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New Manufacturing Technology and Work Design

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Thomas G. Cummings
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Melvin Blumberg
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To appear in The Human Side of New Manufacturing Technology, Wall, T.D., Clegg, C.W., and Kemp, N.J. (Eds.).
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Modern organizations are showing an increased interest in new manufacturing technologies. Driven by recent advances in computers and automated methods, these new technologies are rapidly expanding into most functions of manufacturing, including design, fabrication, assembly, planning, and control. They can drastically alter how organizations produce products, as well as deal with suppliers, customers, and support personnel. Perhaps most important, the new technologies can have a profound impact on work design--how tasks are grouped into jobs and work groups.

Preliminary evidence suggests that the full potential of the new manufacturing technologies may not be realized because of lack of attention to work design (Blumberg and Gerwin, 1984; Butera and Thurman, 1984). Organizations adopting the new technologies tend to pay far more attention to their technical aspects than to their work-design features. They tend to view the new technologies within the framework of existing work designs which may be inappropriate for operating the technologies. Moreover, although considerable research has been devoted to the new technologies, there is a dearth of information about their work-design implications.

This paper examines the crucial relationship between the new manufacturing technologies and work design. It explores in a preliminary manner how work can be designed to operate the new technologies most effectively. The first part of the paper briefly describes the most prevalent new manufacturing technologies used today. The second part presents a work-design framework which identifies alternative work designs and key contingencies determining their success. Based on the information in the first two parts, the third part of the paper explores how new manufacturing technology impacts work design. The final section draws implications for creating work designs for the new technologies.

New Manufacturing Technology

The primary goal of manufacturing technology is to provide organizations with a competitive advantage through enhanced product performance, reliability, quality, and cost superiority. When combined with good marketing and product-support services, manufacturing technology is the basis for market share, growth, and stability of employment. If manufacturing organizations are to compete successfully in today's world economy, the important question is not whether to adopt new technology, but how to accelerate its implementation.

There are essentially two types of manufacturing systems: continuous and intermittent. Continuous production can be either flow processing, as is found in such industries as petroleum, chemical and paper making, or mass production of discrete items, such as automobiles, refrigerators or straight pins. Continuous manufacturing systems tend to be highly automated with sophisticated command and control technology.

Intermittent production systems consist of job shop or small batch and large batch operations. Small batch manufacturing typically emphasizes obtaining and filling individual orders for varied products in lots of 100 or fewer per year. These are typically produced using general-purpose machines controlled by highly-skilled workers. Large batch operations involve production runs on the order of 100-10,000 units per year with frequent product-line changes. Machines are relatively unspecialized and controlled by a mix of skilled and unskilled workers. In contrast to continuous manufacturing, intermittent production generally follows no invariable sequence, remains in process longer, requires general purpose machine tools with skilled operators and is not highly automated. Because this form of manufacturing represents a high percentage of the manufacturing base in industrialized countries (over 35 percent in the U.S. according to Gerwin, 1982), it is the major target for applications of new manufacturing technology.

In this section, we briefly describe five new manufacturing technologies: (1) computer-aided design, (2) computer-aided manufacturing, (3) group technology, (4) robotics, and (5) flexible manufacturing systems. Although in practice these technologies are not mutually exclusive (e.g., flexible manufacturing systems are a form of group technology and can involve the use of robots), we will discuss them separately for ease of presentation.

Computer-Aided Design

Computer-aided design (CAD) has three major capabilities: interactive computer graphics, simulation, and data bases. In its simplest form, a CAD system is nothing more than an electronic drawing board. In its advanced forms, interactive computer graphics allow engineers and drafters to work in two or three dimensions by means of a light pen. Wire mesh can be generated automatically to perform finite element analysis of structure to simulate a product's reaction to stress. The results of design analysis can be displayed statistically or graphically showing distorted wire mesh or color stress patterns.

CAD programs are capable of performing geometric transformations enabling designers to rotate the product about any axis, to zoom in for a close up, or to take a distance perspective. Kinematics capability permits the parts to be placed into motion to check for mating with other parts or for vibration. Data bases are available which provide the capability to retrieve previously-designed products and to incorporate elements of them into new products. It is also possible to obtain hardcopy printouts of the drawings with prewritten textual material incorporated.

CAD systems can also generate manufacturing-process instructions, tapes, or programs for automatic machine tools, together with bills of materials. Thus, the same database used to design the product may also produce orders to vendors for parts and materials, manufacturing instructions for a nearly-unmanned factory, and manufacturing and financial information for other systems.

A recent challenge is to integrate CAD systems with other computer-aided functions. This has led to the development of a computer-integrated manufacturing (CIM) system in which CAD systems are linked via a hierarchically-ordered network of computers with other manufacturing and business systems, such as computer-aided process planning and tool design, computer-aided manufacturing testing and inspection, manufacturing resources planning, and financial performance reporting (Hubbard, 1985; Kegg and Carter, 1982).

Computer-Aided Manufacturing

The modern era of automated manufacturing technology can be traced to the development of record/playback technology by General Electric, Gisholt, and others in the late 1940s, and to the development of numerically controlled (NC) machine tools in the 1950s. Record/playback technology involves the production of a part by a skilled machinist on a specially-equipped machine which allows the speed, feed, and cutting motions under operator control to be recorded on tape. Numerical control, however, involves an entirely different philosophy of manufacturing (see Noble, 1980). Rather than relying on the capacity and willingness of human operators to generate optimal movements of the cutting tool, the instructions for NC tools are derived from mathematical equations representing the geometry of the parts to be produced. The equations are translated into a series of discrete instructions coded most commonly on paper or mylar tape. When fed into the machine's electronic-control unit, the taped instructions cause the cutting tool to move through the required trajectory.

With the development of compact and reliable microprocessors in the 1970s, it became possible to mount dedicated, stored-program computers directly on the machine tools to perform basic NC functions. These computer numerical control (CNC) tools were able to store and retrieve the information from a number of tapes and permit editing of existing programs to reflect engineering-design changes and correction of errors (See Noble, 1980). Early NC and CNC machine tools were able to perform only a single metal-cutting function, such as drilling. Modern machines equipped with automatic tool changers are able to perform a wide variety of functions, such as drilling, boring, tapping, and reaming without the need for operator intervention or movement of the work piece to a different machine. These advanced multi-function systems are referred to as "machining centers."

Computer numerical control has evolved into direct numerical control (DNC). Here, several NC or CNC machines are organized into a machining group or "cell" under the real-time control of a central computer. Inputs, bypassing the tapereader circuitry, are linked directly to the machine-control units regulating their operation and accumulating performance data.

Group Technology

Group technology is both a facility layout and a philosophy of manufacturing management that attempts to bring the efficiencies of mass production to batch manufacturing. Continuous production systems achieve cost effectiveness not so much by reducing machine time required to produce the parts, but by significant reductions in material handling, setup time, waiting time, and work-in-process inventories. Batch manufacturing, on the other hand, is typically organized by function. Parts are processed in lots, then transported to another machine for the next operation. Although this has the advantage of reducing set-up costs, it increases inventory costs because parts may spend days or weeks in transit and waiting. Parts must also be handled many times, increasing the likelihood of damage, and may travel several miles crisscrossing the shop floor to return to the same functional area many times.

Group technology begins with a recognition that similarities exist in the characteristics of parts involving their shape, weight, size, material, and process requirements. Next, these parts are associated with a group of machines possessing the necessary capabilities for processing them. Simply stated, group technology involves the identification of a "family" of parts and a "cell" of machines to process them. Ideally, a part is completed in a cell and there is no duplicate machinery between cells. (See Hyer and Wemmerlov, 1984 for an excellent bibliography and detailed discussion of the formation of group technology cells.) Research suggests that group technology can provide substantial savings in areas such as setup time, scrap, rework, and both in-process and finished-goods inventory (Hyer and Wemmerlov, 1984).

Robots

A robot, according to the Robot Institute of America (now called the Robotics Industries Association) (1980) is:

> A reprogrammable, multifunction manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks (p. 7).

Robots consist of two major subsystems: a controller and a manipulator. The controller is the mechanism, as complex as a microcomputer or as simple as a cam, which allows the robot to be programmed and guides its motions. The manipulator consists of the electro-mechanical, hydraulic, or pneumatic base which supports and powers the arm, and the arm itself. In addition to lifting capacity, manipulators are characterized by their ability to move the robot easily through different geometric patterns in three dimensional space, as well as their capacity, complexity, and cost. Manipulators are further classified in terms of their end effectors. Usually not part of the robot itself, the end effector consists of the rotational devices, grippers, and other tools which the robot uses to grasp, hold, bend, rotate, or press the material being processed.

Robots have been used primarily in manufacturing, particularly for unpleasant, hazardous, or monotonous tasks where worker turnover and product quality tend to be problematic. Major applications include welding, spray painting, material handling, machine loading and machining assembly (Kolpanen, 1984). In the U.S., robots have been increasingly applied to industrial training and education (U.S. International Trade Commission, 1983).

Future growth in the use of robots is highly speculative. Realistically, explosive growth of robots would depend on widening the scope of their application through improved technology, and on reducing their cost. If robots are to spread beyond the manufacturing sector, improvements are needed in such areas as proximity, touch, force, and vision sensors, and the ability to respond to spoken command. Also, improved software is needed which will provide robots with the ability to adapt to changes in their environment.

Flexible Manufacturing Systems

Flexible manufacturing systems (FMS) integrate most of the technologies just described. They are a natural outgrowth of group technology and CNC/DNC systems combined with automated tool changers, part conveyors, information reporting, and in more advanced forms, robots for material handling, inspection, or assembly tasks. FMS typically use one or more central computers for generating operation instructions, routing parts, monitoring activities, and compiling statistics. FMS can process a wide variety of parts, run in any random sequence. They can also acquire production capacity incrementally, convert production capacity as required by product life cycles, and produce other parts to be specified in the future (Hutchinson, 1976).

Blumberg and Gerwin (1984) extensively studied FMS and provided the following description of one in the United States. It was purchased in 1972 for approximately $5 million by the tractor division of a diversified manufacturer. The system, developed to produce six major housings for a new line of tractors, consisted of six general-purpose machining centers, four head indexers, three loading stations, and two computers arrayed over a floor area of approximately 9,000 square meters. The individual housings--approximately one meter cubes weighing about a metric ton each--were manually palletized and loaded onto carts with the aid of a crane and fork lift. Power for the carts was provided by 12 underground tow chains into which a tow pin attached to each cart was inserted. Under control of an FMS computer, the carts were routed to a work station where the palletized casting was transferred to the machine by a shuttle carriage. A DNC computer controlled processing of the casting. Then, it was returned to a cart and routed to its next work station or returned to a loading station. This process was carried on simultaneously for approximately a dozen parts of several families which appear in random sequence at the work stations.

The equipment was run on a two-shift, five-day schedule with an occasional third-shift skeleton crew. The shift crew consisted of a foreman, three loaders, three operators, a tool setter, and a mechanical repairman. Human intervention was required at the loading stations, and at the machines for inprocess inspection, reclamping, tool replacements, chip-clearing, and clearing of shuttle-carriage malfunctions.

A more advanced FMS is employed at Fujitsu Fanuc's factory in Japan. It consists of 29 machining cells served either by automatic pallet changers or robots. Palletized workpieces are transported between the work stations and storage areas by computer-controlled, wire-guided carts. At night, NC machining is monitored by a single worker stationed in a control room. Machining availability runs close to 100 percent, and machine use averages 65 to 70 percent (Usui, 1982; Merchant, 1983; Bylinsky, 1983).

Work-Design Framework

This section of the paper provides a framework for understanding work design. The framework derives from socio-technical system theory (Trist et al., 1963; Cummings and Srivastva, 1977), and includes designing jobs and work groups for high levels of productivity and employee satisfaction. Because work design ties people to technology, it provides the critical link between the new manufacturing technology just discussed and employee behaviors and attitudes.

Socio-technical systems theory includes two underlying premises. The first premise is that whenever people are organized to perform work, there is a joint system operating, a socio-technical system. It consists of two independent yet correlated parts--a technological part which consists of the tools, machines, and techniques required for task performance, and a social part which comprises the people and the relationships among them needed to perform the tasks. Because the technical and social parts must work together to create a useful product or service, it is necessary to design work to facilitate that interaction. This requires work designs that jointly match technological requirements and people's needs. Such jointly optimized work designs result in high levels of productivity and employee fulfillment.

The second premise is that socio-technical systems are open systems which exist in the context of a larger environment. The environment provides the system with needed inputs, such as raw materials, and serves as an outlet for system outputs, such as goods and services.

Table 1: Work Designs and Contingencies

CONTINGENCIES

	Technical Interdependence		Technical Uncertainty		Environmental Dynamics		Growth Needs		Social Needs	
Work Designs	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi
Traditional Jobs	X		X		X		X		X	
Traditional Work Groups		X	X		X		X			X
Enriched Jobs	X			X		X		X	X	
Self-Regulating Work Groups		X		X		X		X		X

Because socio-technical systems are dependent on their environment, they must create and maintain effective environmental relationships in order to survive and develop. This may require adapting to environmental changes, as well as influencing the environment in favored directions.

Based on these two premises, work design is aimed at jointly satisfying technological and personal needs, and matching environmental conditions. These technical, personal, and environmental contingencies determine the kinds of work designs that are likely to be most successful. This section first discusses these work-design contingencies, and then describes specific work designs appropriate to various combinations of the contingencies. Specific features of the work context which support the different work designs are also discussed.

Work-Design Contingencies

Technical factors. Two key technological features can impact work-design success: technical interdependence, or the extent to which the technology requires cooperation among employees to produce a product or service, and technical uncertainty, or the amount of information processing and decision making employees must do during task execution (Slocum and Sims, 1983; Cummings, 1978; Susman, 1976). The degree of technical interdependence determines whether work should be designed for individual jobs or for work groups. When technical interdependence is low and there is little need for employee cooperation, work should be designed for individual jobs. When technical interdependence is high, on the other hand, work should be designed for groups composed of people performing interrelated tasks. The amount of technical uncertainty determines whether work should be designed for external forms of control, such as supervision, standardization, and scheduling, or for employee self-control. When technical uncertainty is low and employees have to process little information during task performance, work should be designed for external control mechanisms, such as hierarchical supervision and schedules. Conversely, when technical uncertainty is high, work should be designed for employee self-control and decision making.

Personal factors. Researchers have found that at least two kinds of personal needs can impact work-design effectiveness: social needs, or the desire for significant social relationships, and growth needs, or the desire for personal accomplishment, learning, and development (Brousseau, 1983; Hackman and Oldham, 1980). In general, the degree of social needs determines whether work should be designed for individual jobs or for work groups. The greater are people's social needs, the more they should be satisfied with group forms of work. Growth needs determines whether work designs should be routine and repetitive or complex and challenging. The greater are people's growth needs, the more they should be attracted to enriched kinds of work offering high levels of autonomy, task variety, and feedback of results.

Environmental factors. The last work-design contingency involves the task environment of the socio-technical system. Because the system must exchange matter-energy and information with its environment, the nature of the environment should impact how the system is designed to manage those exchanges (Susman, 1966). Specifically, when task environments are relatively stable, exchanges can be programmed and standardized. In this situation, work designs should emphasize routine performance. Conversely, when task environments are relatively dynamic and are changing unpredictably, exchanges must be managed adaptively as the circumstances demand. Here, work should be designed for high levels of information processing and decision making, and should emphasize flexible behaviors.

Work Designs

The technical, personal, and environmental contingencies affecting work-design success can be used to identify four pure kinds of work design suited to different combinations of the contingencies: (1) traditional jobs (2) traditional work groups; (3) enriched jobs; and (4) self-regulating work groups (Huse and Cummings, 1985). The work designs and relevant contingencies are shown in Table 1, and described briefly below.

Traditional jobs. Historically, the tendency has been to break jobs down into their simplest components and to specify the tasks and work methods of the components. Individual jobholders are expected to do routine and repetitive work, with planning, evaluation, and decision making being relegated to others, such as supervisors, inspectors, and engineers. Although traditional jobs have come under increasing criticism by quality-of-work-life advocates, the contingencies shown in Table 1 suggest that under the following conditions, such jobs can be productive, satisfying, and responsive to environmental exchanges: when technical interdependence and uncertainty are both low; when people have low social and growth needs; when the environment is stable.

Traditional work groups. These are composed of members performing routine yet related tasks, such as might be found on assembly lines. The group task is typically broken down into simpler, discrete parts, often called jobs. The tasks and work methods are specified for each part, and the different parts are assigned to group members. Coordination and control of members' performances and of environmental exchanges are carried out by external control devices, such as supervision and schedules. Traditional work groups are most effective: when technical interdependence is high yet technical uncertainty is low; when people have high social needs yet low growth needs; when the environment is stable.

Enriched jobs. These work designs provide employees with increased opportunities for responsibility, decision making, and challenge. Individual jobs are designed for high levels of skill variety, autonomy, and feedback about results. The task is also organized so jobholders experience a whole piece of work which has positive significance for others, such as co-workers or customers (Hackman and Oldham, 1980). Enriched jobs are most successful: when technical interdependence is low but technical uncertainty is high; when people have low social needs yet high growth needs; when the task environment is dynamic.

Self-regulating work groups. Alternatively referred to as autonomous or self-managing work groups, these work designs involve multi-skilled members controlling their own task behaviors around an overall group task. The task forms a relatively self-completing whole, and members are given the necessary autonomy, skills, and information to regulate task behaviors and manage environmental exchanges (Cummings, 1978). The group may help determine production goals, as well as perform such functions as inspection, maintenance, purchasing, and hiring new members. Self-regulating work groups are most effective: when technical interdependence and uncertainty are both high; when people have high social and growth needs; when the task environment is dynamic.

Work Context

Work designs exist in a larger organizational context which can impact whether the designs are implemented and operated effectively. This work context consists of various personnel, measurement, and control practices having to do with the selection, training, compensation, and supervision of employees. To the extent that these practices fit or match the work designs, they are likely to reinforce the kinds of task performances required to operate the designs. Historically, organizations have devised a traditional set of personnel, measurement, and control methods which support and reinforce traditional forms of work designs. These practices reinforce repetitive behaviors, with low amounts of decision making and self control. In order to operate enriched jobs and self-regulating work groups, however, these traditional practice need to be modified. Selection needs to be aimed at employees with growth and/or social needs, while training programs need to emphasize multiple skills, complex decision making, and self control. Similarly, compensation practices need to reinforce both learning and good performance at the individual level for enriched jobs and at the group level for self-regulating work groups. Finally, supervision needs to support employee growth and decision making.

The Impact of New Manufacturing Technology on Work Design

So far, we have described briefly the new manufacturing technologies being applied to organizations today, and introduced a contingency framework relating different work designs to different technological, personal, and environmental conditions. Given this knowledge, we can now examine the key interface between the new technologies and the work designs, with particular attention to the kinds of work designs necessary for operating the technologies effectively.

Unfortunately, there is little research directly relating new manufacturing technologies to work design. Most of the relevant literature is at best speculative regarding this key interface, typically offering general predictions or observations about how the technologies are likely to affect employees' work lives, organization strategies and designs, and labor market characteristics (see, for example, Susman and Chase, in press; Ayres and Miller, 1983; Bylinsky, 1983). The relatively few empirical studies in this area have tended to offer rich case descriptions of the introduction of the new technologies into organizations, with relatively little direct examination of work-design effects (see, for example, Argote et al., 1983; Petro, 1983).

In the relative absence of an extensive body of scientific knowledge relating new manufacturing technologies to work design, we will first offer some reasonable speculations about this linkage. This can be accomplished by examining how the new technologies can be expected to impact three key work-design contingencies: technical interdependence, technical uncertainty, and environmental stability. Such information provides a reasonable basis for predicting which work designs are likely to be most appropriate for the contingencies. Then, in light of these predictions, we will review three case studies examining the introduction of new manufacturing technologies into organizations. We will assess the extent to which the organizations' work designs match the demands of the new technologies, as well as the consequences of that matching. This information should allow us to draw several pertinent implications of the new technologies for work design effectiveness.

New Technologies, Contingencies, and Work Designs

The new technologies can be expected to have a number of impacts on the technological and environmental contingencies determining work design success. Knowledge of these effects is necessary to specify the kinds of work designs most appropriate to matching the contingencies.

Technical interdependence. This technical contingency refers to the extent to which the different parts or phases of the technology are interrelated requiring cooperation among employees to produce a product or service. In general, the new manufacturing technologies seem to score high on this dimension. Flexible manufacturing systems, for example, integrate the different phases of the manufacturing process, such as design, fabrication, and assembly, into a tightly-coordinated yet flexible system. Central computers control operations, materials transfer, monitoring, and scheduling. This helps to reduce unnecessary buffer inventories and to shorten lead times between the production of different products. Because the overall flow of production is accelerated and more tightly linked, technical interdependence is greatly increased. Similarly, in computer-aided manufacturing, different CAD systems are linked via a network of computers with other manufacturing and business systems, thus increasing the interdependence among these components.

Technical uncertainty. This dimension involves the amount of information processing and decision making that employees must do during task performance. The new technologies drastically reduce the amount of routine information processing and decision making that employees customarily do. Automated production systems, such as computer-aided manufacturing and flexible manufacturing systems, are generally capable of detecting and correcting many of the variances occurring during operation with relatively little human intervention. There is increased need, however, for employees to manage the unforeseen and nonroutine variances that cannot readily be controlled by computers. Such variances can be particularly costly in new manufacturing technologies. They can quickly shutdown the entire manufacturing system because the different parts are highly integrated; they can result in large amounts of inferior product because of the accelerated speed of production. In order to control nonroutine variances rapidly and as close to their source as possible, employees must process a good deal of information and engage in complex problem solving and decision making in real-time. Consequently, they must cope with a high level of technical uncertainty during task performance.

Environmental stability. This final contingency refers to the extent to which the task environment of the manufacturing system is predictable and allows programmed and routine responses. Traditional manufacturing technologies tend to face relatively stable task environments. They are buffered or decoupled from external disruptions by such mechanisms as raw-materials and finished-goods inventories. The new manufacturing technologies, on the other hand, potentially face more dynamic task environments. The technologies are more tightly coupled to vendors and customers, as well as to staff and service functions in the organization. Thus, unpredictable changes in these external functions can place severe demands on the system's adaptive capacity. Flexible manufacturing systems, for example, have few inventories, and are susceptible to disruptions in raw material deliveries and to bottlenecks in the transportation and distribution system. Although many of these external disruptions can be routinely managed, the tighter coupling of the manufacturing system to its task environment requires more timely, novel responses when unpredictable conditions are encountered.

Work designs. The above analysis suggests that new manufacturing technologies are likely to result in higher levels of technical interdependence, technical uncertainty, and environmental dynamics. If so, appropriate work designs should be oriented to groups of employees rather than individualized jobs, and to employee self-control and decision making rather than external forms of control, such as supervision. This calls for self-regulating work groups, a conclusion also reached by others examining work-design implications of the new technologies (Susman and Chase, in press; Blumberg and Gerwin, 1984). Such groups are organized around interdependent tasks to facilitate coordination of task performance. For example, they might by responsible for a manufacturing cell or an entire shift in a flexible manufacturing system. Members are given the necessary skills, information, and freedom to respond to unforeseen disturbances arising from within the production system and its task environment. They have the multiple skills to deploy themselves as the circumstances demand, and the capacity to detect and control nonroutine variances. For example, group members might rotate between jobs, sharing the burden of the most boring tasks and gaining greater insight of the overall manufacturing process. They might be responsible for engaging with management and service staff in on-line problem solving.

Case Studies

Now that we have derived a relevant work design for the contingencies associated with the new manufacturing technologies, we can examine three of the few field studies assessing the introduction of the new technologies into organizations. We are especially interested in whether the organizations responded to the new technologies by redesigning work along the lines suggested here, self-regulating work groups. If so, productivity and employee satisfaction should be relatively high, particularly if employees have high social and growth needs. On the other hand, failure to design work appropriately should have negative consequences for managing necessary technical interdependencies and nonroutine variances arising from the technology and the task environment. Employees should have problems achieving high levels of productivity, and they should experience undue stress and trouble in trying to operate with an inappropriate work design. The three case studies include the introduction of computer-aided design into a drafting department, the application of a robot in a manufacturing plant, and the implementation of a flexible manufacturing system in a tractor factory.

Case 1: Computer-Aided Drafting. Petro (1983) studied the drafting department of a northern New Jersey manufacturing company with annual sales of $130 million. After an exhaustive search lasting nearly two years, the company purchased a computer-aided drafting system called CADAM based upon its compatibility with the company's mainframe computer.

All decisions regarding the new equipment were made by managers. They communicated with vendors, attended demonstrations, and after the purchase decision was made, decided how to implement the new equipment. Only after the system had been purchased--three months prior to its installation--were drafters officially advised of the imminent change. Prior to the official announcement, however, word of the purchase had circulated via the company grapevine raising considerable speculation and fear about job reassignment and layoffs.

According to Petro, the first meeting between management and the company's drafters lasted about an hour, and consisted of an explanation of the CAD system's capabilities and its potential benefit to the company. No actual demonstration was given, nor were potential employee benefits discussed. Management representatives made commitments that there would be no layoffs because of the CAD system. They also stated that the position of CAD operator was considered a lateral move for drafters with no increase in pay over the old system. Management then requested volunteers to work on the new system. Of 40 drafters present, eight volunteered; four of those subsequently withdrew. The remaining four were trained by the vendor.

Management's original plan was that all drafting would be done by the CAD operators with the remaining drafters doing set up and checking tasks. It soon became apparent that the four CAD operators could not service the entire workload. Additional work stations and a second shift were added. At the time of the study, a call for more volunteers had been issued with little response.

In an attempt to determine the reason for the lack of interest in working on the CAD system, Petro interviewed the drafters who refused to volunteer. A typical first response was, "Why should I go learn a new job with more pressure for no more pay?" When pressed further, the drafters admitted a fear of being unable to master the new job. A typical remark was, "I don't know anything about computers."

When the drafters were asked how they felt their job status compared with that of the CAD operators, the majority responded that their present status was equal to or slightly above that of the CAD operators. The CAD operators, on the other hand, responded that their new job status was considerably higher than that of their previous job. There also appeared to be friction between the CAD operators and the remaining drafters. Some drafters continued to do drawings manually and even took work home in an effort to show that the new system was less productive than the old method. When management learned of this, reprimands were issued. This further exacerbated the deterioration in the required working relationship between the manual drafters and the CAD operators, resulting in a further decline in productivity.

Petro referred to this behavior as the "Bunyan syndrome." Paul Bunyan was a legendary American folk hero and lumberjack who boasted that he could outperform anyone in cutting trees. According to legend, when power saws were invented, a contest was called. After mighty effort and close results, Bunyan lost and faded from the scene to be replaced by lesser men with better equipment.

Petro also interviewed persons in departments which depended upon the CAD department for the drawings necessary to produce customer orders. Interfaces with other departments were particularly troublesome because the CAD department did not have its own manager who was available to deal full-time with scheduling problems and to communicate with user departments. People in other departments felt animosity toward the CAD system because it affected their ability to meet schedules, yet it afforded no direct way to communicate with "it."

When the system was originally purchased, it had a dedicated computer and excellent response time. However, the company's information systems department began using the CAD computer for other purposes, and response time of the system fell with resulting boredom for the CAD operators and loss of productivity for the drafting department.

Another interesting outcome of Petro's study concerns a different aspect of the CAD system's impact on operator productivity. He found that the CAD system multiplied the effectiveness of all of the workers. However, this productivity effect was greatest for those manual drafters having the highest level of skills.

Finally, Petro found that pay was a major source of dissatisfaction for the CAD operators. Because most of the literature on CAD systems was written by equipment vendors, there was little mention of appropriate pay scales for CAD operators. However, once pay scales from comparable firms became available, the salaries in the company under study were shown to be below the norm. Even though management had initially stressed that CAD operators would be paid the same as manual drafters, the operators felt that management would have to change this policy. Older operators appeared willing to accept the situation, yet younger ones indicated they were ready to leave when a better offer became available. The dilemma facing management was either to assign drafters to the CAD system rather than depend upon volunteers, or to hire from the outside at a premium salary. In the letter case, the firm would have to deal with the problem of salary inequity for existing workers. It would also have to layoff some of the present drafters and thereby break the original commitment not to do so.

Case 2: Robotics. Argote, Schkade and Goodman (1983) studied employee reactions to the application of a robot in a non-unionized manufacturing plant employing approximately 1,000 people. The robot was introduced into a department responsible for grinding and milling bar stock. The department employed 40 people spread over three shifts. The robot was placed at the beginning of a horseshoe-shaped line through which products proceeded sequentially. The robot was used to load and unload two milling machines, and was operated by one person on each shift.

The company informed employees about the robot approximately one year before it was installed. Talks were given by the plant manager, notices were placed in the cafeteria, and discussions were held with first-line supervisors. In addition, the company held an open house during which the robot was demonstrated.

Workers were interviewed twice, several months before and several months after the robot was put on line. Interviews were conducted with first-line supervisors, higher-level managers, and production staff and support personnel from other departments.

Implementing the robot involved creating a manufacturing cell consisting of two milling machines, the robot, and an employee. The robot took over the material-handling task previously performed by a human operator. The operator's task changed from largely physical activities to more cognitive monitoring and control activities. This required the development of new skills aimed at problem solving, controlling the interface between the milling machines and the robot, and programming and operating the robot.

The introduction of the robot was stressful for employees. The researchers suggested that this stemmed in part from having to learn new tasks and responsibilities, and partly from operating a new and expensive piece of equipment. There was also some evidence of the Bunyan Syndrome here too. In the early interviews, Argote and her colleagues reported that there was considerable speculation regarding whether an exceptional operator could outpace the robot. In the later interviews, operators appeared resigned to the fact that the robot was faster. As the researchers pointed out, even though operators knew objectively that they were operating the robot, subjectively they still considered themselves in competition with it.

Although the robot did not change the workflow in the department, it did alter some of the interaction patterns. Operators reported that they had less time to talk with their co-workers because they needed to concentrate more on the task. There were also changes in relationships with other departments. Operators had to interact more frequently with support personnel from the engineering and maintenance departments.

Support personnel also felt that their jobs had changed. The robot represented a new level of complexity for maintenance, engineering quality control, and scheduling. The researchers reported feelings of frustration among support personnel. They were not involved in planning for the new robot, and they needed to acquire new skills and procedures.

Pay for the new job classification was also an issue in this case. Management re-evaluated and reclassified the operator's job based on task changes. Although the job was subsequently upgraded, workers felt that the new pay grade was too low for the skills required.

Case 3: Flexible-Manufacturing System. Blumberg and Gerwin (1984) and their colleagues (Blumberg and Alber, 1982; Gerwin, 1982; Gerwin, 1981; Gerwin and Tarondeau, 1982; Gerwin and Leung, 1980) studied the individual and organizational impacts of flexible manufacturing systems in five firms in Europe and the U.S. The first phase of the research began in 1979 with semi-structured interviews of managers and staff specialists in such areas as manufacturing, quality control, maintenance, manufacturing engineering, and data processing. These interviews led to more specific questions, and finally culminated in an in-depth survey of foremen and worker reactions to a flexible manufacturing system in an American firm (the same FMS described previously in this paper).

The plan to adopt the new technology was part of a corporate strategy to replace obsolete, single-purpose machinery with more modern equipment needed to produce a new line of farm tractors. The decision to purchase a FMS rather than some other technology was made by an *ad hoc* task force from the company's industrial-engineering department.

The FMS went on line in 1972, and was the second one implemented in the United States. After installation, a team of highly-skilled personnel led by engineers from the manufacturing-engineering department initially operated the equipment. This improved equipment utilization during the break-in period, but created other difficulties when the equipment was turned over to operating personnel.

Blumberg and Gerwin designed a comprehensive questionnaire for measuring several factors which have been shown to affect employee performance, motivation, satisfaction, attendance, and retention. These included variables having to do with task characteristics, personal growth needs, job satisfaction, equitable rules and pay, healthful and safe working conditions, meaningful work, work-related stress, job attitudes, job switching, and aspirations for the future. (See Blumberg and Gerwin, 1984; and Blumberg and Alber, 1982 for a complete description of the measures used.) The research sample consisted of two foremen, two machine repairmen, six operators, six loaders, and two tool setters. All employees were male and worked a two-shift, five-day schedule. Except for the foremen, all of the employees were members of the United Auto Workers Union.

Questionnaire results were compared with the responses of a normative sample of employees in the machine trades and a more general sample of employed adults. (See Blumberg and Gerwin, 1984 for details and sources). These comparisons suggested that jobs on the FMS were not sufficiently enriched in terms of meaningfulness, autonomy, task identify, responsibility, and feedback. Consequently, employee work motivation was low.

The researchers also found that job satisfaction was generally low, although it varied somewhat with occupation. Employees with higher paid, more challenging occupations tended to have higher job satisfaction. Results for work-related stress indicated that work on the FMS was relatively stressful, especially for two stress factors -- inability to use valued skills and likelihood of job loss. Interestingly, foremen felt that employees had too much say about workplace decisions, while employees felt that they had too little participation in decision making.

Blumberg and Gerwin also asked a number of open-ended questions. In response to a question asking what the men hoped to be doing in five years, over half responded they would like to be in lines of work having more variety and responsibility. Sixteen of the eighteen employees responded that they felt worried about health and safety, particularly from moving carts and fumes caused by the coolant. They also identified five major problem areas: pay, performance, maintenance, safety, and tooling.

Pay problems centered around the lack of an incentive system. FMS operators were the same pay grade as other machine operators, but could not earn additional money because the equipment set the upper limit to productivity. They were extremely dissatisfied because lower-skilled employees were on an incentive system and frequently made more money than they did. Moreover, once assigned to the FMS, employees were not allowed to "bid off" to other areas where they could earn incentive pay.

Performance problems resulted from people on one shift not completing work properly, not making needed machine adjustments and tool changes, and not cleaning the equipment and adding coolant. This negligence made work more difficult for the next shift.

Maintenance problems resulted, ironically, from the versatility of the FMS. Because it made many key parts that directly fed the production line, there was little opportunity to take the equipment out of service for needed maintenance. Management was also unwilling to schedule mechanics for overtime on third shift, weekends, or during plant shutdown. Consequently, a number of "quick fixes" had been installed that made machine operation very eccentric. This angered many of the operators who constantly had to kick or push parts into position when a 20-minute maintenance procedure was denied during working hours.

Tooling problems had to do with disorganization of the tool room, lack of enough tooling, and insufficient time to adjust certain tooling properly. Moreover, because tooling as well as spare parts for the FMS were very expensive, management was reluctant to keep sufficient stock on hand.

Blumberg and Gerwin's study suggests that work on the FMS had little potential for motivating people, was not very satisfying, and was stressful. Unfortunately, the work situation also seemed to lack opportunities for extrinsic motivation. Pay, especially the lack of an incentive system, was of major concern to most of the employees. Other factors affecting motivation were job stress, health and safety worries, and frequent equipment breakdown or eccentric operation.

Case Studies and Work Design

The three case studies provide a much-needed empirical examination of the consequences of introducing new manufacturing technology into existing organizations. Although the studies involve different kinds of technology and different industries, they offer some strikingly similar observations regarding work-design effects.

First, work redesign appeared to receive only scant attention in the organizations. Although there was ample realization that operating the new technologies required learning new skills and behaviors, there was little if any recognition that traditional job designs should be modified accordingly. As suggested previously, the new technologies seem suited to self-regulating work groups. Yet, none of the organizations appeared to move in this direction, with the possible exception of the robotics case, where employees' jobs involved more decision making and self-control. In the CAD case, the new jobs were treated as equivalent to the existing, traditional drafting jobs. Similarly, in the FMS case where technical interdependence and uncertainty were highest and where self-regulating work groups would be most relevant, jobs remained factionated along functional lines--e.g., machine repairmen, operators, loaders, and tool setters. Thus, the organizations seemed to respond to the new technologies within the framework of existing, traditional job designs. They showed little appreciation for the need to redesign work in the directions suggested here.

Second, the new technologies resulted in increased interdependence between the organizations' production system and various support, supplier, and user groups. Yet, there appears to have been relatively little recognition that such interfaces might require special attention and work redesign. In all three cases, support personnel had problems relating to the new technologies. They had to learn new skills and procedures to service the technologies; they had to face new demands that affected their ability to function effectively. These external groups were afforded few opportunities to influence either the design of the new technologies or the way they related to them. Moreover, the organizations paid relatively little attention to redesigning work so that employees operating the new technologies could better manage interdependencies with other units. Again, there appears to have been little recognition of the way the new technologies had changed key technical and environmental contingencies, and of the need for redesigning work to account for those factors.

Third, in addition to neglecting the work-design effects of the new technologies, the organizations also appear to have underestimated the degree to which the work context should be modified to support the new tasks. In all three cases, employees experienced pay inequities in operating the new technologies. In the CAD and robotics cases, employees had to learn new skills and perform new tasks, and felt that pay should be adjusted to account for these changes. In the FMS case, the new technology set upper limits on productivity, and thus employees were not able to take advantage of the company's incentive system. Rather than recognizing and resolving pay inequities initially when the new technologies were being designed and implemented, the organizations confronted the pay problems only after they had become a major source of employee dissatisfaction. Similarly, in all three cases, employees experienced stress associated with the new technologies, yet the organizations failed to anticipate and help manage the stress before it became a problem. In the CAD and robotics cases, the stress resulted from having to learn new tasks and to make significant changes in work methods. In the FMS case, stress was the consequence of underutilization of employees' valued skills and of fear of job loss. Rather than take special steps to confront and manage these problems, the organizations seemed to treat the introduction of the new technologies as something that could be managed with traditional organizational responses.

Fourth, the three cases show the negative consequences that can result when organizations fail to redesign work and modify the work context to accommodate new manufacturing technologies. As described above, there was considerable employee dissatisfaction with pay, as well as stress associated with learning new skills and performing new tasks. In the FMS case where employees felt that the new technology had not sufficiently enriched their jobs, work motivation and job satisfaction were generally low. Employees also felt that there was too little participation in decision making, and that in the future, they would like work having more variety and responsibility. In all three cases, there was a general dissatisfaction with the way the new technologies were linked to external support groups. Thus, the negative consequences were not limited to employees directly operating the new technologies but were experienced by those indirectly impacted by them.

Implications for Work Design

The work design framework and case study analyses suggest a number of practical implications for creating effective work designs for new manufacturing technologies. Because there is so little research in this area, the implications should be treated as general guides to work design rather than precise, scientific prescriptions. Clearly, there is considerable need for conceptual refinement and empirical exploration in this area.

Work Design Choices

Choices about work design should take into account those technical, environmental, and personal contingencies determining work design success. Analysis of the new manufacturing technologies suggests that they are likely to result in increased amounts of technical interdependence and uncertainty and of environmental dynamics. If so, the most appropriate work design should be self-regulating groups, where members interact around interdependent tasks and have the necessary skills, autonomy, and information to control technical and environmental variances as close to their source as possible. Such work groups derive from socio-technical systems theory, and were initially applied in continuous-process technologies, such as oil refineries, coal mines, and weaving mills (e.g., Hill, 1971; Susman, 1970; Trist et al., 1963). Interestingly, the new manufacturing technologies have many of the properties of continuous-process technologies, particularly tight integration among the different functional parts. Thus, earlier attempts to create work designs relevant for continuous-process technologies seem to have contemporary relevance to new manufacturing technologies.

Susman and Chase (in press) suggested that designing work for the new technologies requires a fundamental choice about whether to downgrade or upgrade the skills of shopfloor employees. A downgrading strategy would relegate most decision making and variance control to managers and support personnel while leaving lower-level operatives to perform whatever simple tasks cannot readily be automated. Although this approach affords management more control over shopfloor personnel, it may increase managerial and staff overhead costs as well as sever the learning loop between those who initially detect variance and those who subsequently correct it. Given these problems, Susman and Chase argued strongly for an upgrading strategy where employees have the necessary skills and abilities to regulate their own work activities and control variances. Such upgrading is congruent with applying self-regulating work groups to the new technologies. It provides employees with the skills and abilities to operate such work designs.

In addition to upgrading employee skills, applications of self-regulating work groups require attention to key individual differences that impact how employees respond to work designs. Specifically, employees having high growth needs and social needs are likely to be most responsive to self-regulating work groups. They would enjoy the challenge and opportunities for development afforded by increased skill use and decision making; they would like the social contact of working in an interactive work group. Thus, choices about applying self-regulating work groups to new manufacturing technologies also involve decisions about upgrading employee skills and about selecting employees with high growth needs and social needs. Such choices have important implications for modifying the work context to support and reinforce self-regulating groups.

Work Context Modifications

As suggested previously, the larger work context can affect whether work designs are implemented and operated effectively. The organization's personnel, measurement, and control practices need to fit with and reinforce the kinds of task behaviors implied by the work designs. Self-regulating work groups require interactive performances around an overall group task as well as considerable information processing and decision making during task execution. The following work-context features can be expected to support those task behaviors:

1) Selection practices that are aimed at employees having high growth needs and social needs. This can be facilitated by providing potential recruits with realistic job previews about working in self-regulating groups and allowing them to voluntarily self select into such work designs (Cummings and Srivastva, 1977). Although direct measures of these individual differences can also be obtained, they are probably

better used for helping people make more informed job and career decisions than for selection purposes.

2) Training programs that help to provide employees with multiple skills needed to detect and control technical and environmental variances, and social skills necessary to engage in group problem solving.

3) Reward systems that promote learning multiple skills and performing tasks effectively. This might include a skill-based pay system where employees are compensated for the breadth and/or depth of skills they have mastered (Lawler and Ledford, 1984). It could also involve a group-based, pay-for-performance system where the overall group is rewarded for specific productivity gains (Lawler, 1981).

4) Management styles that are oriented to helping group members develop the necessary competence to make work-related decisions and solve complex problems. This leadership role would be highly consultative and include helping the group manage key external interdependencies.

The Design Process

A final implication of the work-design framework and case-study analyses involves the process by which work designs are formulated and implemented. Organizations have traditionally viewed work design as something that occurs after the technical system has been designed. They have tended to design the technology and then adapt or fit the work design to it. This can severely limit the time needed to develop a fully-functioning work design. Self-regulating work groups, for example, take considerable lead time to develop. Employees need to gain the multiple skills necessary to operate the technology; they need the teambuilding necessary to form a problem-solving group. These developmental activities may take as long if not longer than the time needed to make the new manufacturing technologies operational. Consequently, work design needs to be considered early in the design process when the new technologies themselves are being designed. This would provide more lead time to develop the work design. It might also result in a better fit between the work design and the technology because both would be designed jointly.

In addition to designing work earlier in the design process, organizations need to treat subsequent implementation of the work designs as an evolving process requiring considerable learning and adjustment (Cummings and Mohrman, in press). In contrast to implementing technology which tends to follow a mechanical-construction process, implementing work designs requires a more developmental process. Work designs generally proceed through a series of growth stages as they develop towards maturity. Employees need to learn new skills and procedures as well as the behaviors required to enact the designs. This learning requires continual feedback about how the new work design is progressing. The feedback enables employees to make necessary adjustments in the design and their behaviors as the circumstances require. In implementing self-regulating work groups, for example, members may use information about their interactions to make adjustments in how they jointly detect and control variances. This feedback/adjustment cycle continues until the work design is implemented fully. It supports the learning required to implement the work design.

Conclusion

New manufacturing technologies are increasingly being implemented in modern organizations. These technical advances raise expectations for significant improvements in production and responsiveness to customer demands. In order to achieve the full impact of these improvements, however, organizations need to design appropriate work structures to operate the new technologies. The work designs need to be responsive to specific technical, environmental, and personal contingencies associated with the new technologies. Moreover, organizations need to assure that their personnel, measurement, and control practices support and reinforce the work designs.

Although there is little research on the relation between new manufacturing technologies and work design, a review of the few empirical studies strongly suggests that organizations may have problems implementing and operating the technologies. They tend to view the new technologies within the framework of existing, traditional work designs. These designs involve relatively narrow job descriptions and external forms of control, and are best suited to technologies having low degrees of uncertainty and interdependence and to stable task environments. The studies also suggest that organizations tend to underestimate the extent to which the work context needs to be modified to support the new technologies, including changes in reward systems, training, and relations with support services. Failure to design work appropriately and to modify the work context accordingly can result in poor performance, job dissatisfaction, and increased employee stress.

This paper proposes that the new manufacturing technologies require nontraditional work designs and significant modifications in the work context. Specifically, the new technologies tend to increase technical interdependence and uncertainty and environmental dynamics. These contingencies call for self-regulating work groups composed of multi-skilled employees who can jointly control technical and environmental variances. Such work designs are best suited to employees with high growth and social needs, and may require upgrading employee skills and making changes in selection practices, training programs, reward systems, and management styles.

Clearly, organizations need to attend to work design and the work context early in the design process, preferably when the new technology is being developed. This will provide more lead time to develop appropriate work designs and to make necessary contextual modifications. It should also increase the likelihood that the work design and the technology will jointly support each other.

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