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Socio-Technical Unit Operations[1]

This analysis is based on a study with the aim of devising a conceptual scheme for the analysis of worker/machine/equipment relations within the more common unit operations, presupposing a classification of unit operations and a systematic description of their characteristics. The other members of the project team were Hans van Beinum of the Tavistock Institute; Louis Davis, visiting from the Department of Engineering, University of California, Berkeley; and P.G. (David) Herbst, on loan from the Institute of Industrial Socidal Research, Technical University of Norway, Trondheim. An associate was Per Engelstad, a chemical engineer with a postgraduate diploma in Sociology, Institute of Work Research, Oslo.

A determined effort to build on the Arthur D. Little (ADL) concept of unit operations convinced us that this would not answer our problems, although it seemed useful for machine tool development. We found it necessary to develop concepts and scales for total production systems.

The two Tavistock Documents to which this report is ancillary (Davis and Engelstad, *Unit Operations in Socio-Technical Systems*: Analysis and Design and Herbst, Socio-Technical Unit Design) report the main findings of the study group but do not give an overview of how the group works. In this report we have indicated the initial perspective of the study

[1]Reprinted from a Tavistock Institute document, 1966.

group and its subsequent development.

Initial Perspective

The support of the Social Science Research Council was sought to enable Davis and senior members of the Tavistock staff to prepare a theoretical paper called *Unit Operation Analyses of Socio-Technical Systems.*

This represented for us a direct and vital continuation of work previously supported by the Department of Scientific and Industrial Research (DSIR). Their grant in 1958 enabled us to formalize the concepts and generalizations arising from the Institute's earlier work on socio-technical systems. In this report, *Characteristics of Socio-Technical Systems* (Emery, 1959/Vol. II), we presented a conceptual scheme for measuring the "degree of mechanization/automation" and drew attention to the independent dimension of the unit operations required for production, maintenance and supply. Marek and Emery (Marek, 1962) subsequently collaborated to measure in detail the variations in degree of mechanization/automation in engineering and power generation plants. The measured differences appeared to be sensibly related to observed differences in what was required of the operators and supervisors. This work, which DSIR sponsored for many years, has been continued for three years in Norway (on behalf of the Norwegian Trade Union Congress and Employers Federation) and in active collaboration with the Technical University of Norway, Trondheim (Thorsrud and Emery, 1964). There was at that time no interest in the Britain in active collaboration with socio-technical experiments.

Our three Norwegian field experiments have revealed that

- it is possible to formulate general principles for designing jobs and work organizations so as to increase human satisfaction with, and involvement in, the work (Thorsrud and Emery, 1964)
- it is possible with current tools adequately to analyze a technology so as to determine how jointly to optimize the social and technical systems (Marek et al., 1966)
- it is <u>not</u> possible systematically to argue from experience with one type of technology to another, at least not in the detail needed to decide on specific changes in job organization or technology
- it is <u>not</u> possible for social science findings in this field to be widely diffused to, and applied by, management and unions unless socio-technical analysis can be so conceptualized as to be free of some of the restriction to types of technology and to be comprehensible to the professions most readily available to industry.

It is urgent that we find a solution to these theoretical questions. The Norwegian project is moving from the experimental stage to diffusion and will, we hope, become a challenge to British industry's thinking about the utility of social science. Already a major British refining company has adopted what is essentially the Norwegian approach to joint optimization of social and technical systems; it has involved all of its top and middle management, through a series of residential conferences and has decided to establish its own field experiments (Hill and Emery, Vol. II, "Toward a New Philosophy of Management").

Davis and his coworkers had quite independently arrived at the same conclusions as a result of their socio-technical experiments in U.S. industry (Davis, 1966). Exchange of working papers led to Davis taking leave of absence from Berkeley so that, in cooperation, we might be more successful in solving this problem.

Our present line of thinking is that there is a finite number of unit operations that is significantly smaller than the number of different productive technologies. Many of the technologies differ only in the way they combine members of this more limited set of unit operations. If principles can be evolved for worker/machine/equipment relations for the most common unit operations, then a useful beginning will have been made to generalizing knowledge of socio-technical systems. We should note in passing that such broad classifications as process industries, mass production, etc., are invaluable for a sociology of industry or a psychology of occupations but are next to useless for this task, owing to the wide variety of operations and wide range of mechanization within each plant.

A major contribution to classifying unit operations has been released by Arthur D. Little, Inc. (as part of their government sponsored Automation Project). Furthermore, they have reported on the use of information theory as a common language for both the human and the technical components of any unit operation.

Davis has supervised a series of case studies of different unit operations and, among his coworkers, Crossman (1960) has further developed the use of information theory in worker/machine systems.

By working with van Beinum, we have at our fingertips a fairly wide range of unit operations with which we have had intimate contact. Among the theoretical lines we wish to pursue are the following:

- Evolving a more fundamental, and hence shorter, list of unit operations. This seems feasible. Many of the operations named in the ADL catalogue are, for purposes of socio-technical analysis, identical. In some cases, the differences in name simply reflect differences in the history of the operation; in other cases, they reflect differences which could make no difference in the variances that human beings could cope with.

• Developing a more appropriate common language than information theory for the human and the technical aspects of work. Information theory is too general. A more promising theory is that of directive correlation (Sommerhoff, 1950). Directive correlation can itself be formulated in terms of information theory, but it includes feedback as a special case and it is specifically concerned with the joint operation of processes obeying different laws. Within this theoretical language it is possible to handle not only technical processes but also such concepts as responsibility.

First Stage

Throughout June, Davis, Engelstad and Emery worked directly on the ADL concept of Unit Operations. Engelstad collaborated actively because this was of direct relevance to the continuing socio-technical experiment in Norway.

Two main conclusions emerged from this stage:

It seemed perfectly feasible to evolve toward a more fundamental, shorter list of unit operations. Primarily, this meant a classification of "tool" and "material" according to their physical state characteristics (e.g., solid-structured plastic aggregate, fluid or gas). Within the cells thus formed, it is possible to group the ADL unit operations and to detect their essential communalities in terms of the interstate processes involved. However, this led us in the direction currently being pursued in machine tool research. It was not the direction in which we wished to go, even though there were useful payoffs in a technical analysis that identified logical models of basic processes such as paring off surface layers of solid structures and segregating liquid-aggregate, liquid-liquid mixtures.

Analysis in terms of unit operations failed to encompass many of the critical variances for which production design (or redesign) decisions have to be made. Such an analysis could not indicate to the designers whether, for instance, they should automate workers out of a system, whether they should opt for a segmented, externally controlled task structure (a la conveyor belt assembly) or whether they should trade off a deliberately degraded technical system for greater on-the-job learning. The critical variances excluded by unit operations analysis were those emerging from the environment within which the production system had to survive economically and from the human input which is always essential to this survival. This last statement is very strong and should be explained. We were unable to identify, or even conceive of, any production system, no matter how happily automated, that did not require for its integrity as an economic unit a human element for command and "reprogramming" (design and maintenance).

These conclusions could have been reached on theoretical grounds. We preferred to reach them by detailed analysis and discussion of existing production systems and the process of industrial design (for this latter we are very much indebted to the special knowledge Davis brought to the group). The document by Davis and Engelstad reports the steps leading to the second conclusion. We did not prepare a document on the first conclusion as this was going into areas beyond our competence.

Second Stage

Discussions throughout July were extended to include Herbst and van Beinum. The general direction that we took is shown in Herbst's document. After the critical work of the first stage, we proceeded on the assumption that the *basic unit for socio-technical analysis must itself be a socio-technical unit and have the characteristics of an open system*. In design terms this represents the last level at which decisions can be taken for joint optimization of the human and technical systems with respect to environmental requirements. Failure to recognize this may lead to design decisions being made solely on technical and economic cost criteria with consequent inefficiencies due to excess operating costs, difficult maintenance, lack of growth in system performance, high overheads for control and supervision or lack of adaptability to market shifts. Examples of each of these can readily be given from current design practice.

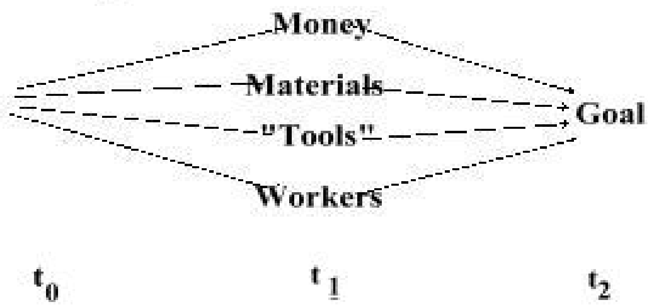
For theoretical purposes it is necessary to identify the conceptual dimensions of such a unit. At a fairly crude level one can postulate that they share the properties of open systems generally, i.e., that they can achieve "steady state" only by maintenance of direction and a steady rate of progress in that direction, and that, like coupled systems, they are governed by the principle of joint optimization. A more precise and systematic way of expressing these characteristics is Sommerhoff's theory of directive correlations. This deals explicitly with coupled systems when at least one of the systems has the properties of information absorption and retention processing and of self-selected response variability. These properties are characteristic of living systems but are also built into many servo-controlled mechanisms (e.g., a radar controlled antiaircraft gun). Interaction between different systems can be conceived of only with the principle of *contemporaneous causation*, i.e., a past event cannot be a cause because it is past and no longer exists; a future event cannot be a cause because it does not yet exist. Only systems that exist together can interact. However, independent systems[2] cannot be conceived of as coupled together unless at time, t_0 (Figure 1), there is a movement of information at least from one system to another (such a movement could be regarded as a minimal interaction, provided that one recognizes that this usage extends the dimension of interaction far beyond the lower limits of what were until recently considered the significant energy exchanges).

This information can only remain "potential information" unless capabilities exist for processing it together with existing "memories." This condition would appear to open the way for an infinite regress, i.e., no information unless there is prior information. We accept that the regression may be beyond the time span of an individual human but believe that it is finite at

[2]We are not discussing sets of systems or conditions that are "epistemically dependent," i.e., where the value taken by one conceptually determines the values that will be given to others. In substantive terms, we are discussing neither the relation of parts within the same system nor the relation of a part to the whole.

Figure 1

Directive correlation of production factors



least within the span of *a species* emerging and adapting to a physical environment that has in itself an informational structure. Even when processed within memoried categories (a further assumption), the information would be "useless" unless it in-formed action at some later point in time (t_1) which could correspond with, and be contemporaneous with, what had in the meantime issued from processes internal to the other system. It is still not enough to warrant a coupling of two or more systems that there should be an informational flow at t_0 which shapes the interaction at t_1. The interaction at t_1 must give issue to a state of affairs at t_2 that is of the sort that we typically described in terms of "goals" for the cognizing system. Although there is a communicable intuitive content to the notion of a "goal state," it is worthwhile to attempt to explicate what we mean in this theoretical context. We do not mean to refer only to subjectively perceived goal states that might be reflected in emotions or organizational morale. Our reference is to changes in the objective probabilities of the cognizing system persisting as a system. If the state of affairs resulting from interaction at t_1 neither endangers nor promotes survival of the cognizing system, then we may be observing a chance interaction, not a coupling.

This last stage again presupposes information transfer and processing. Unless the initial information imports, the response and the resulting state of affairs (t_2) are registered and processed within memoried categories of system states, response tendencies and object characteristics, there can be no change in the probabilities of future survival, i.e., in response capabilities given similar initial inputs.

The situation with which we are concerned is represented in Figure 1. Following on the preceding discussion of the abstracted characteristics of directive correlation, we may be able to specify the necessary conceptual dimensions of socio-technical units. The goal state can often be conceived of as a product/cost relation where the product is specified in terms of quantity and quality and the cost is assumed to include some allowances for product distribution (at least for those instances where product variations entail differing distribution costs, e.g., costs for overcoming novelty or for sustaining freshness or finish). This in itself might appear to reinstate an intolerable degree of indeterminacy insofar as the cost element of the goal state cannot be related to survivability without some specification of market prices. For our purposes we assume that the problem does not exist insofar as the designer of a production system should be given the costs per unit of given quality within which the designing must be done. We will take it that our problems of conceptualization are within this limit.

If the goal state can be specified in the ways indicated in the preceding paragraph then we can identify one of the dimensions relevant to survivability (what Herbst refers to as viability). There must be a specification of a product/cost relation (or some determinate transform thereof) that enables the results of the interactions of people, tools, money and equipment to be recognized as such and judged harmful or beneficial. For the latter judgment to occur there must be "knowledge of results" and a frame of reference.

Working back through our general statement of directive correlations, there must be also

- A choice of responses, which of necessity means that some of the responses are potentially less beneficial or more harmful than others but are, in the absence of past experience, equally likely to occur.
- A knowledge of which initial states in people, tools, money and materials are likely to presage subsequent states.
- An input of information about the state of all variables (people, tools, money and materials) in time for the necessary thinking to be done and the interaction to be shaped by human intervention.

Within this framework we can postulate the following as the dimensions for analyzing our basic socio-technical units:

- specification of objectives;
- knowledge of results;
- judgmental criteria for results;
- range of responses;
- process knowledge;
- stimulus access and timing.

As we have formulated it, the process of judging one socio-technical unit against another (or against itself at a different time) is obviously relative to the objectives that are being specified and the complexity of the other processes involved in the directive correlation. The first is not properly part of our problem. As already stated, the designer cannot start unless the objectives are specified. The second source of indeterminacy can be regarded as also outside our problem area because the designer can pursue given objectives only from the basis of present knowledge; there can be no hope of reducing complexity below the level of current knowledge about what will lead to what.

We are henceforth assuming that economic analysis will determine the objectives to be pursued and that technical knowledge will determine the range of alternative unit operations (in the original A.D. Little sense) that will contribute to achieving these objectives. We shall ignore, at least for the moment, those process characteristics of people and money that reveal themselves during the course of a directive correlation.

Accepting these two limitations to what we are trying to explain, we can now observe an important, interesting convergence. The criteria by which we think socio-technical units should be judged are very similar to those that the Ambers (1962) devised for judging the degree of automation of a production process. The Ambers proposed that the degree of automation should be judged by the human attributes that were mechanized. They further proposed that these attributes should be ordered as follows:

- none;
- energy (for material transformation);
- dexterity (for material/tool orientation);
- diligence (for habitual performance of dexterity);
- judgment (of what is beneficial or harmful);

• evaluation (of multiple judgments);

• learning (of what follows what);

• reasoning (of what could follow what);

• creativeness (to change existing range of responses);

• dominance (commanding a change in goals).

They assert that the last named attribute would be a property of the machine vis-a-vis people, if it possessed all the preceding properties. With regard to the other attributes (apart from creativeness) they specify related system properties and identify examples, even if only embryonic.

The convergence is not accidental. Their studies were concentrated, as were ours, on productive systems that are, or have been, socio-technical systems and hence could theoretically become, or have become, purely technical systems. Their concern is opposite to ours, namely to measure general characteristics of the technical system, but they have, implicitly, drawn their criteria from properties possessed by the total production system.

The conclusion we wish to draw is simple. Given the objectives and the current technical knowledge, the design of a production system must be subordinated to achieving the highest possible level of overall system properties. As implied, the level cannot justifiably be higher than that which can increase goal attainment other than by the learning that could conceivably take place on existing knowledge. Does this conclusion follow from what has been stated? We think it does, because each of the levels specified by the Ambers corresponds to an interdependent part of the directive correlations we call production (allowing for diligence as a property reflected in speed and precision of response). A shortfall in any of these parts can reduce goal achievement.

This brings us to our last point, which should take us back to where we started. If we are usefully to generalize from lessons learned from a particular socio-technical system, we should seek to do so in terms of the level of overall system performance that is being sought. That is, it will be more relevant if we have been trying to raise the total system to a level involving diligence (or learning or creativity) than if the technical unit operations involved were in drilling, pressing or distillation.

Possible Outcomes of the Discussions

Two documents and the present reflections have arisen from the discussion of unit operations. Insofar as these discussions took place between key members of three different research teams, we cannot predict the further outcomes. The current understanding is that the teams will continue these lines of thought in their local settings (within their own budgets) and seek joint publication in the very near future. As much as we are averse to premature publication, we are convinced that these matters require an early airing to a much wider audience than can be reached by the circulation lists of the three institutions. Although these three documents represent fairly adequately our progress in June/July, we shall circulate the further documents we expect to emerge and shall expedite publication of whatsoever will usefully extend the universe of discourse.

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