by methods of systems analysis, on the basis of systems principle and using the systems approach as the methodology. As the main tool, especially under solving practical tasks, systems modeling and corresponding mathematical methods are applied.

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