

Philosophy of Socio-Technical Systems

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1. Introduction: The Meaning of the Key Words

The notion of the *socio-technical system* was created in the context of labor studies by the Tavistock Institute in London about the end of the fifties (Emery/Trist, 1960). During the first decades of our century, labor studies had been largely concerned with the adaptation of humans to the organizational and technical framework of production; I just mention well known names such as Frederick Winslow Taylor or Henry Ford. In the thirties already, it is true, some researchers, like Elton Mayo (1946) and others in their famous Hawthorne studies, discovered the so-called human factor in industrial relations, but they mainly focused on individual psychology. Although these findings seemed to disprove the idea of technological determinism, in labor studies and industrial sociology, nevertheless, this idea remained prevalent for a long time. Technology was considered to be the independent, more or less autonomous variable; the mental and social conditions of human work had to follow the given technical structures and could be improved just marginally in one or the other case.

The concept of the socio-technical system was established to stress the reciprocal interrelationship between humans and machines and to foster the program of shaping both the technical and the social conditions of work, in such a way that efficiency and humanity would not contradict each other any longer. The notion of the system, on the other hand, was used very consciously according to general systems theory, which I am going to explain in the next paragraph. Here it may be sufficient to say that this research program aims at understanding the complexity of real situations rather than at analyzing separated aspects. So the idea of socio-technical systems was designed to cope with the theoretical and practical problems of working conditions in industry. Widening this idea, I suggest that we regard the socio-technical system as the theoretical construct for describing and explaining technology generally (Ropohl, 1979). In the following paragraphs I am going to supply a brief outline of this approach.

There is, however, another key word in my title, the word *philosophy*. Nobody, of course, will expect me to give an exhaustive explication of this confusing concept in a couple of sentences. Instead of trying any definition, I should like to introduce a distinction, which seems crucial to me. Roughly speaking, there are two kinds of philosophy: (i) a philosophy of philosophy and (ii) a philosophy of the world. The first, busy with book learning, supplies the three-hundred-thirty-third interpretation of Aristotle and Hegel and does not refer to anything else than to its own web of reasoning. Of course, I do not deny that it may be fruitful to read the classical writers, particularly, when it is done with regard to topical questions. But exactly this is the essence of a realistic philosophy: "its very age comprehended in thought" (Hegel, 1833, preface). Remember, however, that our age is different from that of Hegel.

A philosophy that aims at comprehending the present age in thought must not neglect science and technology. Thinking is nourished by knowledge, and most of our knowledge nowadays originates from science; thinking is nourished by practice as well, and most of human practice nowadays is affected by technology. So science and technology are not only worthy objects, but, above all, indispensable sources of timely philosophy. Specialized sciences have neglected the context of comprehensive understanding (Husserl, 1936), and they are unable to synthesize heterogeneous knowledge with regard to practical problems. So everybody cries for

interdisciplinarity; but hardly anyone is aware of the theoretical point of interdisciplinary integration. I will bring it to the point. This is exactly the mission of a realistic philosophy of the world.

Even the most common approach for dealing with interdisciplinary contexts—I mean systems theory—was established in philosophy first. So I start with a brief survey of systems theory; then I shall apply its basic notions to socio-technical systems; and last I shall report on some results suggested by the systems point of view.

2. General Systems Theory

2.1 Origins

As far as I know, a complete history of systems thinking has not been written yet. To be sure, there are several references to precursors. So let me just mention some ancient names and some recent originators. First, there is Aristotle, who does not use the word *system* (although it is a Greek word), but specifies the *holon*, the whole, as opposed to the *pan*, the *multiplicity*; in explaining the whole, Aristotle, however, states the well-known principle of systems thinking that the whole is characterized not only by its parts, but by the relations between the parts as well (*Metaphysics*, 1024a). Then there is a rather unknown author, who has written important essays on the concept of system: J. H. Lambert (1782, pp. 510ff; 1787, pp. 385ff) applies the notion of the system to theoretical thinking first, as was usual at that time, but later on he gives a more general explication, defining the system as "a whole composed by parts in a purposeful way." Moreover, he offers a classification of systems including natural phenomena such as the solar system, but also societies, buildings, and machines. This was forgotten for a long time, until modern systems research rediscovered this remarkable thinker. Last there is a name, among the early approaches, I will just mention. I am convinced that Hegel's dialectics, understood adequately, is a manifestation of systems theory; but, of course, I cannot substantiate this idea in a few words (Ropohl, 1997).

Among recent approaches, Ludwig von Bertalanffy (1949) has to be acknowledged as the real originator of modern system studies. Norbert Wiener (1948), on the other hand—when founding cybernetics—did not stress the concept of system, but later on his ideas about control and communication proved to be important characteristics of complex systems. Mathematical descriptions of a system, which Bertalanffy still tried to give in terms of the infinitesimal calculus, work much better in terms of set algebra, following the Bourbaki school. Sociological thinking, too, has been approaching the idea of systems, even if the respective terms of Talcott Parsons, for instance, are not very precise. In my opinion, the definitions of social systems given by philosopher of science Mario Bunge (1980) far exceed all the sociologists, including the peculiar sophistication of the very German thinker, Niklas Luhmann (1986). At last, I have to mention several praxiological approaches, including systems engineering, computer science, operations research, and others, which on their part have brought forward systems thinking as well. All these fields overlap each other to a considerable extent.

2.2 Basic Concepts and Laws

After having sketched some historical outlines of systems theory, I am now going to present current definitions of the system and its characteristic properties. First, I must stress that, strictly speaking, there exist three different interpretations of the system. The structural concept is known best. According to this view, a system includes a set of elements and a set of relations between these elements; this complies with the ancient definition of the *holon* by Aristotle. A modern

concept, however, is equally important: the functional concept. According to this view, a system is an entity, sometimes called *black box*, which transforms inputs into outputs, depending on specific internal states; the kind of transformation is called a *function* (in the descriptive meaning of the word). In the end, the structural concept may turn into the hierarchical concept, if the elements are regarded as *subsystems*. Concluding by analogy, the original system may be considered as a subsystem of a more extensive *supersystem*.

For a time, these three concepts existed in separation from each other, and led to different and specialized theories. The three approaches, however, may be connected as well and unified within general systems theory. The starting point is the definition of the mathematical system, which seems to represent the structural view, but in fact is completely formal and does not imply any substantial contents:

$$MS = \{E, R\}; E = \text{set of elements } e_i; R = \text{set of relations } r_i$$

The formal concept, though, may be interpreted in two ways. First, we get the system's *function*:

$$SF = \{A, F\}; A = \text{set of attributes } a_i; F = \text{set of functions } f_i \subset X \text{ } a_i$$

Second, we receive the system's *structure*:

$$SS = \{K, P\}; K = \text{set of parts } k_i; P = \text{set of relations } p_i \subset X \text{ } k_i$$

This implies a minimal assumption about reality, the assumption that every object in reality that is modelled by systems theory exhibits an "outside" and an "inside," an external behavior and an internal construction. Therefore, the comprehensive definition of the *system* combines the partial definitions and forms a quadruple of sets:

$$S = \{A, F, K, P\}$$

Moreover, the overall definition implies the hierarchical concept as well, as the system in view may be regarded as an element of the superstructure, and every element of the structure in view may be regarded as a subsystem. This way we get the system's *hierarchy*:

$$SH = (\dots, S^+, S, S', \dots); S^+ = \text{supersystem } (S \in K^+); S' = \text{subsystem } (S' \in K)$$

This definition indicates that the hierarchy, considered formally, is open in both directions; for realistic interpretations, of course, there are obvious limits, given by the universe on one side and by the elementary parts of matter on the other. There is a large variety of possible systems, and each type of system will be treated by specific mathematical procedures. All those specialized system theories, however, have their common grounds in the overall definitions given above. Even on this most general level, there exist a few basic laws:

1. The system is more than the set of its elements (because, above all, the set of relations determines the very character of the system).
2. The structure of the system determines its function.
3. The function of the system may be produced by different structures (principle of equifunctionality).

4. The system cannot be described completely on just one level of hierarchy (principle of excluded reductionism).

These laws, of course, will have different consequences in specific scientific applications.

2.3 Epistemological Remarks

Before applying the systems model to the phenomena of technology in society, it seems useful to make sure of the epistemological import of systems theory. There are three polarities to be discussed: (i) unity vs. diversity, (ii) holism vs. atomism, and (iii) model vs. reality.

Unity vs. diversity: Systems theory offers a uniform language for describing and explaining diverse phenomena. Instead of appreciating this advantage, several critics complain that systems theory is no more than a translation from a disciplinary language into a general language. Even if systems theory would not supply anything more, it would deserve acknowledgment just for that reason. Particularly for solving problems in practice it is indispensable to cope with the confusion between different expert languages, and systems theory is a promising candidate for this issue, because it supplies a broad range of expressions, including:

- the formal language of set theory, which may be used for qualitative statements and may be specified in different quantitative methods of mathematical description as well;
- graphic representations, which illustrate complexity much better than unilinear verbal language;
- verbal interpretations of formal and graphic terms, which correspond with specific science languages as the background of rational precision.

So systems theory does not suppress diversity, but it constitutes a new level of unity beyond specialization. Just recently, the notable German philosopher Odo Marquardt (1994, pp. 30ff) claimed to consider the tension between unity and diversity, one compensating for the one-sidedness of the other; unfortunately he failed to take notice of general systems theory, which is appropriate to make precise the dialectics of unity and diversity. Above all, systems theory compensates for the overspecialization in modern science, but, ironically, it is just this overspecialization that seems unable to understand the promising prospects of systems thinking.

Holism vs. atomism: In the history of human thinking there are two principles of dimensioning the scope of cognition:

- generalizing of overall connections and broadening the scope towards the totality of the world;
- specializing in isolated elements and narrowing the scope to the atoms of the world.

These are extreme cases, of course, ideal types in the sense of Max Weber, and the reality of research mostly takes place in between. In modern science, however, the atomistic trends prevail, and from there the complications arise with problem solving and comprehensive understanding. So systems theory turns out to be the holistic compensation for atomistic separatism by grasping the connections and interrelationships between the parts. Totality, to be sure, is just the vanishing point of the holistic perspective, but it indicates the direction of understanding strategies. On the

other side, systems theory does not abolish atomism, but supplies the proper compensation for disintegrating the whole of knowledge.

Model vs. reality: There is one question that has not been settled among systems researchers, the question, what mode of existence may be attributed to the system. Materialism holds that systems are real objects and may be found within the material world. Idealism (and some varieties of so-called social constructivism), on the other hand, state that systems are intellectual products only, ideas of individual persons, shaped more or less by social factors, and without any correspondence to the objective reality. So systems theory shares the issue, which in Marxism has been called "the basic question of philosophy." I tend to give a dialectic answer to that question. The contradiction of materialism and idealism may be cancelled, preserved, and raised in a coincident step (*aufgehoben* in the threefold sense of Hegel), and this step leads to a synthesis such as pragmatic modelism (Stachowiak, 1973) or interpretative constructivism (Lenk, 1993).

Along this line and omitting sophisticated details, I regard systems as human-made models, but in reality there do exist objective entities to which the models correspond. A system is a cognitive map of reality and, therefore, cannot depict everything at a time; the depicted landscape, however, really exists in all its complexity. Models are characterized by three specifications:

- the depicting specification, implying that they are pictures of reality;
- the reducing specification, implying that the picture cannot include every detail of the real world;
- the user-related specification, implying that the scale and the items of mapping are selected dependent on the investigator, on the time and on the purpose of investigation.

Models, to a certain degree, are relative, but this does not mean they are arbitrary. The interpretation, to be sure, cannot be deduced from the formal concepts alone, but has to be supported by results of the respective empirical sciences; methods such as phenomenology or hermeneutics also may be used to fill in concrete contents within the abstract framework. Moreover, the pragmatic character of models suggests that the model builder reflect his activity through a kind of second order model: a model of model building; in a way, this follows from the fourth systems law, the principle of excluded reductionism. Anyway, models have to be theoretically consistent and, as far as applicable, empirically provable.

To summarize this paragraph, systems theory is the synthesis of competing epistemological ideas,

- the synthesis of unity and diversity,
- the synthesis of holism and atomism,
- the synthesis of idealism and materialism.

So systems theory turns out to be the rational completion of well-understood dialectic philosophy.

3. Theory of Socio-Technical Systems

The starting point for designing a theory of socio-technical systems is the observation that hardly anybody has a general understanding of the technical society; this applies to laypeople as well as to specialists. Particularly, engineers tend to ignore the social concerns of their work, and social

scientists, on the other hand, do not know very much about technology and are reluctant to consider the artificial reality of technical objects. That is the reason why I came to systems theory; I needed a powerful tool to bring both sides together. So I take the systems model to describe both social and technical phenomena, persons and machines, the technization of society and the socialization of technology (Ropohl, 1982).

Let us assume an active entity which is called *an action system*. An action system is, unlike the concepts of sociological systems theory, no fictitious system of actions, but an empirical subject of acting, a system that acts. Acting is understood as transforming a starting situation into a final situation according to pre-set goals, or, in the functional terms of systems theory, as a transformation of inputs into outputs dependent on specific internal states (including goals); inputs, states, and outputs can be characterized as matter, energy, or information and occur in space and time. Acting includes, above all, work and communication; work has to be emphasized against certain approaches in sociology which focus on communication only, as if the production structure of societal work could be neglected.

Now let us remember the fourth systems law, the principle of excluded reductionism. This requires us to design a *hierarchy of action systems*. This hierarchy may be justified in substance by the socio-psychological finding that individual acting cannot be understood adequately without regarding the social structures. Within the complete hierarchy three levels are accentuated, the well-known triplet of micro-, meso- and macro-level: the individual, the organization, and the society; all of them may be conceived as action systems in a functional sense. Taking the action system as such, we can, on the other hand, analyze its internal *structure* by identifying certain subsystems which play their role in any action. The execution system performs the transformation of matter and energy; it is the main agency of physical work. Physical work, however, needs informational coordination; this coordination and the communication functions are performed by the information system. Finally, we have to conceive of a goal-setting system, which generates normative guidelines for communication and work. There are significant couplings and feedback loops between the subsystems, which I cannot discuss in detail here. Anyway, I have to mention that each subsystem may be subdivided into sub-subsystems, taking over specific partial functions such as receiving, storing, processing, and so on (Miller, 1978).

Now I am going to make use of the third systems law, the principle of equifunctionality. A great many acting functions, indeed, may be performed by human subsystems as well as by technical subsystems, except for the goal-setting function of course. Therefore, the block scheme of the *technical object system* looks quite similar to the scheme of the action system. So it seems obvious to combine both models, at first just formally, and to get the model of the *socio-technical system*, an action system that relies both on human and technical function carriers. The substantial reason to justify that formal operation is the principle of the division of labor. Division of labor means that acting functions, which originally were united within one action system, now are separated, and each single acting function will be performed by a particular action system. This societal principle has several manifestations: the differentiation of society into diverse sectors, the specialization of professions, or the division of manufacturing labor in industry.

Now I add another manifestation, the *socio-technical division of work*, the distribution of acting functions among humans and machines. This applies, remember, because, to a large extent, technical object systems are equi-functional with human abilities. To summarize these considerations I repeat the structural model of the action system. Most of its subfunctions may be realized either by humans or by technical object systems. So we can transform the abstract action system into a socio-technical system by conceiving object systems for every suitable acting

function and by integrating them into the human acting or working relations. Thus, we obtain a coherent understanding of technology in society.

4. Philosophical Implications

The model of socio-technical systems which I have outlined here is not only an interesting conceptual framework, but suggests a couple of substantial implications which answer some basic questions of the philosophy of technology. Briefly I shall deal with two main issues: first with the question, which forces drive technical development, and then with the problem, why technology changes society.

4.1 Technical Development

The model of realizing socio-technical systems turns out to be the basic model of *technical development*. In a first step, technical development means creating an ever growing number of new technical objects. In a second step, however, we have to keep in mind that object systems represent acting functions and are introduced into human acting relations. So technical development, really, means the formation of novel socio-technical systems. This idea is appropriate to answer both questions mentioned above, but first I shall go more deeply into the genetic issue. For that, the process of realizing the socio-technical system has to be studied in detail. As the realizing process will be performed by an action system as well, the basic model is changed slightly, and the abstract action system is replaced by the socio-technical production system. At a first glance, the production system designs and manufactures just technical objects, but actually it follows a more or less elaborated conception of the socio-technical system, in which the object will take place. In other words, the production system contributes to the formation process.

The production system exhibits activities such as research and development, inventing, innovating, manufacturing, marketing, and maintenance. Now we have to remember the principle of excluded reductionism and its consequence that action systems form a hierarchy. So the production system cannot be understood as an individual person only (except for borderline cases like Robinson Crusoe), but rather as an organization of persons. Moreover, even the organization or corporation is not self-sustainable, but relies on various relations of the overall social system. This applies, above all, to the origins of socio-technical innovation ideas, to economic and social goals, to cultural shaping and governmental interventions. A complete theory of technical development would have to systematize all these factors and their interplay within and across the hierarchy levels (e.g., Huisinga, 1996). Anyway, one finding is obvious already at this stage of investigation. Technical development is no autonomous process with its own law, and it is not only the outcome of isolated intentional actions of individual persons; neither the misconception of a universal technical destiny (Schelsky, 1961) nor the misconception of individuals discovering pre-shaped technical ideas in a Platonic heaven (Dessauer, 1956) can be defended any longer. Technical development is a social process; science and technology are necessary conditions of this process, but they are, by no means, sufficient to determine its performance. As a consequence, an isolated philosophy of technology does not make much sense; rather it must turn to social philosophy, which, obviously includes a philosophy of the economy.

4.2 Social Change

The basic model of forming socio-technical systems will be useful also for explaining the impacts of technology on society. Every invention represents a novel acting function rather than solely a new artifact. There is no invention which would not constitute a novel pattern of human action at

the same time. Object systems introduced into the socio-technical system partly substitute given human functions, and partly add novel acting functions, not feasible by humans. In consequence the states of the human subsystems and the characteristics of socio-technical relations are changing. Every invention is an intervention, an intervention into nature and society. That is the reason why technical development is equivalent to social change. To say it with the words of Karl Marx (1856): "Steam, electricity, and the spinning machine have been revolutionaries much more dangerous than even the citizens Barbès, Raspail and Blanqui." Up to now, all this has taken place in a more or less anarchic way, and the present globalization of capitalism is going to aggravate this situation unless the human race learns to master its own history by approaches such as technology assessment and global policies aimed at sustainable development (Ropohl, 1996).

To clarify these general statements I suggest a closer look at what really is happening with new products. Every technical product—take the pocket calculator for instance—incorporates functions which originally had been personal abilities, knowledge and intentions. What has been inside certain individual persons is externalized and objectified in the technical system, and it is thus generalized beyond the individuals. This process of transindividual generalization of value and behavior patterns is called institutionalization in sociology, and hence, technical development has to be understood as *technical institutionalization*. Institutions (in the abstract meaning), on the other hand, channel and shape the behavior of the individuals, and integrate them into a common culture, an effect which is called socialization in sociology. Formerly, this happened through human communication mainly, but nowadays technical products exhibit the same performance. When utilized within the socio-technical system, they transfer their institutional power to the individual. I call this effect *technical socialization*. What has been transmitted by human communication before, is internalized now through the appropriation of artifacts. To return to the simple example. Everybody who owns a pocket calculator is able to extract the square root of any number, even if he never has learnt the respective calculus.

Utilizing technical products means making use of alien abilities and knowledge, sometimes even to be overwhelmed by alien goals, which may be incorporated in the artifacts as well. So the venerable concept of *alienation* takes on its proper sense. Humans in socio-technical systems are alienated by the transindividual power of artifacts, in principle and regardless of the relations of property. I think this is an important reason for the uneasiness of many people towards the utilization of modern technology. The inconvenience of alienation results from the socio-technical division of labor; it cannot be abolished, but it may be relieved by technological enlightenment (Ropohl, 1998), which aims to accompany the appropriation of artifacts by an appropriation of the appropriate understanding.

This, however, is a genuine mission of philosophy.

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