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Designing with Minimal Critical Specifications[1]

Critical Specification Design

There are a number of recent developments in molecular engineering, in biosimulation and in the study of socio-technical systems that point to the emergence of new design principles.

Early engineering techniques were based on the method of building up increasingly complex machine structures that produced simple components which were then assembled to produce a final product.

In molecular engineering the structure of material itself, either as it exists or as it can be produced to specified criteria, is used to effect required transformations. Further, since many materials have metastable states, their structural form can change in response to signals, in the form of heat, pressure or light, so that the same material can operate as a different machine depending on environmental conditions (von Hippel, 1965). This points to the emergence of new forms of production engineering which are no longer based on the principle of successive decomposition, linkage of components and hierarchical control structure.

From the point of view of production design, the key development lies in the

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[1]A shortened and revised version of chapter 2 in P.G. Herbst, Socio-technical Design: Strategies in Multidisciplinary Research. London: Tavistock Publications, 1974.

study and design of autonomous systems. Here we find two lines of development, one from biophysics and the other in the socio-technical study of work organization.

The last few decades have seen the emergence of cybernetics (Wiener, 1961), showing that self-adjustment requires the existence of cyclic feedback processes; of communication theory (Shannon and Weaver, 1949), which provides measures of structure and error variance of discrete processes; and of open-system theory (von Bertalanffy, 1950), which demonstrates that open systems can maintain steady-state functioning without the use of a separate control mechanism.

An interesting point of departure is the non-specification technique described by Beurle (1962) in a paper on the properties of random nets. These are generally a set of elements with random connections. Beurle argues that the nervous system may initially be somewhat like this but that later, in response to transactions with an already structured environment, an internal adjusted structure which corresponds to a biased network structure should gradually emerge. Clearly, a random network can learn practically any desired response, but something has to be added to get to a workable model.[2] Without going into the detail of recent, more sophisticated, work, what we find here is a new approach to the problem of design which is no longer concerned with complete detailed specification but with <u>minimal critical specifications</u>.

The main reason for this approach was a concern with systems that can learn and that can adjust themselves to environmental changes. Adjustment, learning and creative and intelligent behavior minimally require:

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[2]The simplest model of this type is found in stochastic learning theory which is based on a single type of response element that can change its probability of response. What is lacking here is the possibility of structural growth.

- internal variability to create alternative response patterns;
- the testing of alternative response patterns and evaluation of the outcome;
- selection of the most appropriate response.

This is one of the lines of development that led to the study of autonomous systems. What was made clear at this stage was that variability, and thus making errors, was not a bad thing and that, on the contrary, systems must have sufficient potential and mobilizable internal variability and mechanisms for the self-correction of error in order to be able to adjust to a variable environment.

The third, and to some extent parallel, line of development is more directly relevant to the design of production systems. Before the Second World War, the problem of optimizing the functioning of industrial and work organizations was looked at either from a techno-economic point of view or in terms of improving the social organization and human relations. What was left out of account was that the social organization is not independent of the technical production system. It is possible, as has been done in the past, to look for an optimal technical solution. However, if the correlated social system required is inferior then the total production system may be far short of the optimal. A series of studies of socio-technical systems undertaken in the coal-mining industry showed that this was indeed the case and demonstrated further that a given technological system can be operated by several different types of work organization. The variables that may remain to some extent free are the pattern of task allocation, the allocation of task responsibility and the method of payment.

What emerged at this stage was the concept of autonomous work groups that would overcome the dysfunctional properties of fractionated work organizations (Trist and Bamforth, 1951; Wilson, 1951; Rice, 1958; Emery and Trist, 1960; Herbst, 1962; Trist et al, 1963). This work converged with new principles that were being developed in the field of job design (Davis, 1962; 1966).

The principle of minimal critical specification design can be stated as that of identifying the minimal set of conditions required to create viable self-maintaining and self-adjusting production units. An optimal solution is obtained if the unit requires no external supervision and control of its internal functioning and no internal staff concerned with supervision, control or work coordination. The management function should primarily be supportive and concerned with mediating the relationship of the unit to its environment.

There is consistent evidence that work systems of this type are superior in terms of relevant social and psychological criteria. Chronic conflict between workers, and between workers and management, disappears. For individual members, the task provides the opportunity for learning and for participating in technical and organizational problem-solving. The group as a whole can learn on the basis of its experience and becomes able to utilize experts as consultants. Conditions are created for the development of mutual trust and respect and thus also of self-respect. Just as internal conflicts and warring factions export their conflict into their environment, cooperative relationships can now be developed with the environment. At the same time, a considerable reduction of unproductive overhead and management costs can be achieved.

It cannot be expected that social organizations of this type will be ideal for and attractive to everyone. Since human beings differ in their emotional and social maturity, and human needs change in the course of development and growth, no single type of social system can be optimal. If in the case of autonomous groups there is less of a problem, this is because such groups cannot be imposed but depend for their development and maintenance on the consent of all involved. At the same time, a significant point about self-maintaining systems is that they do not possess a single rigid structure but have the characteristics of a matrix organization that can adapt its internal structure to meet internal and external task demands.

There are two problems that will need to be considered in more detail:

> What are the critical conditions for the operation of self-maintaining socio-technical units? What we are looking for here is a minimal set of necessary and sufficient conditions. It should be noted that, insofar as we are dealing with a set of interdependent variables, there will be more than one possible set of critical conditions. We shall in that case need to find a set of variables that can be included in the set of design criteria.

> Given this, we need new design techniques based not on the iteration of techno-economic variables only but on the joint iteration of techno-economic and socio-psychological variables.

Supporting conditions for a viable self-maintaining production unit are the following:

A clearly definable total task with an, as far as possible, easily measurable outcome state that may be in the form of the quantity and quality of a product and also an easily measurable set of relevant input states. These provide the necessary information both for evaluation of the system's performance and for maintenance and adjustment of the internal process.

A single social system responsible for the total production unit. The unit should include, as far as possible, all the equipment and skills required for process control and technical maintenance.

Given that the functional elements of the production process are interdependent with respect to the achievement of the outcome state, the social organization should be such that individual members do not establish primary commitment to any part function--that is, do not lay claim to ownership of, or preferential access to, any task or equipment--but are jointly committed to optimizing the functioning of the unit with the outcome state as the primary focal goal.

In traditional types of work organization, doing and deciding tend to be split and decision-making functions are allocated to higher levels of the hierarchy. Self-maintenance requires that relevant decision-making functions be brought down to the lowest possible level and reintegrated into the operational work organization. This becomes of particular importance where the decision-making content of component tasks has become depleted by means of computer programming and automation.

Responsible autonomy cannot generally be established and maintained unless the available tasks require personal responsibility based on some degree of competence, judgment and skill. Similarly, unless the total task allocated to a production unit requires the development and use of personal competence, acceptance of joint responsibility for the organization and functioning of the unit may not be achievable.

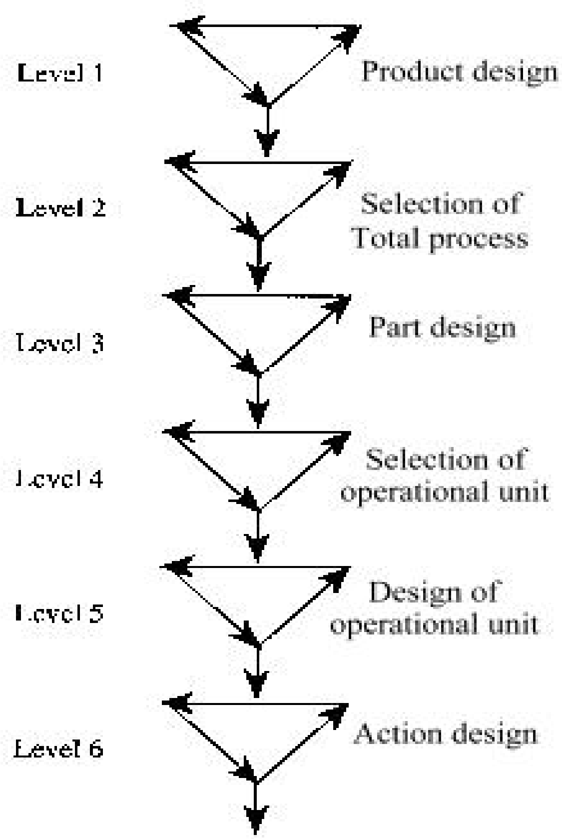
Emery and Thorsrud (1969) have formulated relevant criteria for job design in the form of hypotheses about the way in which tasks may be more effectively put together to make jobs and at the same time to satisfy general psychological requirements.

Any new design technique will need to incorporate the basic set of techno-economic variables. However, instead of providing a detailed specification of all variables, the critical specification technique requires the identification of a minimal set of variables that have to be specified and the identification of other variables that have to be left free. The free variables are those that are required if the system is to achieve self-maintaining properties. The initial set of variables that require specification and are thus turned into fixed structural parameters may later be even further reducible since, given system properties, the specification of a given set of characteristics may lead to the emergence of steady-state properties of other system characteristics.

The existing production design technique is based on the successive decomposition of the total production process into part-product processes; these are then decomposed into operational units; and these are finally decomposed into elementary person/machine operations. At each level there is an iteration cycle which provides the specification for the next lower unit until, ideally, every movement of operators and machine operation is rigidly specified (Figure 1).

Figure 1

Technical unit design



What is produced in the end is not a functioning unit. In order to coordinate the often thousands of split-off process elements, to counter the variances that arise in each processing and transport segment and also the variance produced by the social-organizational links created by workers and finally to adjust the system to variances in input and changing product specifications, a superstructure of work is required in the form of supervision, inspection, control, planning, scheduling and personnel work. This additional system again requires coordination and produces variances for which a next higher level has to be provided, and so on. Insofar as the system finally produces more variance than it can control at any level, it exports the unmanageable surplus variance to the environment wherever it can be absorbed, compensated for or simply got rid of. Both the rapidly growing rate of environmental pollution and the increasing incidence of chronic mental health disorders show that the problems exported can no longer be absorbed by the environment or effectively compensated for by the social and professional organizations created for this purpose.

The creation of viable systems at the production-process level is aimed at:

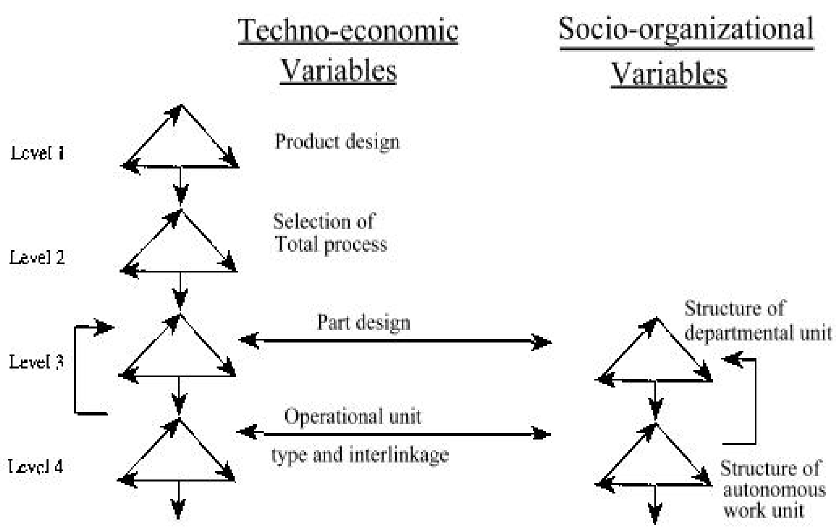
• avoiding the production of variance due to incompatible technical-process requirements and social-organizational requirements;

• providing the conditions, where possible, for variance to be controlled <u>within</u> the unit itself.

An alternative design procedure will therefore need to include, at each iteration level, the corresponding set of social-system variables. This will require, at each level, methods for studying the social-organizational implications of technical decisions. The critical level for viable system construction is Level 4, which is concerned with the selection and linkage of operational units. While at this point the design problem is made more complex, this should be more than compensated for by cutting off fixed specification at this level since Levels 5 and 6 contain variables that should almost all remain free in order to provide the necessary conditions for the production unit to operate as a self-maintaining socio-technical unit. The design process would in this case take the form shown in Figure 2.

Figure 2

Socio-Technical unit design



Design techniques require:

- definition of the relevant social-organizational variables;
- socio-technical methods for inferring the organizational implications of a given technical-process structure;
- construction of a feasible joint iteration procedure.

Evolutionary System Design

Nature does not create in the way in which factories do. A seed does not contain a complete specification of the organism, and the information given by the genes does not provide for one-step implementation. Yet, in spite of the fact that the information given by the gene structure is quite limited, the growth process proceeds with self-maintenance properties at each stage until a viable organism is completed that structurally reproduces the original one with a very high degree of reliability.

Let us simply note at this stage that:

> Reliable production does not require a complete specification of either the production process or the final product.
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> The creation of a complex structure does not require the initial production of elements which are later connected to produce the final product.
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> The production process is not one step from specification of structure to structural implementation, but always goes though successive growth stages.
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> It is not simply the final product that is a viable system, but a viable system exists at every stage of growth.

It appears likely that production processes incorporating these principles will eventually be developed.

However that may be, an understanding of growth principles is necessary for an understanding of the conditions for psychological and organizational development. A technological system can be designed and implemented by construction. A social organization cannot be created in the same way. The conditions for both psychological and organizational growth are more similar to biological growth, as against the mechanical construction type. This means that

> If we want to implement viable autonomous social systems, the design will not consist of a specification of the final system (although the characteristics of this system which are aimed at will have to be defined and accepted); rather, what has to be specified and implemented are the conditions that make it possible for a system of this type to develop.
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> The social system aimed at can rarely be implemented in one step but will need to go through successive stages of growth. The technical design should, in this case, be such that a viable socio-technical system exists at each stage. Thus if a system is designed for composite group operation there should also be provision for the possibility of more fractionated operation during the initial learning stage, and also for the possibility of regression to a more primitive organizational form.

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