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1. Introduction

During the last 15 years the use of systems concepts in organizational science has become a habit. It is believed that after the period of terminological contributions of system theory to organizational theory we are entering a second period wherein a paradigm of control will be the most important theme in systems theory as well as in the organizational sciences. Therefore the main part of this chapter will be devoted to the concept of control.

A minor part of the chapter is directed to another theme. Recently critical remarks about systems theory have been formulated. So, for example, Silverman is very critical about this 'Systems frame of reference' (Silverman [1]). Also W.G. Scott confessed in a recent article that he made a mistake when he wrote in 1961 that organizational science should be based on the concept of system (Scott [2,3]).

In order to avoid misunderstandings we will have to make a distinction between several branches of systems theory.

We will argue that much of the critique that is formulated with respect to systems theory in the organizational sciences is directed to one of these branches, to which the paradigm of control does not belong.

2. Confusions about systems theory

Despite the unifying aims of systems theory one must recognize that systems theory itself is anything but unified. It therefore is very important that criticisms about systems approaches be directed to a specified part of systems theory. Most criticisms however are directed to 'systems theory' or 'systems-thinking' without any further specification.

Now I am convinced that there are at least two reasons for this. On the one hand, there is a lack of knowledge within some circles. This is exemplified by the fact that critical articles about systems theory do not contain references to the different branches of systems theory. Silverman's critical study, for example, does not contain any reference to, for instance, Ashby, Mésarovic, Klir, Wiener or any other author in the more exact branch. Especially in the realm of organizational science one must remember that in sociology, a field of extreme importance for organizational science, the concept of system has a long tradition.

Shortening a long story one may say that sometimes systems thinking is identified with a particular way of theorizing in sociology: the structural functionalistic mode of thought. The second reason has to do with a lack of knowledge and shortcomings in circles of systems-theorists.

Some systems-theorists themselves clearly do not know that their work belongs to a specific branch. Also one gets the impression from the literature that some systems theorists have an over-optimistic view about their contributions to organizational science which is based largely upon a lack of knowledge about organizational science.

In order to avoid misunderstandings of the indicated nature one may distinguish four branches within systems theory

1. A philosophical branch.
   The philosophical branch is exemplified by the work of Lazlo [4] who sees systems theory as a new philosophical view of the world.
2. An organismic branch.
   In this branch the work of J.G. Miller [5] may be called representative.
   In this branch systems theory is seen as a general and empirical theory about systems of different kinds. It heavily rests upon biological ways of thinking.
3. An axiomatical branch.
   Herein systems theory is seen as an abstract non-empirical set of concepts and models which may be filled up with empirical content by specific mapping procedures. So here systems theory merely is a kind of modelling box.
   W.R. Ashby [6] may be mentioned to further clarify the character of this branch, which is closer to control theory than to biology.
4. A methodical branch.
   The methodical branch sees systems theory as a new and more convenient means for solving problems.
   R.L. Ackoff is one of the best known representatives of this branch. The methodical branch is relatively close to operational research.

Now what mostly is called systems theory is a specific selection out of one or more of these four branches. The confusion is illustrated very well by comparing the Spring 1975 number of 'Organization and administration sciences' which is devoted largely to systems thinking and the book 'Trends in General Systems Theory' edited by George Klir [7].

We have studied (de Leeuw [8]) the characteristics a helpful systems-theory should have.

We concluded that the axiomatic branch is the best alternative. The control paradigm we will develop belongs to this axiomatic branch. Now structural-functionalistic thinking in organizational theory mostly is confused with systems-theory. This is understandable because the structural-functionalistic mode of thinking comes very close to the organismic branch. And, unhappily, most systems thinking in organizational theory bears an organismic character.

Concluding this paragraph we might say that the critical remarks about systems theory do not purport to the axiomatic branch of systems theory. This axiomatic branch seems to offer the best perspectives. The control paradigm is a contribution from this axiomatic branch.

3. Important problems of organizational science

To say that something is an important contribution to a field implies a view about its most important problems.

Distinguishing a field of organizational analysis and a field of organizational design (the descriptive and the normative part of organizational science), we believe that the theme of control is central to both.

The central problem of the descriptive part is that of integration. The empirical theories of organizations form a jungle of partly contradicting and incoherent insights. This situation is not judged to be comfortable from the scientific point of view. Therefore one of the main problems of organizational science is the problem of integration of its theories, the problem of how to achieve a unified organizational theory.

The central problem of the prescriptive part of organizational science is the problem of coordination.

Organizational design means choosing of organizational structures meeting certain criteria.

It is clear that in the history of organizational design the problem of splitting up the work and coordinating the parts has been most central.

It needs no arguing that nowadays the problem of coordination is even more important.

The paradigm of control may offer important insights to these two problems. The problem of integration of theories and the problem of coordination. There are contributions to other parts of the field but we shall have to concentrate upon these two.

4. Some elements of the paradigm of control

The concept of control has a rather broad meaning in our theory. It refers to any way of purposive influence. To state some examples, one might think of a re-organization, goal displacement, learning to drive a car, ordering materials, influencing the market by the marketing mix, controlling the production, trying to convince someone, designing and so on.

One must remember that especially the growth of cybernetics is most central to this broadening of the concept of control. This broad meaning of the concept of control enables the very broad application of results of system theoretical work about control.

We shall now develop some elements of a paradigm of control. The paradigm of control is a class of abstract systems, each consisting of a controlled part, an environment and a controller. They are, with respect to certain criteria, adapted to each other in a rational way. This class is accompanied by the conviction that for any interesting phenomenon there is a system in the class which can function as a model of it. It is only possible to develop some elements of the theory (see de Leeuw [8], Kramer and de Leeuw [9]). We start with the simple system of Fig.1.

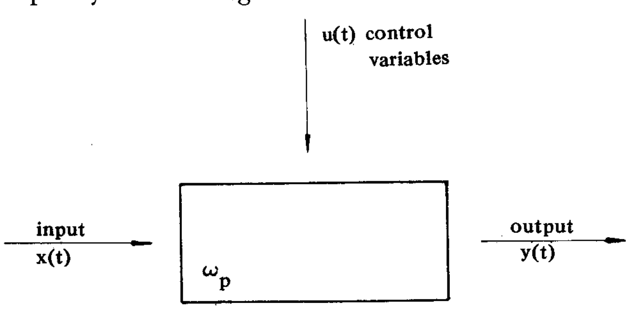

Fig.1 A simple system

Suppose the behavior of the system is described by a relation f

$$f \subset D(x(t)) \times D(u(t)) \times D(y(t))$$

wherein

$D(x(t))$	the input space
$D(u(t))$	the control space
$D(y(t))$	the output space

And, because one cannot talk about control without a goal, we call a certain $G \subset D(y(t))$ the goal of the system ω_p.†

A problem of control now might be defined by:

1. A specification of the system to be controlled.
2. A specification of the goal G.
3. A specification of a certain $X \subset D(x(t))$ as the class of inputs to which the actual inputs during the relevant period of time will belong.

The first step of solving a control problem consists of these three specifications. After the specification of the problem of control one has to look whether it can be solved or not. Thereafter the problem might be solved by designing an appropriate controller.

Thus we have the following three steps:

1. Specification of the problem.
2. The solvability problem.
3. The design of a controller.

We shall further concentrate upon the solvability problem and the problem of the design of a controller.

The solvability problem

The next important concept of control theory in this respect is the controllability concept.

It mostly is defined with respect to the state space. It says that a system is completely controllable if for any two states and for any input signal one can find at least one control signal, which brings the system from the one state into the other within a limited period of time.

Suppose that the behavior of a simple system ω_p is described by the function f

$$f : D(x(t)) \times D(u(t)) \rightarrow D(y(t))$$

We then may define the $[X, G]$ controllability as follows:

Definition

Let $X \subset D(x(t))$
$G \subset D(y(t))$ the goal of the system*

The system ω_p is $[X, G]$ controllable if

$$\forall x(t) \, \exists \, u(t)(x(t) \in X \wedge u(t) \in D(u(t) \Rightarrow f(x(t), u(t)) \in G))$$

†Elsewhere we dealt with the concept of goal (de Leeuw [10]).

*We suppose that G is not trivial. That is we suppose $G \neq \emptyset$ and $G \neq D(y(t))$

Thus for any input belonging to the class X one can find a control signal such that the resulting output is a good one.

We now take a system ω_p with memory described by the state equation f

($D(s(t)$ denotes the state space**)

$$f : D(s(t)) \times D(x(t)) \times D(u(t)) \Rightarrow D(s(t+1))$$

The concept of controllability now has to be adapted.

Definition

Let $S \subset D(s(t))$ (suppose $S \neq D(s(t)) \wedge S \neq \emptyset$)
$X \subset D(x(t))$
$G \subset D(s(t))$ the goal of the system

The system ω_p is $[X, S, G,$ one step$]$ controllable if

$$\forall x(t)\ \forall s(t)\ \exists u(t)(x(t) \in D(x(t)) \wedge s(t) \in S \wedge u(t) \in D(u(t)) \Rightarrow f(s(t), x(t), u(t)) \in G)$$

This means that a system is $[X, S, G,$ one step$]$ controllable if for any input from X and for any state from S we can find at least one control signal such that the resulting new state is inside G.

It is not difficult to see that several other and realted controllability concepts may be defined. I would like to confine myself to these two examples.

We now try to look systematically at the different possibilities for control in the broad sense of the word.

These are:

1. Trying to look for an appropriate control signal $u(t)$.
   We call this internal routine control (IR).
2. Changing the structure of the system.
   In our equations this is the function f.
   This control possibility influences the controllability of the system and may be used for making the system controllable or for making easier the IR control task.
   This type of control is called internal adaptive control (IA).
3. Changing the system's goal G.
   This possibility is called internal strategic control (IG).
   This control mode influences the controllability and may be used if the system is not controllable or one wishes to have an easier IR task. The choice between IA and IG cannot be described in general.

Especially the third mode of control seems to be rather silly. However, in the reality of organizations this phenomenon is not at all peculiar. We only refer to the theories in social psychology about changing aspiration levels and the concept of goal displacement.

The environment of the system may be conceptualized as a system too. A fourth way of trying to reach the goal may then be to (indirectly) influence the input. By analogy this may be done at three levels. So we have

4. External routine control (ER)
   This is influencing the environment without changing the structure and the goal of the environment.
5. External adaptive control (EA).
   Changing the structure of the environment in a way which is favorable for the system.
6. External strategic control (EG).
   In this control mode the system tries to change the environmental goal in a way which is favorable.

The six-tuple ⟨IR, IA, IG, ER, EA, EG⟩ is called the control characteristic.

The solution of any control problem implies a choice of a specific combination of these six possibilities. We will call this choice the determination of the mix of control.

The design of a controller

The next step of solving a control problem is the design of an appropriate controller.

It must be clear that an appropriate controller should be tailored. Nevertheless one can state some general criteria an effective controller should meet.

We will treat only the most simple case: the requisites of an effective routine controller.

That is, we do neither consider the case of changing goals (strategic) nor changing the structure of the system (adaptive).

Because of this restriction one must define an effective controller as a controller which gets the maximum out of the given system in the given environment with the given goal.

This maximum might be less than the goal.

The result of the most perfect controller is bounded by the controllability of the system.

In order to avoid complications we shall assume

**We suppose that the spaces are constant
Thus $D(s(t)) = D(s(t+1))$.

that the system is controllable.

The requisites of any effective controller are:

1. The controller should have some index of performance to evaluate systems behavior.
2. The controller should have a model of the system to be controlled.
3. The controller should get information about the input and the state of the system.
4. The controller should have at its disposal enough alternative measures of control.

Requisites number 2 and 3 clearly follow from the work of Ashby and Conant (Conant and Ashby [11], Conant [12]).

Number 4 is Ashby's famous Law of the Requisite Variety (Ashby [6]).

Besides the requisites of an effective controller one might think of the case where one tries to design a controller which is efficient too. Also it is possible that the requisites cannot be met by one single controller. It now becomes interesting to see whether the problem can be split up into smaller problems.

Decomposition of the control problem may contribute to an effective solution.

This raises in a natural way two connected questions: the problem of decomposition and the problem of coordination of the decomposed system.

It is important to note that the more interesting organizational problems of control cannot be formulated with the aid of mathematical equations.

So the known techniques of decomposition do not offer much help. As was the case with the requisites of an effective controller we must use qualitative but not imprecise reasoning as a guideline. In order to formulate different ways of decomposition we must introduce three types of part-system.†

Firstly, we have the subsystem. A subsystem consists of a subset of the objects (elements) of a certain original system together with all the relations within the subset.

The partial system consists of all the objects of a certain original system together with a certain part of the relations in the original system. The phase system is created from an original system by concentrating only on a subset of the original time-set.

Summarizing we might restrict ourselves to some elements to get a subsystem, to some relationships to get a partial system and to some moments of time to get a phase system.

These three part systems indicate three ways of decomposition. Besides, one may look whether the goal of the system may be decomposed. If one gets part-goals corresponding with subsystems we have decomposition into subgoals. If they correspond with partial systems we have decomposition into partial goals. In the same way decomposition into phase goals may be introduced. Also the environment of the system may be decomposed. Viewed as a system it is possible to speak of subenvironments, partial environments and phase environments.

Summarizing we have the nine ways of decomposition pictured in Fig.2.

There are at least two marginal notes to be made. Further research must be directed to the interdependence between these types of decomposition.

Also the relation between the control characteristic and the decomposition has to be cleared up.

We suppose that this may shed new light on the features of the hierarchical nature of controllers in more complex cases.

Indicating possible ways of decomposition is not enough. For any specific case a choice must be made. It appears to be wise to decompose in such a way that the resulting parts of the control problem are more or less autonomous because this minimizes coordination effort. (Simon [13].)

It is clear that this is an outline of a theory. It cannot do more than to give an impression of a way of qualitative theorizing which may be of importance for systems theory and organizational science.

† For more precise definitions see de Leeuw [8].

	Phase	Partial	Sub
Goal			
System			
Environment			

Fig.2 Ways of decomposition

5. Contributions to organizational science

As said before organizational science may be distinguished into organizational analysis leading to insight into the functioning and the structure of organizations and organizational design leading to guidelines for the structuring of organizations.

These two parts are interdependent. Any good normative theory of design presupposes good empirical theory. The formation of good empirical theory presupposes contact with the real world. However we will not treat the rather complicated question of the interrelations between the two parts of the field. We only want to give some examples of the use of the control paradigm for each of them.

Understanding organizations

The key to understanding organizations in our opinion is not the creation of an all encompassing theory. There is, there will be and there must be a set of theories. We do not believe in the possibility nor the usefulness of a single theory for understanding individual behavior in organizations, group functioning and organizational behavior. In our opinion one should have different theories for different levels of aggregation (levels of resolution). I wish to recall that general systems theory does not try to unify science by building one all encompassing theory but only points to isomorphisms.

It is precisely this type of unifying we should look for in organizational science. We must look for isomorphic phenomena at different levels of aggregation. We believe that the paradigm of control is very useful in this respect.

Because of the fact that the paradigm of control is empirically empty it has to be filled up with empirical content. This can be done in different ways. The control paradigm is a potential way for viewing an individual. Its resemblance to theories, for instance, in ergonomics and organizational psychology, is remarkable. Especially the requisites for effective control and the control characteristic are in accordance with the view of an individual acting in an environment (internal and external control) on the basis of his perception of the situation (model of the system to be controlled).

The interpretation of the paradigm of control for understanding the functioning of an organizational group is possible too. Because of space limitations we will not do that but instead, look at the whole organization. We postulate that it is useful to view an organization as a controller, a system to be controlled and an environment.

The reasoning of the foregoing paragraph then leads to further understanding of the relationships between organization, technology and environment.

Two examples will illustrate the point.

First of all, the concept of technology. Mostly technology is defined as the transformational processes of an organization. So we have the technology of education, of producing shavers, of printing books and so on. The control paradigm, however, suggests strongly that one should define technology as the system to be controlled.

This urges for a definition which is relative to the chosen viewpoint. We shall explain our point with the aid of Fig.3.

If we want to understand the structure of S2 we might look at it as a controller for S1. Technology is identified with S1.

If, however, we are interested in the structure of S3, we might look at it as a controller for the system consisting of S1′ and S2′.

Technology is identified with S1′ and S2′.

The second example is the dual control between an organization and its environment. The view that organizations must be seen as open systems is not new any more.

Now precisely because of the fact that most of the systems theoretical work in organizational science is of an organismic nature mostly this statement is stressing the adaptive nature of organizations.

An organization, it is said then, must adapt to its environment if it is to survive. But in this view the environment is considered as given, mostly changing but not as controllable. To paraphrase Ackoff's view that the future should be redesigned (Ackoff [14]) we would say that the system not only adapts to but also redesigns its environment. This view is entirely in accordance with the control characteristic.

The three modes of external control are pointing to this activity of the system.

Now the structure of the organization might be seen as controlled by as well as controlling the environment.

The environment is a system to be controlled. However, because of its complexity we shall decompose the environment into parts. The organization, viewed as a controller will reflect this decomposition.

This does not mean, however, that one will find in every organization a subsystem corresponding with every part of the environment. We will shortly elaborate this remark.

The theory one develops for understanding the external control runs as follows.

Firstly, one tries to identify the characteristics of the environment which are relevant for its control.

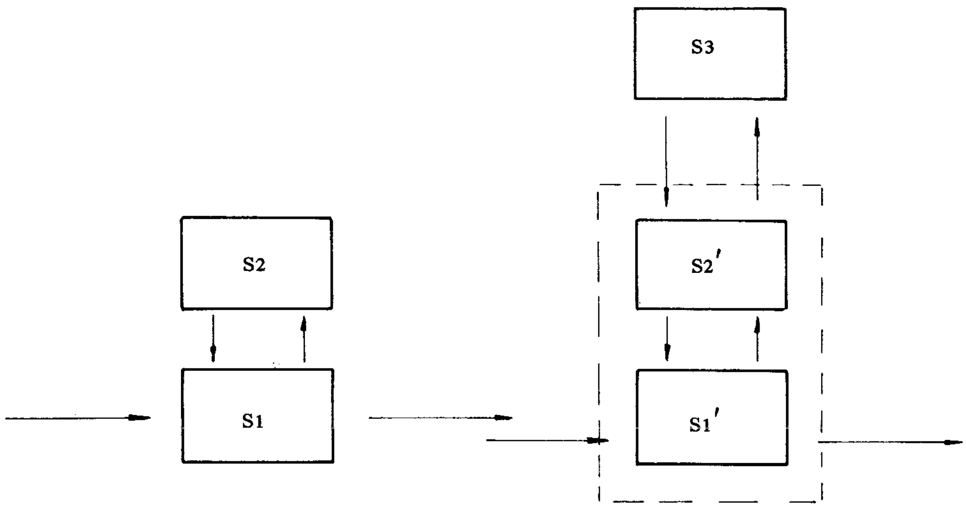

Fig.3

Secondly one tries to split up the control problem by decomposing the environment. And, thirdly, the requisites of effective control are applied to the organization as a controller.

We recall that the requisites of an effective controller are developed for the controller as a black box.

It follows that we cannot expect to find subsystems for any environmental part when we reticulate the black box. It is possible that it will be not a subsystem but a partial system.

These two examples possibly give an impression of the usefulness of the control paradigm for the descriptive part of organizational science.

Designing organizations

The usefulness of the control paradigm for the design of organizations presumably will be clear from the above examples. There are, however, two remarks to be made.

Out of the rational reasoning based upon the control paradigm are the following statements with respect to organizational structure. They are used for the descriptive part of the field as hypotheses to be tested. On the other hand, for the normative part, they are used as guide-lines for design.

For the design case we must use an iterative strategy as will be illustrated.

Suppose we have decided upon the structive of S1 and S2 as controllers for S_{01} (see Fig.4).

Thereafter one decides upon S_3 as a controller for S_{02}. When this control structive is implemented one must decide upon the allocation of the control tasks.

Suppose for example that the S_1 control task is allocated to organizational member S_1^*. Analyzing the expected behavior of S_1^* one should not forget that S_1 and S_1^* are not the same. Especially if one uses the control paradigm for analyzing the situation we might expect that S_1^* will function not only as a controller for S_{01} but also as a controller for S_3.

The analysis of the design may show unwished peculiarities. In this case one should change the design.

Therefore, we advise to approach the design problem as follows:

1. Try to design the structure using the guide-lines from the control paradigm.
2. Decide upon the allocation of the tasks to the members of the organization.
3. Analyze what will happen if this structure is implemented in the chosen way using the control paradigm.
4. If necessary go back to steps 1 and 2.
5. Implement the chosen solution.

The second remark is an observation.

The classical theories of organization were full of guide-lines for design. These are thrown away as unscientific and not useful. We now are entering a new period of guide-lines for designs. The rules are different however.

They are more complex and, most important, they are conditionally stated. On the other hand I personally find this 'come-back' of principles a rehabilitation of the much abused classical writers. For example, the principle of the span of control is

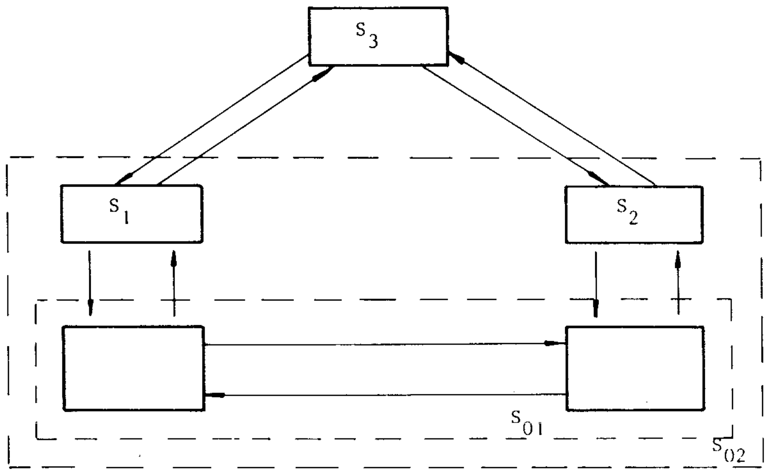

Fig.4

not silly at all. When we use the control paradigm for design this principle is discovered again.

We hopefully have gained a deeper understanding of it.

6. Conclusion

Work has to be done. The further development of the control paradigm and its application in the field of organizations seems to be promising.

Besides the usefulness of the control paradigm for the integration of the field it has another benefit.

The essence of it shows common sense, wisdom and rational reasoning.

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