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SOCIO-TECHNICAL APPROACH TO PROBLEMS OF PROCESS CONTROL

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Synopsis The Industrial Democracy Project in Norway is a long-term research sponsored jointly by the Confederation of Employers and the Trades Union Council. The field experiment reported took place in the chemical pulp department of an integrated papermill as one of a series of four experiments carried out in different industrial settings. Extensive task fragmentation and bureaucratisation in modern industry have produced widespread feelings of alienation in the work force, owing to an increasing mismatch between technologically based task requirements and human needs. Emerging theories of socio-technical systems, including a list of psychological job requirements, offers a frame of reference for understanding these problems. Previous experience suggests that full commitment to productive aims can be achieved only under conditions that allow for a high level of self-regulation and learning. In process technology (including pulp and paper), the dependence relationships among the state characteristics of the materials form a complex network. In the present case, this resulted in uncontrolled variations being transmitted along the process. Having identified the optimum unit for experimentation, individual jobs were redesigned in order to facilitate group learning, which would permit the work groups to increase their control of the process. Results of the socio-technical analyses before and after the experiment are reported and reference is made to the *variance matrix* technique.

Introduction

THIS paper describes a concrete experiment conducted by a team of social scientists in the Hunsfos pulp and paper mill during 1964–67 under the supervision of the author. This is part of the research team's complete programme for which Prof. Einar Thorsrud (Work Research Institutes, Oslo) and Prof. Fred E. Emery (Human Resources Centre, Tavistock Institute of Human Relations, London) have been responsible. The study is one of the four experiments carried out in different industries under the so-called Industrial Democracy Project, an action research programme sponsored

Under the chairmanship of N. C. Underwood jointly by the Norwegian Federation of Employers (NAF) and the Trades Union Council of Norway (LO).[1]

The primary objective of this programme was, through a systematic re-design of jobs, to improve the conditions whereby men could exercise more discretion and have greater influence over their own work situation. To achieve these goals, however, neither party was willing to sacrifice the rising standard of living resulting from economic growth in industry.

Existing evidence indicated that one could reduce the feeling of alienation and release human resources in the company if jobs could be constructed either in accordance with the well-known principle of job enlargement or with the more promising model of partly autonomous work groups. The changes required were expected to be primarily related to the type of technology involved, taking for granted that the changes were in accordance with basic constraints imposed by the psychological needs of job-holders (see the next section and Appendix 1).

The research task was conceived of as twofold. Firstly, to give practical demonstrations of new principles of job design and, secondly, to encourage the diffusion of possible results that were found useful. In the following, we shall confine ourselves to the first task in general and to the experiment at Hunsfos in particular.* Consequently, it should be noted that, although this one field experiment might properly illustrate the socio-technical approach as such, a full evaluation of the results achieved by this research programme requires the four field experiments to be considered as a whole.

Even though the specific goals of this project have been different from what might be conceived of as of major concern by participants in this symposium, the author believes that there should be a convergence of interest over the problems of control in those complex systems, including technical as well as human components. Before describing our case material, we shall very briefly consider the problem as we see it and indicate some of the principles that have served as guidelines in the carrying out of our research.

The socio-technical approach

IMPROVED production control in industry has hitherto very much been looked upon as a question of finding the best technical solution to the problem, whereas organisational factors were not taken so much into consideration, particularly during the design phase. This takes for granted that people, within their physical capacities, will be able to cope with and adapt to whatever type of task structures and variances they are left with. This procedure

* The other field experiments were carried out in a wiredrawing department at Christiania Spigerverk, Oslo, in a department for assembling electrical panels at Nobo, Trondheim and in a fertiliser plant at Norsk Hydro, Porsgrunn

has led to a compartmentalisation of the organisation. Hence, many of the artificial segregations of crafts advocated by the trades unions are also reflections of traditional management practices. To our mind, it appears evident that these procedures must have resulted in sub-optimum solutions for the socio-technical system as a whole, since the reliability of the total system in this case will be decided by its weakest link. It should be noted that, with the general development towards automation, the location and character of the socio-technical interface will change, though such an interface will always persist at some level of an enterprise. Furthermore, in a period when almost everyone in society receives an increasingly higher education, it appears to be a paradox that the jobs, in particular at the lower levels in industry still tend to be rigidly delineated, offering little scope for variation, learning and joint problem solving and decision-making.

The socio-technical approach is based on organisational thinking that, within the unavoidable constraints of the technology, encourage as far as possible local initiative and responsible autonomy.

In our terms of reference, enterprises and their subsystems are considered as open socio-technical systems. Hence, like other living systems, they are open to matter-energy-information exchanges with an environment. Without trying to go more deeply into any of the principles that are a consequence of the open system characteristics of the enterprise, the following may be listed as being of particular relevance to the present project[2]—

1. The primary task of a manager is to control the boundary conditions of his unit.
2. The goals of an open system can be understood only as special forms of interdependence between the system and its environment.
3. The goal state has the characteristics of a steady state, which requires (*a*) a constancy of direction and (*b*) a tolerable rate of progress.
4. Steady state can be achieved only through leadership and commitment.
5. The basic regulation of open systems is self-regulation.
6. As individuals have open system properties, the enterprise must allow its members a sufficient measure of autonomy.

It is well known that motivations and attitudes of job-holders are not decided only by external rewards and sanctions, but also by certain intrinsic characteristics of the tasks. Hence, empirical evidence suggests that workers prefer tasks[3]—

1. Of a substantial degree of wholeness (that is, which show a strong *gestalt*).
2. Where the individual has control over the materials and the processes involved.

These requirements have been further translated into a set of psychological job requirements (Appendix 1).

The co-existence of a social and a technical system involve a coupling of two part-systems, each independently governed by its own laws, towards a common goal. As the contributions of these systems are essentially complementary, special attention must be paid to the interdependencies between them.

The two systems are primarily coupled through the reciprocal allocation of tasks to work roles, each of which is able to form systems of a higher order. Existing evidence shows that, when units tasks were small, job enlargement has been a useful organisational model.(4) In the English coalmines, where a number of tasks exceed the one man/one shift unit, it appeared that technological requirement as well as human needs could be adequately met by an autonomous work group.(5) The same principles of job design have later been applied also in the textile industry.(6) In these cases, the problem of identifying naturally bounded areas (in the sense that they had a high potential for self-regulation) was relatively easy. This task is considerably more difficult in an integrated pulp and paper technology where—

1. The dependence relationships of process variables form a complex network along the process.
2. The continuity of production, the level of throughput and the restricted buffer capacities in the process, to be effective, require that the disturbance control sequences be operated at appropriate speeds.

In order to identify units that would optimally meet these requirements, a method of analysis based on task structure has been developed. The so-called *matrix of variances*, which is based on the dependence relationship between state characteristics of the material, has been useful in identifying natural clusters of variances that are to be allocated within the same organisational unit (Appendix 2).

Finally, conditions for self-regulation can be improved by various changes in the social and the technical systems. This is best illustrated by our case material.

Hunsfos pulp and paper-mill

THIS account is an abstracted and rewritten version of a much more detailed report on the Hunsfos experiment, 1964–65, written for another purpose.(7) Further reference to this report will not be made in the following.

The Hunsfos mill is situated in a small community, about 10 miles north of the industrial seaport of Kristiansand, in the very south of Norway. The rural surroundings as well as the tidiness of the workplaces contribute to the general impression of a friendly atmosphere when one is visiting the site.

Since the end of the last century, the company has been the major employer in the community and, even in 1963, employed almost 50 per cent of its adult male working population. About 80 per cent of the Hunsfos labour force of 900–1 000 had close links with the community and the mill through their families, often employed by Hunsfos for three generations. The personal relationships at work are stable and closely linked to the religious, political and economic life of the community. The workers and foremen have been recruited mainly from the local district; the managers and most of the technical staff have moved in from other parts of the country. Hunsfos has a strongly professional management, respected both within the industry and within the plant, also a local union leadership with effective working relations with the central union headquarters in Oslo.

The company is one of five integrated papermills in Norway that offer the full range of the major technologies—mechanical pulping, chemical pulping and papermaking. Of the approximate total of 80 mills in the country, Hunsfos ranks fifth in terms of total sales. In 1964, the mill converted 200 000 m^3 of timber to 20 000 tons of mechanical woodpulp and 34 000 tons of chemical pulp. This again resulted in a total output of 65 000 tons of paper. The production covers a wide range of qualities within the sectors of magazine, packaging and fine papers. Total sales, of which 85 per cent were exported, came close to 80m. N.Cr.

The economic situation of the pulp and paper industries in Norway has been difficult for years and Hunsfos during the last ten years, in order to meet the challenge, has carried out two large reconstructions and investment programmes.

In 1959, the company, as the first one in Europe, introduced the magnesium bisulphite process in order economically to exploit the firs and hardwoods that combined are more prevalent than spruce in the south of Norway. Soon afterwards, fully continuous running, based on a four-shift schedule, was introduced to maximise plant utilisation. A number of technical improvements have been effected, including the reconstruction of some of the papermachines. This has allowed the company gradually to change its paper grades toward qualities of a higher converting value.

Selection of the chemical pulp department for experimenting

In September 1964, the management and the trades union at Hunsfos agreed to have the research team find a suitable area in the plant to introduce new principles of job design experimentally. From a research point of view, sites would be acceptable only in so far as they would have—

1. Process technology characteristics.
2. A high potential for diffusing possible results to the company as a whole.

Initially, this left us a choice among wood preparation, mechanical and chemical pulping, stock preparation and papermachines. Interviews with employees covering all levels of responsibility in these areas of production provided a detailed picture of the role system and how the technical interdependencies were coped with by role interrelations. The attitudes expressed by the employees were taken as clues to the fit or lack of fit of the social and technical systems.

A matrix of variances, based on the dependence relationships between state characteristics of the materials in different parts of the process, was constructed in close co-operation with some of the process technologists. Our focal concern, unlike that of the design engineer, however, was with those variances arising from the technical system that required responses from the organisation of individuals if the production goals were to be achieved. The matrix helped us to identify where these variances arose in the technological process and where in the subsequent stages of production they could be identified, communicated or acted upon. The matrix was worked out in close co-operation with technologists in the company. Our analysis also entailed working over historical records of plant operations, estimating cost/benefit ratios for possible changes in different parts of the mill and collecting labour force statistics that would indicate social costs incurred by different departments.

It was agreed to start the experiment in the chemical pulp department. Taking into consideration such factors as the dependence structure of the variances in the materials, the spatio-temporal aspects of the process, potential input/output measurements and certain variables in the social system, this department appeared to be a naturally bounded socio-technical unit with a relatively high potential for self-regulation. It appeared also to be an optimum choice, because—

1. The department showed an opening for significant improvement in that some of the variances in the timber, if not coped with in the chemical pulping, could be met in the papermaking only by downgrading the quality (and economic value) of the paper. (To a much lesser extent, mechanical pulping had the same effect.)
2. Located in between the wood preparation and the papermill, changes in the mode of chemical pulp operations would exert maximum leverage on these parts.
3. Local leadership on the management as well as on the union side appeared to be sufficiently capable and willing. This we expected would offset the resistance to change that might be expected from the senior operators (10 out of 15 of whom were over 50 years of age) and from some of the men who were apt to stick to their viewpoints or to seek isolation.

Tasks arising from the technical system

The chemical pulp process—For readers familiar with pulp and paper technology, any detailed description of the manufacturing process and the technical equipment can obviously be dispensed with. I shall therefore describe only those aspects of the technology that were found to be of particular importance for this experiment. Only a schematic presentation of the equipment therefore has been reprinted from a company report (Fig. 1).

The technical system of the chemical pulp department consists of five converting processes carried out in different, but adjacent areas— boiling, screening and bleaching and the preparation of boiling acid and of bleaching liquids.

As the reader will know, chips of spruce, fir and hardwood are boiled separately in large digesters with acid magnesium bisulphite. (In the wood,

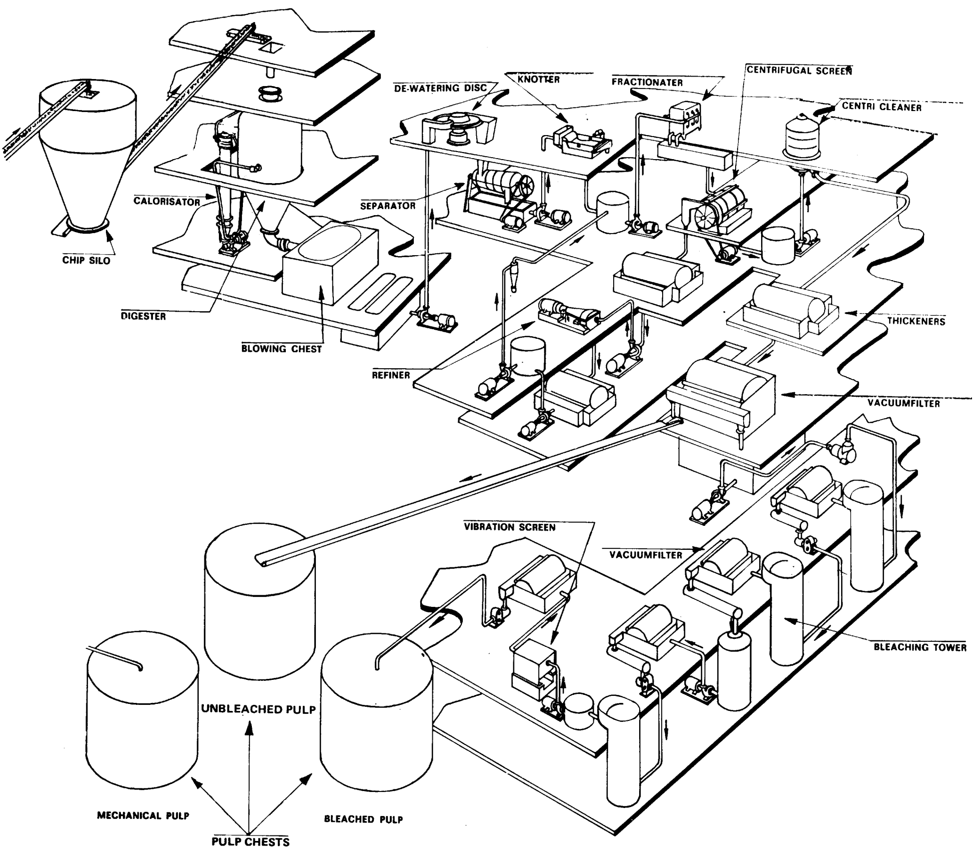


Fig. 1—The chemical pulp department

the two major components of lignin and cellulose form a rigid three-dimensional structure.) Under the right conditions of acid concentration, temperature, pressure, time, etc., the lignin is dissolved and the cellulose fibres are released. The fibres, together with other undissolved material, are washed and prepared for further separation in the screening section; the lignin and the used boiling liquid go to waste.

Fresh acid magnesium bisulphite is drawn from a buffer tank, to which acid is continuously fed after it has been prepared from magnesium oxide and sulphur dioxide in a separate section.

A complex system of screens raises the homogeneity and purity of the fibres by removing unboiled wood particles (knots, splinters, etc.), small fibre fragments (fines), as well as sand, bark, resin and other impurities. From the screening section, the spruce pulp goes to buffer storage as unbleached pulp, whereas the fir and hardwood are transferred to the bleaching floor.

The bleaching liquid, prepared from chlorine and sodium hydroxide in a separate section, is used mainly to dissolve residual lignin still attached to the fibres and colouring them. The three pulps together with the mechanical woodpulp constitute the major inputs to the papermill.

Variances in the technical system—The following groups of variances arising from the system's technology were of particular relevance to be controlled by the social system—

1. The use of fir as one of the raw materials had led to serious pitch problems, which were only partly brought under control. Whenever sticky resin accumulated on the screens or in the bleaching equipment, extensive cleaning was required.
2. Since the growing and storage conditions of the timber vary a great deal, some of these input variances would be transmitted along with the flow of materials and, if not controlled, would reduce the paper quality.
3. The conversion of spruce, fir and hardwood batches in the same equipment induced additional variances, owing to pitch contamination one with the other and the mixing of fibres of different wood species.
4. The variances resulting from mechanical breakdowns had been extreme during the period after the introduction of the bisulphite method, but, by 1965, they had been reduced to a near-normal level.

Key characteristics of operator tasks—These are—

1. The individual part-processes were by themselves relatively complex and demanding. Spatially separate from each other, the present level of their performance could be sustained with a limited number of contacts with other areas. Hence, they appeared to form a strong *gestalt* by themselves.

2. In addition to the cluster of internal interdependencies, however, a number of important relationships still existed between the part-processes and across shifts. For example, the boiling and the bleaching operations were interdependent in terms of removing the lignin from the fibres and the 16 h cycle between filling and emptying each of the four boilers required close co-operation and contact across shifts. Hence, the naturally bounded unit tasks clearly exceeded the traditional one man/one shift type of work role.
3. Finally, it became evident in this case, as in others, that the requirements of the technology were not fully known and predictable. As previously indicated, the pitch problem was far from being fully understood and the variances in raw material made it impossible to predict what problems the operators at any time would have to tackle. Moreover, the properties of the technical equipment would change somewhat over a period. This implies that the designated process control standards were arbitrary ones based on current knowledge. Hence, they ought to be adjusted to the extent that the changing properties of the technical system caused a relocation of the optimum point for some of the process variables. For example, the evolutionary operation technique is based on this fact.[8]

The respond resources in the social system

Formal organisation The department organisation included seven shift positions and four shift teams, plus one daytime worker preparing the bleaching agents. A senior operator was charged with the responsibility for each of the other four part-processes. These men belonged to the highest of two formally recognised status levels. There were also a boiler assistant, a screener assistant and a reserve on each shift who, together with the daily worker, made up the second grade of operators.

In supporting roles outside the department were two laboratory technicians providing data for process control. In case of mechanical breakdowns or pitch troubles, the operators had to rely on maintenance men and cleaning people being called in from other areas by the foreman. Special contact man positions had been set up to facilitate communications between maintenance and operations.

Four shift foremen (plus one assistant foreman to cover absentees) were responsible for the chemical and mechanical pulping, even though the two processes were not technically interdependent. The levels above the shift foremen included the general foreman, the production engineer, the pulpmill manager and the general manager.

It should be noted that the number of operator positions is strictly prescribed in the central agreement between the employer and the trades union.

This arrangement, having a long tradition in the Norwegian pulp and paper industry, is specific to this industry. This had undoubtedly added to the tendency of a strict delineation of work between individual job-holders, a well-known result of traditional job design in industry. Being of crucial importance to the problems of self-regulation and process control in this kind of technology, this point will be further explored in what follows.

Wages and bonus—The total wage of the operator includes hourly pay, shift allowances, regular overtime, additional hours and production bonus. Generally speaking, the complexity of this arrangement make it difficult for the average man to see any direct connection between his efforts and his wage packet.

In accordance with this, the production bonus was based on the number of batches produced, even though the papermachines used to be the bottleneck in the production line. Thus, by leaving out the quality aspects of the pulp, which the operators could influence and by which alone *they* could facilitate the production of the papermachine, the production bonus, though paid out out on a group basis, could not in fact function as a group goal. This is of particular significance, since management (at that time, extremely anxious to build up the quality reputation of the company in the market) could through a quality bonus have effectively translated such a quality-oriented policy into operational terms at the lower levels in the organisation.

Of particular interest also are the additional hours, a form of extra pay earned by the men for odd jobs done in addition to their permanent tasks and within their regular working hours. This exemplifies one of the measures used by management in order to cope with the lack of flexibility on the shop floor, to be considered in the following section.

Segregation of operator jobs—Since 1961, the total manning had been gradually reduced through natural turnover, the major part of which used to occur in the spring. Recruitment was done mainly therefore through the annual intake of holiday reserves for the summer months. Operator training was, in keeping with the tradition in the industry, limited by the notion of one man/one job. Hence, when a man had been permanently selected for one department, further advancements would be confined to the more recognised jobs in the same area.

The segregation of jobs and lack of overlapping skills in the permanent shift teams had made the work organisation increasingly unable to cope with the existing variances as the number of stand-ins in the general manpower pool was gradually reduced. In the chemical pulp department, for instance, one multi-skilled reserve had been introduced on each shift in order to stand in for absentees and otherwise to help out with odd jobs. Even if it had functioned, however, this arrangement would probably have proved inadequate to solve the flexibility problem on the shop floor. As it was, the lack of balance between the higher skill requirements for this key position in the shift groups and, on the other hand, the pay, security and working conditions offered, resulted in a disturbingly high turnover among the reserves.

Traditionally—and not only in the pulp and paper industry—management has seen apparent advantages in strict delineation and specification of individual jobs. The time needed for training is short and the supervisory control is strengthened through a clear definition of what each worker is accountable for. The workers for their part will tend to react to this system by interpreting the job specification as the maximum they owe rather than the minimum.

Beyond the first line of defence established by the union, the men make out of the job specification and customary practice a second line of defence against management. Moreover, within the welter of expectations about what is mine and what is yours, the men create a pecking order among themselves based on who gets the cosier jobs and who gets the less attractive ones.

Consequently, while the individual jobs may be lacking in intrinsic satisfaction, because of this rigid definition and segregation, they gain psychological significance because of what are merely relative advantages. As the men come to base their judgment of themselves and others on their ability to seize these relative advantages, they become stronger defenders of this system of job design than would be warranted by the built-in limitations for self-fulfilment.

As an example of this insidious trend, our post hoc analysis of the records revealed that one of the four digesters was a particularly good piece of equipment for pulping a certain wood. This we found was not public knowledge. In discussion, however, we found that one of the boilermen had already discovered this long ago and kept it to himself. This suggested to us at least that the lack of learning in the department was due not only to a laissez-faire attitude or feeling of uncertainty among the men, but that the system failed to encourage the men to share self-acquired knowledge, as they did not regard themselves as integrated members of a group.

Operator responses to task requirements—Our analysis of tasks and attitudes showed that, among the first three psychological requirements (Appendix 1), these jobs lacked mainly in the interest, excitement and self-enhancement that comes from being able to learn to do one's task better. Knowledge of results appeared adequate so long as learning was inhibited. The degree of variety and demand and the scope for personal control were higher than is usually found in industrial jobs and felt to be so by the operators.

This explained the relatively high level of job satisfaction expressed in interviews with senior operators and older workers, who had little reason to want to change in order to participate in a more comprehensive learning process that might disturb some of the privileges they had obtained. The more dependent nature of the assistant jobs and the particular situation of the reserves explain the lower level of satisfaction expressed by the second grade operators.

Interaction of operator roles with foreman and management roles—The position of the shift foreman in the chemical pulp department was introduced as a management response to increasing variances and planning problems arising after the changeover to the magnesium bisulphite method. This was in accordance with the traditional approach to organisational problems on the shop floor. These include such measures as specifying individual jobs in more detail, strengthening the hand of the supervisor, calling in specialists, introducing a new level in the organisation, etc. In this case, a short-term solution was achieved at the cost of a more serious long-term problem.

Recruited from among the best operators, the foremen would only with extensive training succeed in forming a leadership and planning position clearly ranking above and essentially complementary to the operating group. Familiar with operator work and lacking the means and self-confidence to lift himself to a new level, the foreman tended to focus his attention primarily within the work group rather than on controlling its boundary conditions. Hence, the foreman had developed the practice of being constantly on the move as a troubleshooter within the department; he would then do most of the unpredictable tasks that the operators were reluctant to carry out without special compensations (see remarks on additional hours), perceiving such tasks as falling outside their own strictly defined jobs.

The behaviour of the foreman then became part of a vicious circle of job segregation by reducing the job content and thereby further limiting the learning and growth potentials of the operators. As the first level of management was in this way lowering itself in order to complete the tasks within its particular area of command, so each higher level was correspondingly pulled down to fill out what was then lacking in control and co-ordination. The adverse consequences of such work organisation at the floor level will easily affect all levels of management, a fact typically found in large organisations. Even at Hunsfos, these tendencies were evident. By filling in for their subordinates, the managers and foremen were subtly redefining their own jobs in a way that reinforced the tendencies of the men on the shop floor not to show more initiative than was demanded by the traditional job design. Thus, the vicious circle was established.

Conditions for optimum control by self-regulation

WHEN the goals and purposes of an enterprise are operationalised on different levels in the organisation, it is not arbitrary which of the factors—throughput, quality, material, labour, etc.—are given the highest priority in the ongoing optimisation processes on each level. According to the theory of open systems, the choice of priorities will depend on conditions outside as well as inside the enterprise. Hence, at Hunsfos, we felt that key problems of optimisation on the two lowest levels of the socio-technical system were the following—

1. Process control to achieve for each product a given set of quality specifications minimising machine hours, cost of material, labour cost, etc. Among the cost factors, primary attention is usually paid to machine utilisation.

2. Production planning to achieve optimum allocation of products and orders for market requirements as well as production costs. Whereas the individual customer would vary in terms of quality demands, time of delivery, etc., machine down-time would depend on the size of the orders, the production sequence of products, etc.

The two activities are obviously interdependent and complementary, yet the latter area potentially contains tasks for which a new type of supervision could develop.

For the process control function, this type of technology requires that it matches an extended interdependency network, as well as meeting the demands for immediate responses in the social system. This implies that the control sequences have to be explored in detail. Generally speaking, a self-regulating production system requires at least the following components—

1. *A production unit* that converts a specific input material into a specific output.
2. *An output standard* against which the output of the production unit can be judged at any time.
3. *A measuring device* that can detect deviations from the target output standard and feed the information back to a 'brain' unit.
4. *A 'brain' unit* that can translate the information received into a new set of operational instructions, appropriate to returning the production performance to the target, while also taking the momentary input characteristics into consideration.
5. *An operation unit* capable of carrying out the operational instructions.
6. *An input standard* (usually identical with the output standard of the preceding production unit) against which the input can be judged and a feedforward to the 'brain' unit of information about momentary deviations.

Applied to man/machine systems, this classification implies that human elements to some extent will be part of the control sequence either by performing the component tasks or by transmitting information between the components. The effectiveness of the feedback loops will therefore depend on—

1. The properties of the components.
2. The transmission of information.

Firstly, considering the qualitative aspect of pulp production, we found that, among the output criteria most relevant to process control, only degree of digestion, brightness and tearing strength were measured systematically by the laboratory technicians. Cleanliness was judged subjectively from special test sheets, but factors such as pitch and homogeneity were too expensive or difficult for regular measuring. While there were no measurements on the quality of the input chips, information about pH value and percentage of sulphur dioxide in the acid were available. The use of standards and control limits were rarely based on statistical calculations. Because of the great variances observed in some of the quality measurements of individual batches, it was difficult to reveal long-term trends in the process control. The lack of feedback on this level reduced possibilities for continuous learning and control. With some improvements, we felt that these measurements might form the basis of a temporary bonus that would make potential group goals visible to the operators. Since the measurement requirements were insufficiently met for us to bring such aspects as throughput, yield, waste or material costs directly into the experiment, we shall only note in passing that the lack of measuring devices for dry weight and moisture content of the chips in the boilers restricted further learning among the boilermen.

Secondly, in order to keep the feedback loops as short as possible, we suggest that information and decisions be brought to the lowest organisational level for meeting the requirements for skill and responsibility, also that they kept within the fewest work roles that the constraints imposed by the technology and the means communication would allow for. Hence, the well-known benefits of specialisation and centralisation, which tend to extend the information flows across special barriers (work roles, skill differences, levels in the organisation, etc.), must be weighted not only against the obvious costs, incurred by delays and misinterpretations of the information, but also against the loss of task motivation and job satisfaction that pertain to tasks of a substantial degree of wholeness (a strong *gestalt*) and allowing the men themselves a sufficient measure of control over the materials and processes (see the second section).

As a consequence, the segregation of individual operator jobs and the division of labour among operator, laboratory technicians, cleaners, maintenance men and the supervisory levels were not necessarily optimum in terms of the total control requirements of the chemical pulp department.

A practical example of an inadequate feedback loop was test sheets showing the degree of cleanliness of the unbleached pulp, against which the screening performance was judged. These sheets were prepared by the laboratory workers about 1 h after the screening of a new batch had begun. Instead of returning these sheets immediately to the screener, who could then correct the ongoing process according to the information given, the sheets were formerly sent to the foreman and some of the supervisors in other departments. Since the foreman was frequently away from his office, the feedbacks to the operators were often delayed. This is a very obvious case, because there was neither a question of the workers' ability to interpret the information embodied in the test sheets nor any doubts that the other departments would also benefit by a change in this feedback procedure. The critical factor was the speed of the feedback.

Considering the technical means of communication, it appeared that telephones were missing at some critical points and that the system of written information could be improved upon.

Finally, since it was evident that optimum conditions for control could be achieved only if the flow of information matched the technical interdependencies of the process, the actual communication network among operators was analysed before and after the experiment (see summary of analyses and results, page 107).

Programme for redesign of jobs

BASED on the previous analysis, it was assumed that an optimum socio-technical system in the chemical pulp department could be achieved only if—

1. The men as a group took greater responsibility for the operation of the department as a whole.
2. They were enabled and initially encouraged to increase their understanding and control of the processes.

Consequently, increased autonomy for extended groups (across shifts) was a plausible name for the principle forming the basis of the experiment. The method of introducing change was to be step-by-step problem solving by small groups consisting of a representative from the workers, supervisors and management. Among the prerequisites for the development of partly autonomous work groups were—

1. Specification of the group's boundaries in relation to the environment (adjacent units).

2. Clarification and definition of what had to be measured in terms of quality and quantity of raw materials and services both received and delivered by the group as well as specification of quality control limits for the various criteria.
3. A proper incentive, such as a bonus, which could stimulate the group to co-operate.

The following specific measures were to be introduced in order to support the group arrangement—

1. Training the operators to make them as far as possible qualified for all tasks within the department.
2. Allocation of a special repairman to the operator group to cope with smaller breakdowns requiring immediate attention.
3. Setting up an information centre on the shop floor where measurements and other information were quickly available so that everyone would be aware of the current situation in the department. (If necessary, statistical methods would have to be employed.)
4. Arranging suitable conditions for department employees to meet in smaller or larger groups when necessary.
5. Installation of telephones in each department section.
6. Electing a group representative on each shift to facilitate communications.

The process of change

THE changes suggested in the programme were accepted by the management and by the majority of the workers in the department.

Gradually, but not without resistance on the part of some of the men concerned, the various measures were introduced with support from top management and from the union. In addition, operator training was linked to job rotation for the assistants, attempts were made to retrain the foremen and certain technical improvements were introduced in the bleaching. At the same time, the initiative in the socio-technical change process in the department was tranferred from the research team to a project action committee (with one representative each for management, for the foremen and for the operators), then to the department management. Finally, by January 1966, with the introduction of a marginal group bonus paid on cleanliness, tearing strength, degree of digestion and brightness, the new basis for operator participation was established.

The subsequent years of 1966 and 1967 can (in terms of our dependent variable, the level of personal participation) be divided for analytical purposes into a search, a growth and a stagnation phase. Hence, abnormal variances in the timber inputs initiated a search among the men for new means of process control.

With a return to normal inputs before the summer 1966, the results of the above effects, combined with the effects of the change in job design, had made the men experience a situation that allowed them to exercise more discretion. In 1967, however, the project did not get the necessary attention from the management, which at that time had to concentrate their efforts on market problems and a technical reconstruction programme. As will be seen, pulp quality reached a peak in the growth phase and thereafter stabilised at a higher level than before the experiment. Space allows only for a brief summary of the key points in the analysis and the major conclusions.

Summary of analyses and results

THE experiment was designed in such a way that pulp quality as measured by the bonus would be the best single index of operator performance. It is agreed within the company that a general improvement in pulp qualities has been achieved (Table 1). This applies to the bleached pulps in particular. In line with this, the number of extremely bad batches have also been reduced during the experiment. For the majority of the individual quality variables (for each pulp), there appears to be some correspondence between quality achieved and the changes in the conditions for operator participation.

TABLE 1—AVERAGE QUALITY BONUS PER WEEK AND PER BATCH ACROSS ALL TYPES OF TIMBER RELATED TO HALF-YEAR PERIODS OF THE EXPERIMENT

Period	*Average/week*	*Average/batch*
First half-year	100 per cent	100 per cent
Second half-year	145 per cent	140 per cent
Third half-year	124 per cent	137 per cent
Fourth half-year	124 per cent	123 per cent

This broad picture of the bonus trend is confirmed by the more detailed breakdown on pulp qualities.

Before inferring too much from these broad indices, we had to explore whether—

1. The improved quality was achieved at excessive costs.
2. The improved quality was due to improved performance on the group level.
3. There was some evidence that the men took a greater interest in their work.
4. The improvement could have occurred without the men changing their approach to the job.
5. The men themselves perceived the new situation as favourable.

Taking these points in turn—

1. There is no evidence that quality has been achieved at the expense of an increased consumption of material resources. The major costs (fibre, yield, chemicals and machine utilisation) that had shown decreasing trends before the experiment, continued to fall during the experiment (Table 2). There is, in fact, some indication that the experiment may have contributed to an increase in yield. It was agreed that manpower should be kept constant during the experiment.

TABLE 2—MEASURES OF COST OF VARIOUS MATERIALS BEFORE AND DURING THE EXPERIMENT

Materials	*Nine month period before experiment*	*Twelve month period during experiment*	*Percentage improvement*
Magnesium oxide per ton of pulp	106·0	91·0	14·0
Chlorine per ton of pulp	87·3	73·5	15·8
Sulphur dioxide per ton of pulp	128·0	123·0	3·9
Pulp yield per m^3 timber	100·0	103·8	3·8

2. The improved control of pulp quality can to a large extent be ascribed to the men who as a group assumed greater responsibility.

(*a*) The quality development of the main product (fir pulp), which goes through all steps in the process, also the bleaching, shows a clear improvement in cleanliness and tearing strength (Table 3). At the same time, the changes in the kappa number show that the boilermen have changed their strategy from overcooking to undercooking, whereas the changes in brightness shows that the bleachers have moved from underbleaching to overbleaching.[7]

The terms underbleaching and overbleaching are to be understood as relative to the given standards for kappa number and brightness, respectively. Nevertheless, these standards are arbitrary ones based on current knowledge and judgment about what would be required to achieve a given pulp quality with the available raw materials, technical equipment and labour force.

A detailed analysis of the situation revealed that the trends in pulp quality indicated could be explained only if the operators, on the basis of the new conditions established, had to some extent changed their attitudes towards the task and their way of working. From previously seeking to optimise within their own delineated work area, therefore, it appeared to be a change in orientation towards optimising on department level, which required an increasing awareness of the technical interdependencies between the part-processes (for example, the removal of lignin in cooking and bleaching, respectively). In other words, the operators now tended to take responsibility as a group.

This conclusion was supported by measurable changes in the pattern of communications and the increased problem-solving activities in the work groups.

(*b*) Analysis of the communication data shows that the flows of information after the experiment match the technical interdependencies in the process more

TABLE 3—BONUS AS A PERCENTAGE OF THE THEORETICAL MAXIMUM FOR PURITY AND TEARING STRENGTH

Quality dimension	*Type of wood*	*Phase*		
		Search	*Growth*	*Stagnation*
Cleanliness (spots)	**Fir**	**42**	**61**	**60**
	Hardwood	45	53	53
	Spruce	3	21	10
Tearing strength	**Fir**	**63**	**90**	**71**
	Hardwood	76	96	93

closely than before.[7] At the same time, the men as a group have attained a higher level of autonomy. It also appears that the assistant operators have now become better integrated into the groups. Table 4 shows that the increased interaction in 1967 in all essentials refers to the substantial growth in inter-operator communication (+70 per cent).

TABLE 4—NUMBER OF CONTACTS PER SHIFT BEFORE AND AFTER THE EXPERIMENT

Contact	*1965*	*1967*	*Difference, per cent*	*1965, per cent*	*1967, per cent*
Operator/operator	26·0	44·1	+70	25	34
Lab. technician/operator	37·7	37·7	0	36	30
Foreman/operator	34·6	39·4	+14	33	31
Foreman/lab. technician	7·6	6·7	+13	7	5
Total	105·9	127·9	+21	101	100

(*c*) Concrete examples of operator participation in problem solving and decision making within the department during the experiments also indicate that the men have increased their capability to operate as a team.

3. The operators have, during the period of the experiment, contributed a number of suggestions for improvement of the technical equipment and the working condition in general, demonstrating an interest in the job that they previously had not shown (Table 5). At the same time, the operators have become more interested in problems of process control, timber utilisation and costs.

4. Obviously, factors other than those included in the experimental design may have contributed to these improvements. It is unlikely, however, that the improved performance gained in the department during the experiment can be assigned to unilateral management actions (regardless of operator response) either in terms of the technical improvements introduced or in terms of the directives given. Indications of this were the lack of pressure from the men before the experiment for improvements in equipment or instrumentation and the fact that, when management's major concern in the summer 1966 turned to input costs, this had no effect on the strategies being followed by the operators

TABLE 5*—NUMBER OF SUGGESTIONS ADVANCED AND ACCEPTED IN THE OPERATOR MEETINGS

Date of meetings	*Shifts*	*Acid*	*Boiling*	*Screening*	*Bleaching*	*Total*
15th March 1966	3+4	5	5	11	3	24
25th March 1966 (additional)	1+2	1	9	3	3	16
August 1966	1+2+3+4	2	4	3	4	13
Total		8	18	17	10	53

* As a comparison, the company suggestion scheme had produced approximately one suggestion per year in the chemical pulp department for the period 1958–64

in the department. As far as our evidence goes, the improved control, the increase in operator suggestions and other changes in group activities were primarily due to the voluntary efforts of the men.

5. No doubt the experiment as it developed in 1966 caused many operators to build up considerable expectations and the feelings of disappointment that were brought out in some of the interviews clearly refer back to the fact that the project was in 1967 only half-heartedly followed up in the department because of other priorities. Unfortunately, at this crucial point in the experiment, new measures necessary to sustain growth in the desired direction, that many had hoped for, were not introduced. In accordance with the logic of systems, it is unlikely that changes in a part will be sustained over an extended period if the changes are not reciprocated by sufficient adjustments in the total system.(9) Within areas where permanent learning has taken place or new technological conditions have been established, however, the socio-technical system in the department appears to have reached a new level of functioning. This applies to pulp quality, operator skill and the degree of flexibility in the shift teams.

Further developments in the company

THE preconditions for a work group or department to assume the increased responsibility conveyed by a higher level of group autonomy are that— (*1*) critical variances in the process can be brought under control and (*2*) the change in job design and operator roles is sufficiently supported by adjustments in tasks and roles of the foreman and of the management. Changes in tasks and roles on department level, however, in the long run require adjustments on company level as well. In practice, this implies that the new principles of job design must be integrated into the objectives, policy and style of management, to guide the activities at all levels in the organisation. In principle, a part of a system influences other parts only through its effects on the total system.

Accordingly, during the autumn of 1966 and the spring of 1967, experiences from the chemical pulp department produced discussions of company policies among the top management. It was decided to follow up the project within the company with a new experiment in the papermill, where a team of operators would run two of the papermachines without shift foremen. The changes in job design that were introduced in 1968 have otherwise mainly corresponded to those in the chemical pulp department, but the initiative in the change process has consistently been carried by the parties concerned through a temporary project action committee. The first six months' agreement about experimentation was extended for another six months. Nine months after the jobs had been redesigned, one could ascertain definite growth in commitment to the new way of working among operators and management. The operating team had then showed that they were able to utilise their machinery in a very flexible way, even without shift supervision and the productivity trend proved very satisfactory.

Finally, by 1969, the company had decided on a three-year plan for re-designing the organisation that will include—

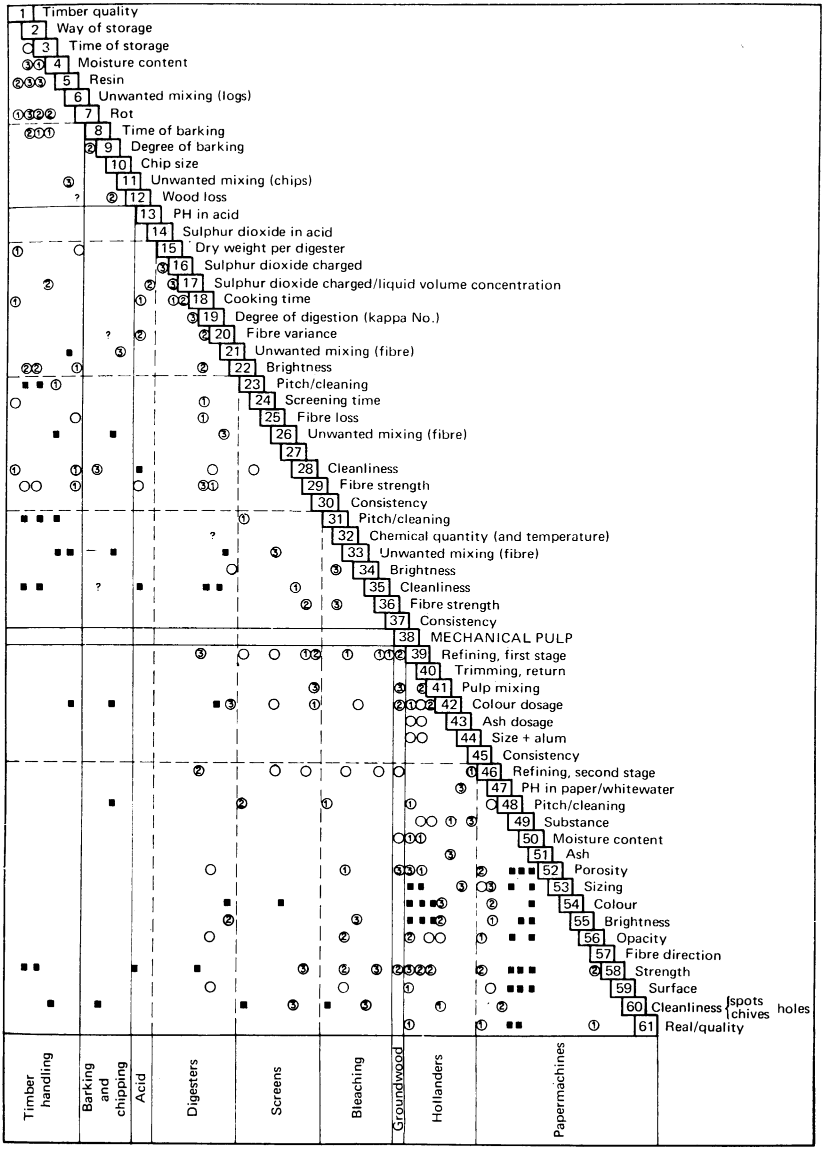
1. Comprehensive operator training for multiple skills and increased technical insight.
2. Doing away with shift supervision of the old type. (By 1964, it had been an explicit policy to strengthen the hand of the foreman.)
3. The introduction of a management philosophy that encourages local problem-solving activities.

In particular, on the basis of what we have seen in the fourth field experiment at Norsk Hydro, we believe that this way of working will lead to a self-sustaining learning process that will improve the reliability of the human component in the process of control as a whole.

Appendix 1—*Psychological job requirements*

1. The need for the content of a job to be reasonably demanding in terms other than sheer endurance, yet providing a minimum of variety (not necessarily novelty).
2. The need for being able to learn on the job (which implies standards and knowledge of results) and go on learning. Again, it is a question of neither too much nor too little.
3. The need for some minimum area of decision-making that the individual can call his own.
4. The need for some minimum degree of social support and recognition in the work place.
5. The need to be able to relate what one does and what one produces to one's social life.
6. The need to feel that the job leads to some sort of desirable future.

Appendix 2—*Matrix of variances*



Meaning of variances

0 – of theoretical interest only
1 – of little practical importance
2 – of medium practical importance
3 – of great practical importance

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    This article, which describes the use of the matrix of variances in socio-technical analysis, will also be published in English

Discussion

The Chairman As I understand it, you start out by defining new goals in many ways for the autonomous groups that you set up. Had you to change any of these goals during the course of your work and how did the men in the groups respond to this?

Mr P. H. Engelstad I think this is a relevant question, but what do you mean by goal—the goal of the men or of the company? We could observe that, when we started the experiment, for instance, it was very much concentrated on creating conditions for the men to do better than they had done before in terms of quality, by acting in an integrated way, when, because of bad timber coming in at the early phase of the experimental period, the expected quality improvements were not obtained. We could then see that the operators themselves were redefining their goals: they started to search for technical and other changes by which the process could be brought under better control. This is indicated in the tables of my paper showing the number of suggestions put forward.

The Chairman If, for example, the company decided to maximise quality, then later on decided to maximise production, how did you put these new objectives to your people and how did they respond?

Mr Engelstad That is quite an interesting matter. The goals set by the company were not clearly conceived by the operators. At the time of the experiment, the company was very conscientious about their quality reputation, so a quality bonus paid on a group level was introduced in the first place as a goal. When, later on, management became very much concerned about the cost of materials too, we could see no effect on the strategy followed by the operators. You can take that as a negative conclusion, but the fact was that these changes in goals were not properly translated into operational terms the men could use, which is exactly what the basis had been for introducing the quality bonus in the first place. The company is of course very much aware now of this link between how goals are perceived on different levels of the system.

Dr D. B. Brewster In an experiment like this, the Hawthorn effect usually occurs. This is an improvement in performance generally attributed to the special attention the people are receiving. This makes it difficult of course to sort out what the actual effect of the changes are. How did you avoid this problem?

Mr Engelstad In fact, we did nothing to avoid the Hawthorn effect, but it is very much a question of how you look at this effect. In my view, I think it is a positive effect that we should try to make permanent rather than as something to avoid. What we are trying to do in this kind of experiment is really to bring more interest into the operators' work and to create a situation where job holders are more interested in each other's job, particularly when these are interdependent.

Mr G. M. Boyle I would like to know something about what steps the company is actively taking to pursue the goals that you described for 1969. Specifically, you indicated that you would extend this notion throughout the company. How will you go about this?

Mr Engelstad May I refer you to the paper (*Further developments*, pages 110-1). The second point does not necessarily mean doing away with the foreman. The problem of the foreman, not touched upon very much in my paper, is that, being visually recruited from among the ranks of the operators, lacking in self-confidence and theoretical background, it is difficult for him without extensive training to bring himself up to a level where he is really *complementary* to the operators. If it is impossible to bring about this change in the foreman's position, then it might be better gradually to do away with his position.

All this is a very broad programme: I cannot at this stage give any information about the concrete steps that will be taken by the company.

Mr J. A. S. Newman A pulp and papermill contains not only process workers, but also engineers and technicians. Should these also be incorporated into the working groups? If so, how should their activities then be controlled?

Mr Engelstad Yes, it is quite true that this presentation is just part of the story. The total enterprise can in general be approached from two sides, probably simultaneously. On one side, the approach is from the socio-technical interface, which we have done and which I emphasise here, because it is the control problems of the *machines* that is the topic of this symposium.

The other thing, of course, is to approach the system from the environment side, which to a large extent defines the goals for the whole system. I have mentioned some of the principles of open systems in the paper, but I had to leave most of them out in the presentation, because time was short. To answer your question more specifically, not so very much has yet been done at management level in this particular company, which is only one out of four experimental sites that are part of this action research programme. Another company making artificial fertiliser is one of Norway's largest companies and there we have really moved in the ranks of the foreman, the engineers and middle management, introducing changes at these levels. Though I cannot go into this, there are very interesting developments in the relationships between operating groups and management roles.

The Chairman Mr Engelstad, is this reference 6 the definitive paper on your work?

Mr Engelstad Yes, it is going to be published in Norwegian now, but it will probably have a title other than that indicated there.

Mr J. W. Scott Could Mr Engelstad tell us how he actually went about getting his information, giving an example from a specific area? He has given us a summary of his conclusions and findings, but not the method by which they were obtained.

Mr Engelstad One part of the data collection will be interviews with people at all levels in the organisation. For instance, this analysis of the communications network was really based on interview responses. It could of course, have been based on the method of participant observation, which was used when we studied the foreman's role.

The matrix variances were constructed in close co-operation with some of the process technologists in the company. I hope it is possible to develop this method further, as it is really in its early stage. Furthermore, of course, we were on the site for about a year speaking regularly to all the people concerned. Finally, we collected production and labour statistics, analysed batch records, etc.